Building Information Modelling (BIM) adoption and implementation: interaction between BIM specialists and non-BIM specialists in Vietnam

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Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of A/Prof. Michael Er and Prof. Shankar Sankaran

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June 2021

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, **Ngoc Quyet Le** declare that this thesis, is submitted in fulfilment of the requirements for the award of *doctor of philosophy*, in the *School of Built Environment- Faculty of Design, Architecture and Building* at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

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Date: 23/06/2021

Acknowledgments

I would first like to thank my supervisors who have shown great patience in providing me with guidance in my research. My research and this document would not have been possible without the supervision team of Associate Professor Michael Er (principal supervisor) and Professor Shankar Sankaran who provided ongoing supportive advice and feedback.

In particular, I would like to express my appreciation to my friends Huu Dat Nguyen and Huynh Long Van Trieu who provided spiritual and emotional support through the entire PhD journey. To Canh Minh Le MScEng, thanks are given for his understanding and support as an advisor on the technical aspects of my research. Thanks to Dr Cong Loc Ha who assisted me early in my research grant application with his recommendation letter. I would like to especially acknowledge fellow PhD student Thanh Tung Huynh for his efforts with the reissue of my Confirmation of Enrolment (CoE) when it was inadvertently cancelled.

Thank you to the many interviewees who volunteered to participate in my research and, particularly within these groups, my initial points of contact who not only provided data but assisted by initiating further interviews.

Last, but not least, I wish to thank my beloved family: my parents, sister, children and wife. I am grateful for their love, encouragement and support, from the moment I decided to pursue this study. The completion of my study is dedicated to my mother for her effort and hard work.

Table of Contents

List of Tables

List of Figures

List of Research Papers

Le, N.Q., Er, M., Sankaran, S. & Ta, N.B. 2020, 'Perspectives on BIM profession of BIM specialists and non-BIM specialists : case study in Vietnam', in H.M. Cuong, D. Van Dao, F. Benboudjema, S. Derrible, D.V.K. Huynh & A.M. Tang (eds), *Innovation for Sustainable Infrastructure, Lecture Notes in Civil Engineering 54*, vol. 54, Springer Nature Singapore Pte Ltd., pp. 1223–8.

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List of Acronyms

AEC: Architecture, Engineering and Construction

AT: Activity Theory

BEP: BIM Execution Plan

BIM: Building Information Model

BOQ: Bill of Quantity

CAD: Computer Aided Design

CDE: Common Data Environment

DOIT: Diffusion of Innovation Theory

EIR: Employer's Information Requirement

FM: Facility Management

ICT: Information Communication Technology

IFC: Industry Foundation Class

LOD: Level of Detail

LODt: Level of Development

MEP: Mechanical, Electrical and Plumbing

O&M: Operation and Maintenance

QS: Quantity Surveyor

RFI: Request for Information

SMEs: Small and Medium Sized Enterprises

Abstract

Building Information Modelling (BIM) offers a digital platform for the integration of all project related information to facilitate effective communication vital to the success of construction projects. Recognising the importance of BIM in construction projects the Vietnamese government issued a mandate in 2016 requiring all public and “first category” projects (buildings which are 20 floors and greater or with a floor area greater than 20,000 square metres) to be implemented using BIM by 2021. This mandate and its implementation provide the context for this research.

This study introduces the combination of Diffusion of Innovation Theory (DOIT) and Activity Theory (AT) as a theoretical framework to investigate the current implementation of BIM in the Vietnamese context. Using a qualitative approach, 17 case studies from medium to large sized Architecture, Engineering and Construction (AEC) firms were studied to present a comprehensive understanding of the current status of BIM practices in the construction industry in Vietnam.

The units of analysis for this study were BIM specialists and non-BIM specialists working in the case studies as their roles are essential for the appropriate use of BIM in projects. 67 semi-structured interviews were used as the main instrument to collect data from these specialists. The data was analysed using a thematic analysis method aided by qualitative analysis software NVivo.

An interpretive framework combining DOIT and AT was used as a lens to identify the main themes of this research. The identified themes (i.e. the major findings) were then developed and reported including perspectives of BIM and non-BIM specialists on the BIM profession, the collaboration using BIM and the responses to contradictions emerging during BIM collaboration activities.

The significant contribution of this study arises from the development and application of the combined DOIT and AT framework which potentially assists the Vietnamese Government and AEC firms to examine BIM interactions in the context of recent BIM mandate. Many sources of conflicts during BIM interactions could be well defined under the lens of the framework and this creates conditions for planning BIM mediation. This study also contributes to research methodology as it applied the systematic combining research process (i.e. abductive approach) in which the initial theory (e.g. DOIT) is not fixed but evolves through on-going case analysis, the revision of literature and the combination with other theory (e.g. AT). In addition to the popularly inductive or deductive approach, abductive approach provides a more creative and flexible mode to gain insights of empirical phenomena and their contexts, in particular the issues on innovation adoption in fast moving digital era.

CHAPTER 1 Introduction

The aim of this thesis is to develop an understanding of the interaction between BIM specialists and non-BIM specialists in the Vietnamese construction industry. Through the study, the initial theoretical framework of Diffusion of Innovation Theory is modified to form a combined framework of Diffusion of Innovation Theory and Activity Theory to improve the interpretation of findings. This chapter presents an overview of this thesis. Section 1.1 introduces the research background and the motivation for undertaking this study, section 1.2 details the research questions and section 1.3 outlines the research objectives pursued to answer the research questions, section 1.4 briefly details the research methodology and outlines the key methods in the study, section 1.5 reflects the scope of the study and section 1.6 presents the structure of this thesis.

1.1 Research background

The construction sector and its activities strongly affect economic, environmental and social development in many developing countries (Afzal, Lim & Prasad 2017; Khalfan et al. 2015; Khan, Liew & Ghazali 2014). While the construction sector is one of the key drivers of the overall national economy, it faces numerous challenges relating to competitiveness, labour shortages, resource efficiency and especially productivity (Hamza et al. 2019; Hussain, Xuetong & Hussain 2020; Juricic, Galic & Marenjak 2021). These challenges are well researched, with a variety of underlying causes. First, the construction industry is seen as a conservative or low-technology sector spending less on activities associated with innovation such as research and development compared to manufacturing industries (Noktehdan, Shahbazpour & Wilkinson 2015). Second, the fragmentation between designers and constructors leads to inconsistency in project execution (Boadu, Wang &

Sunindijo 2020). Third, poor application of knowledge transfer results in knowledge being lost, unavailable or unsuitable for reuse in related projects (Wiewiora et al. 2009). Another barrier to innovation in the construction industry is the lack of cross-functional cooperation which creates challenges to the management of change during execution reducing cost efficiency (Laurent & Leicht 2019; Löfgren 2020; Yadollahi et al. 2014).

Digitalisation of the construction sector through BIM adoption is increasingly recognised as a potential "game changer" for the sector because it could also contribute significantly to sustainable development, with environmentally friendly and productive processes (Sandvik & Fougner 2019). Further, as modern buildings and facilities become more complex in terms of the physical infrastructure and execution, there is a requirement for simultaneous coordination and approval of the design as well as real-time access to information to enable knowledge exchange (Hatmoko et al. 2019; Koseoglu, Keskin & Ozorhon 2019). The ability of BIM to offer a real-time communication platform for project team members and to generate a centralised database of building assets would not only benefit construction stages with fewer delays waiting for information but also post-construction stages with easier location of building components for maintenance and environmental control of space (Abanda et al. 2018; Miettinen et al. 2018).

Developed countries, and also developing countries in close geographic proximity to Vietnam, have made BIM mandatory on public projects. The United States government established a national BIM program through its Public Building Service Office in 2003 and mandated the use of BIM for all state-funded projects in 2007 (Smith 2014). In 2011, the UK government promoted a more ambitious BIM implementation strategy requiring BIM on all government projects by 2016, making the UK a global BIM leader in a relatively short period of time (Ayinla & Adamu 2018). In Singapore, all new building projects with gross floor areas of 5,000 square metres and over have had to make architectural, structural and MEP submissions in BIM format since 2015 (Liao et al. 2020). Although not mandating BIM at a national level, the Chinese government included BIM as one of the core technologies in the built environment in its 12th five-year national plan (2011–2015). China aims to publish a national BIM standard in 2016 (Liu et al. 2015b). Of the countries in the Association of South East Asian Nations (ASEAN), of which Vietnam is a member, Malaysia has made a significant effort to diffuse a national BIM program. The development of BIM in Malaysia was recently driven by the Construction Industry Transformation Program 2016–2020 agenda to transform the Malaysian construction industry towards a more productive, sustainable and competitive sector (Ismail, Chiozzi & Drogemuller 2017). However, Indonesia and Thailand believe that their public sectors are not fully capable of aligning with BIM enforcement. In these two countries, the private sector is encouraged to take more initiative to promote BIM projects (Ismail, Chiozzi & Drogemuller 2017). This has created political pressure on the Vietnamese government to take action to keep up with the emerging trends in construction in the region.

The Vietnam Industry White Paper (2019) considers global cooperation as a vital strategy for national prosperity and the adoption of digital technologies as a means to facilitate strategy implementation activities. The construction industry, one of largest contributors to Vietnam's national economy[1], is expected to lead the digital transformation. The Vietnamese government has taken various steps to encourage BIM adoption by preparing legal frameworks and promoting BIM use. In 2014, the updated construction law recognised BIM implementation as a construction management task (Bui 2019). In December 2016, the Vietnamese government approved a BIM adoption plan that set a goal of completing at least 20 BIM pilot projects between 2018 to 2020 (Ismail, Chiozzi & Drogemuller 2017). The outcomes of the pilot projects constitute the foundation for nationwide BIM

[1] The Vietnamese construction industry and its supply chains (e.g. raw materials, equipment, real estate) comprise average 40% of the GDP growth rate in the recent decade (Le 2020).

implementation, which will begin in early 2021 (Dinh, Nguyen & Khuat 2020). Furthermore, the Ministry of Construction issued Circular 06/2016/TT-BXD, which allows including BIM implementation costs in construction budgets (Bui 2019). In 2017, a national BIM steering committee was formed to develop BIM implementation strategies and advocate BIM use (Matthews & Ta 2020). These recent forward-looking interventions of the Vietnamese government to enforce the application of BIM motivate this study. The actual practices of organisations adopting BIM should also be further investigated to provide empirical evidence to support policy makers on decision making.

BIM research, in general, has used the terms "adoption" and "implementation" interchangeably (Ahmed & Kassem 2018). Klein and Knight (2005), however, argued that innovation adoption is the decision to use an innovation which is often made by top management in an organisational context, such as a decision made by a company's top management that all staff members in the firm will use BIM (Hochscheid & Halin 2018). Innovation implementation, in contrast, is the transition period during which individuals ideally become increasingly skilled, consistent and committed in their use of an innovation (Klein & Knight 2005). The people involved in adoption include those who are responsible for adoption and those who are responsible for implementation. The subjects of adoption activity of BIM are top-level managers and most of them may not directly manipulate BIM tools, called non-BIM specialists. On the other hand, subjects of implementation activity are people at employee level and they can be BIM specialists such as designers or non-BIM specialists such as site teams who undertake BIM collaborative work in daily practice, conforming to decisions of upper management to use BIM.

This ambiguity of defining subjects of activity for adopting BIM and implementing BIM is addressed in this study by proposing a theoretical framework combining Diffusion of Innovation Theory and Activity Theory to investigate the process of adoption and implementation in a holistic manner.

By doing so, the themes emerging from the interplay between BIM specialists and non-BIM specialists at different levels of system hierarchy, such as senior managers and employees, can also be explored.

1.2 Research questions

Figure 1.1 shows the steps taken to develop the research questions from the gap identified in the literature in Chapter 2, the curiosity of interaction between BIM specialists and non-BIM specialists, and the emergent themes during data analysis.

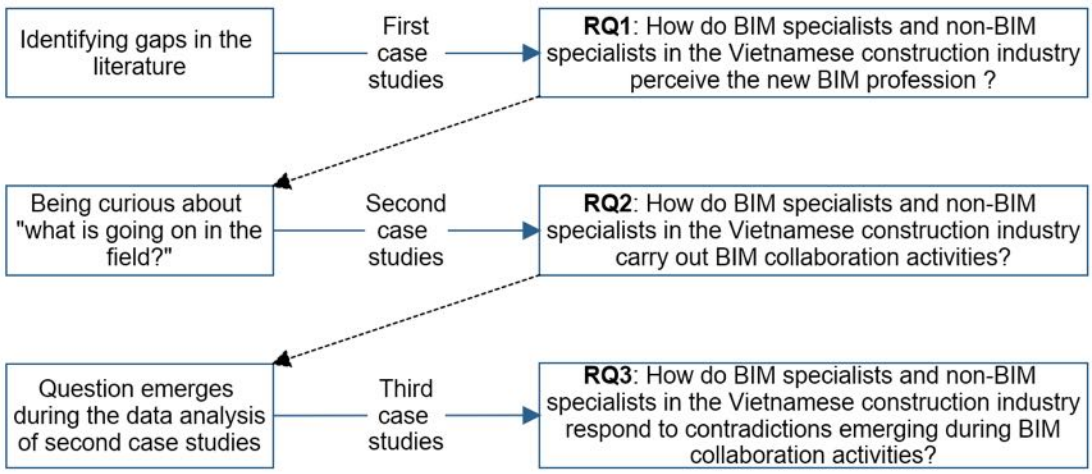

Figure 1.1 The development of research questions and their relationships

As this is a study about how an innovation, BIM, is adopted and diffused in the construction industry in Vietnam, the Diffusion of Innovation Theory developed by Rogers (2003) was critically reviewed. From the literature review on innovation diffusion and adoption, one of the poorly considered issues was how project stakeholders would treat new jobs resulting from the introduction of BIM as a new technology in the construction industry of a developing country like Vietnam. As the study progressed, a narrower focus was taken to investigate the perceptions of BIM specialists and non-BIM specialists on the new BIM profession. This resulted in research question 1: **How do BIM specialists and non-BIM specialists in the Vietnamese**

construction industry perceive the new BIM profession? To answer this question, the first round of case studies was conducted, as described in Chapter 4.

As the study progressed, it became apparent that it was also necessary to investigate whether the perception of the BIM specialists and non-BIM specialists was reflected in their actions based on their daily activities in using BIM. This gave rise to research question 2: **How do BIM specialists and non-BIM specialists in the Vietnamese construction industry carry out BIM collaboration activities?** The second round of case studies was then carried out in response to this question as described in Chapter 7.

Research question 3 arose while interpreting emerging themes from the second round of case studies conducted to answer research question 2. The interactions in BIM based projects are multidisciplinary collaboration activities in which contradictions unavoidably exist due to participants' differences in their preferred tools, motives, social norms, hierarchies, working conditions and personal attributes of skills, knowledge and abilities. This prompts further investigation of conflict resolution behaviours of project stakeholders. Research question 3 was formulated: **How do BIM specialists and non-BIM specialists in the Vietnamese construction industry respond to contradictions emerging during BIM collaboration activities?** The third round of case studies was subsequently undertaken to address this question as described in Chapter 8.

1.3 Research objectives

To address these three research questions specified above, the following research objectives are set out to enable a systematic and empirical investigation of the research problem (see Table 1.1).

Table 1.1 Research objectives

Research questions	Research objectives
Research question 1	- ***Objective 1.1:*** to examine social recognition of BIM job titles including new positions (roles), responsibilities and career opportunities - ***Objective 1.2:*** to examine the relevance of BIM to the current business model including workflow and organisational hierarchy - ***Objective 1.3:*** to justify the utility of the initial theoretical framework of Diffusion of Innovation Theory to properly interpret emerging themes in the case studies of BIM adoption and implementation in Vietnam
Research question 2	- ***Objective 2.1:*** to identify common tools (both BIM and non-BIM) used to mediate the interaction between BIM specialists and non-BIM specialists - ***Objective 2.2:*** to identify objects which motivate the adoption by BIM specialists and non-BIM specialists - ***Objective 2.3:*** to describe who is responsible for which BIM adoption aspects, and their abilities and shortcomings - ***Objective 2.4:*** to examine the expected outcomes versus actual outcomes achieved through BIM interactions - ***Objective 2.5:*** to describe the mandatory BIM conditions at the firm level, project level and national level and their effects on project performance - ***Objective 2.6:*** to identify possible contradictions emerging during the BIM interaction - ***Objective 2.7:*** to apply the combined framework of Diffusion of Innovation Theory and Activity Theory to interpret emerging themes in the case study
Research question 3	- ***Objective 3.1:*** to describe how different Architecture, Engineering and Construction (AEC) professionals at different disciplines, firms and project types respond to conflicts arising during their BIM interactions - ***Objective 3.2:*** to confirm the utility of the combined framework of Diffusion of Innovation Theory and Activity Theory for properly interpreting emerging themes in the case study.

1.4 Research methodology and methods

1.4.1 Research methodology

The research approach adopted is a qualitative inquiry, as it examines the social construction of the reality of BIM adoption as expressed by the people involved in the process. The philosophical position adopted in this study is socio-cultural theory proposed by Lev Vygotsky (1978). Socio-cultural theory focuses on the development of cooperative dialogues between a novice and an expert, such as students and senior teachers (Carpendale & Lewis 2004). Such interactions help less knowledgeable members learn the ways of thinking and behaviours in the shared community from more knowledgeable members. Thus, socio-cultural theory was found to be appropriate for investigating the interaction between BIM specialists and non-BIM specialists.

Multiple case studies were selected as the research methodology to conduct this inquiry to provide valid evidences to take policy and practice decisions to support social change towards digital transformation (Harrison et al. 2017). Theoretical frameworks guiding this research are Diffusion of Innovation Theory (Rogers 2003) and Activity Theory (Engeström 1987). The adoption of a dual theoretical lens is explained in detail in Chapter 3.

1.4.2 Research methods

Data collection was primarily performed using semi-structured interviews. Thematic analysis was used to analyse the interview data collected with the support of the computer assisted qualitative data analysis software tool NVivo. The triangulation method was used to facilitate the validation of findings through cross verification from more than two sources including artefacts collected as secondary data such as documents, drawings and graphic models used by participants, direct observation in site visits and member checking by sending the key findings to participants and asking for verification.

The research process was not linear but iterative as interview questions were constantly revised based on previous responses, with follow-up questions rather than fixed questions. During the iterative design process, three rounds of case studies were conducted, and each round of case studies informed the direction of the next stage of research. Each round of case studies involved multiple key project stakeholders, such as design companies, a main contractor company, a project owner company and the government agency, with a long-term relationship and a collective experience of BIM practices.

The theoretical framework steering the research direction was also not prescribed but evolved. The study commenced with only the first research question and Diffusion of Innovation Theory was initially chosen to answer the first question with data collected from the first round of case studies. As the theory was unable to explain some emerging themes related to social interaction, it was decided to postpone further case studies and return to the literature review to seek help from other theories. Activity Theory was selected due to its strength in interpreting collective activities. Later, the second research question was formed and answered using the combination of Diffusion of Innovation Theory and Activity Theory, with data collected from the second round of case studies. At this point, there was a need to reconfirm themes found in the second round of case studies to increase the research credibility, thus the third round of case studies was conducted. This third round of case studies also aimed to answer the third research question which arose as a follow-up question from the findings of the second round of case studies.

1.5 Research scope

The study was conducted within the confines of the following scope:

- The study was limited to the context of the Vietnamese AEC industry, with the terms company, firm and organisation used interchangeably throughout the thesis.
- The study considered the BIM mandate as a condition which both enables and inhibits adoption and implementation activities but did not critically examine the influence of such regulations on adoption of BIM.
- The units of analysis of this study were exclusively BIM specialists (architects, structural and MEP engineers and site engineers) and non-BIM specialists (project owners, senior managers and government

agents). People in BIM training, in the process of transforming from non-BIM specialists to BIM specialists, were not included in this study.

- This study only examines the interactions between BIM specialists and non-BIM specialists mediated by BIM tools. The use of common BIM tools such as Revit or ArchiCAD is examined but the main concern of this study is their use by the subjects of this study, not the type of tool.
- The term adoption was used to imply the decision making on technology acceptance and use (internalisation or mental process) while the term implementation refers to the execution of a technology (externalisation or physical process).

1.6 Thesis structure

The thesis consists of nine chapters.

1.6.1 Chapter 1: Introduction

This chapter introduces the research study by presenting the research background and motivations, proposing the research questions and objectives, informing the research scope and providing an overview of the research methodology and methods and outlining the thesis structure.

1.6.2 Chapter 2: Literature review

This chapter provides an extensive review of literature pertinent to the field of BIM technologies and a common theory used in BIM adoption research such as Diffusion of Innovation Theory. This includes a critical review of publications on BIM concepts, applications, benefits, enablers and barriers. Chapter 2 considers the basic elements of Diffusion of Innovation Theory as well as applications to BIM research. It highlights the theoretical gaps of BIM research using Diffusion of Innovation Theory, generating the first research question which highlights the need to conduct the first round of case studies in Chapter 4 to answer research question 1.

1.6.3 Chapter 3: Methodology

This chapter presents the details of the research design including research philosophy, research methodology, research approach and relevant methods used for data selection, analysis and validation. Specifically, the chapter justifies the use of a qualitative multiple case study methodology for data collection and the thematic analysis method for data analysis as appropriate choices for studying contemporary events in a specific context of BIM adoption in the Vietnamese construction industry. In addition, the combination of Diffusion of Innovation Theory and Activity Theory is discussed, resulting in a holistic analysis framework to guide the research.

1.6.4 Chapter 4: Findings from the first round of case studies

This chapter presents the context of the first round of case studies including several organisations in the Vietnamese construction industry, and reports main themes which are the perspectives of BIM specialists and non-BIM specialists on the new BIM profession in Vietnam. Diffusion of Innovation Theory is used as the theoretical framework to guide the data analysis of the first cases. Also, Chapter 4 proposes the evolution of the theory according to empirical findings in the first cases and emphasises the need to add another theory to sufficiently interpret the emerging themes related to social interactions.

1.6.5 Chapter 5: Limitations of Diffusion of Innovation Theory in BIM research

The limitations of Diffusion of Innovation Theory, on which the initial stage of the research process in the first round of case studies relies, are identified in this chapter. In particular, in studying BIM adoption Diffusion of Innovation Theory alone was found to insufficiently explain social interactions between BIM specialists and non-BIM specialists. Current weaknesses of Diffusion of Innovation Theory used in BIM research include the pro-innovation bias of change agents with BIM experts and policy makers in favour of technology, the lack of concern about post-adoption behaviours of actual implementers (e.g. employees), and the lack of consideration of negotiating BIM uses among BIM specialists and non-BIM specialists. Interest in investigating collective activities in BIM based projects motivated the researcher to conduct an extensive literature review on theoretical supplements to Diffusion of Innovation Theory from another theory – Activity Theory. This motivation gave rise to Chapter 6.

1.6.6 Chapter 6: Activity Theory – Literature review and discussion of potential combination with Diffusion of Innovation Theory

This chapter begins with the justification of selecting Activity Theory as a theoretical supplement to Diffusion of Innovation Theory in BIM research. A review of Activity Theory is conducted followed by its application in studies on BIM adoption. Chapter 6 concludes that the two theories mutually support each other which results in discussion of the potential combination of Diffusion of Innovation Theory and Activity Theory.

1.6.7 Chapter 7: Findings from the second round of case studies

This chapter proposes the first version of the combined framework of Diffusion of Innovation Theory and Activity Theory and applies it to analyse the second round of case studies. The main themes are reported on the key elements of BIM collaboration activity such as tools, objects, outcomes, subjects, conditions and contradictions. An evolved model is developed based on empirical findings to better explain emerging themes.

1.6.8 Chapter 8: Findings from the third round of case studies

This chapter adopts the second version of the combined framework of Diffusion of Innovation Theory and Activity Theory developed in Chapter 7 to analyse the third round of case studies with two aims: to confirm the main themes identified from the second round of case studies, and to add to these main themes using the responses of Vietnamese AEC professionals to contradictions occurring during BIM collaboration activities. Based on empirical findings, the second version model is refined to establish the third version of the model which can provide greater heuristic and explanatory power to the investigation of interactions between BIM specialists and non-BIM specialists in the Vietnamese context.

1.6.9 Chapter 9: Conclusion

This chapter concludes the study by answering the research questions, explaining contributions from this research to theory, practice and policy, with some recommendations and limitations of this study. Future research areas are also suggested.

CHAPTER 2 Literature review

2.1 Chapter objectives

The main purpose of this chapter is to provide a comprehensive review of the existing literature on the fundamental aspects of BIM technologies, the Vietnamese government mandate to use BIM as the catalyst for the research, and current BIM research mediated by Diffusion of Innovation Theory.

This chapter focuses on three parts. Section 2.2 is a review of BIM research as its adoption is the focus of this study. It reviews the various definitions, dimensions, benefits and related terminology of BIM as well as BIM's enablers, misconceptions and barriers. The mandatory use of BIM in Vietnam is reviewed in Section 2.3 to set the study context. Section 2.4 outlines the main aspects of Diffusion of Innovation Theory and its applications in BIM research. There are two reasons for reviewing Diffusion of Innovation Theory from the beginning of this study. First, the theory by Everett M. Rogers is one of the most widely cited references in many innovation studies (Panuwatwanich & Peansupap 2013). Second, academic research in the area of BIM adoption in the construction industry has previously used the Diffusion of Innovation Theory framework as BIM is considered to be an innovative tool in the delivery of building projects (Jayasena et al. 2019).

2.2 Review of BIM research

2.2.1 Basic knowledge of BIM

2.2.1.1 Concepts of BIM

The acronym BIM has been applied and referred to in a variety of ways as follows:

- a product: Building Information Model, meaning a structured dataset describing a building for simulation, automation and presentation
- a building process or activity: Building Information Modelling, meaning the act of creating a building information model such as thinking, creating, scheduling and organising
- a system: Building Information Management, meaning the business structures of work and communication that increase quality and efficiency such as sharing, preservation, querying the model, organising and maintaining (see Figure 2.1).

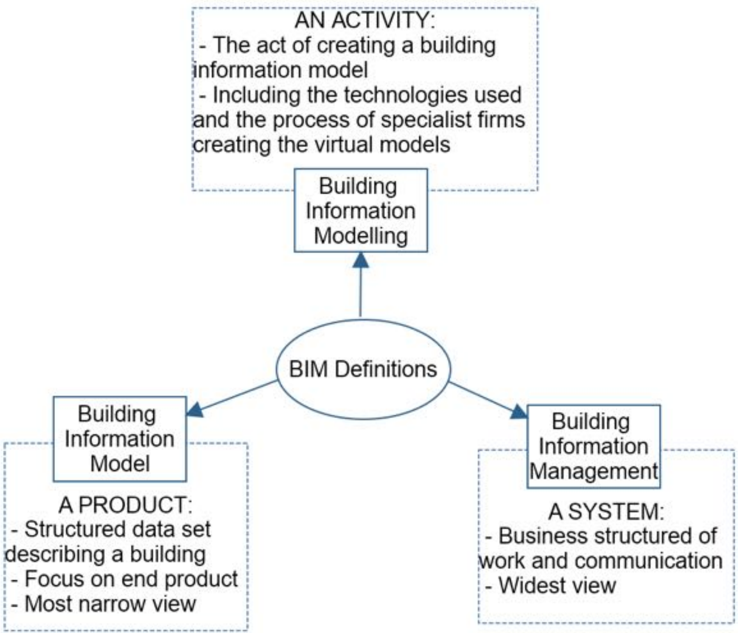

Figure 2.1 BIM is a product, an activity or a system (Ahmad, Demian & Price 2012; NBIMS-US 2007; State of Ohio 2010)

Researchers agree that BIM is defined by various experts and organisations differently due to their perceptions, background and experiences (Eastman et al. 2011; Hardin 2009; Khosrowshahi & Arayici 2012). They also define BIM based on the specific way they work with BIM (Abbasnejad & Moud 2013). Some refer to BIM as a type of software, some call BIM a 3D virtual model of the building while others refer to BIM as a process.

Table 2.1 highlights some of the definitions of BIM commonly used (Wang 2011). Thus, while there are multiple perspectives on what constitutes BIM (Doan et al. 2019), there is a common agreement that BIM provides a framework which allows buildings to be represented three-dimensionally, not simply geometrically, but using objects which have information attached to them (Zima, Plebankiewicz & Wieczorek 2020). While previous research on BIM has focused on technological aspects (e.g. BIM applications) or social aspects (e.g. cultural changes), less attention has been given to viewing BIM as an emerging profession with new roles and social relationships. This research addresses this limitation by accounting for how BIM specialists and non-BIM specialists perceive BIM as a new profession, in the first research question, with Vietnam selected as a context for the study.

Table 2.1 Common BIM definitions

Definition	Source
BIM is the construction of a model that contains information about a building from all phases of the building lifecycle	ISO 16757-1: 2015[2]
BIM is the discrete set of electronic object-oriented information used for design, construction and operation of a built asset	PAS 1192-5:2015[3]
BIM is the digital representation of the physical and functional characteristics of a building over its lifecycle	BS 8536:2010[4]
BIM is a rich information model, consisting of potentially multiple data sources, elements of which can be shared across all stakeholders and be maintained across the life of a building from inception to recycling	National Building Specification-2011 (NBS)[5]
BIM is a shared digital representation of physical and functional characteristics of any built object (including buildings, bridges, roads, etc.) which forms a reliable basis for decisions	BS ISO 29481-1 (2010)[6]
BIM is the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalised (modernised) facility	General Services Administration-2007 (GSA)[7]
BIM is the digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its lifecycle, from earliest conception to demolition	NBIM-US (2013)[8]

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[2] ISO 16757-1:2015: Data structures for electronic product catalogues for building services – Part 1: Concepts, architecture and model (Online). Available at: http://www.iso.org/iso/catalogue_detail.htm?csnumber=57613

[3] BSI PAS 1192-5:2015: Specification for security-minded building information modelling, digital built environments and smart asset management (Online). Available at: http://shop.bsigroup.com/ProductDetail/?pid=000000000030314119

[4] BS 8536:2010: Facility management briefing – Code of practice (Online). Available at: http://shop.bsigroup.com/ProductDetail/?pid=000000000030212807

[5] NBS (2011) National BIM Report March 2011. RIBA Enterprises Ltd. Available at: www.thenbs.com/pdf/bimResearchReport_2011-03.pdf

[6] ISO 29481-1:2010: Building information modelling – Information delivery manual – Part 1: Methodology and format (Online). Available at: http://www.iso.org/iso/catalogue_detail.htm?csnumber=45501

[7] General Services Administration (2007) GSA BIM Guide Series 01 (Online). Available at: http://www.gsa.gov/graphics/pbs/GSA_BIM_Guide_v0_60_Series01_Overview_05_14_07.pdf

[8] NBIM-US (2013). National BIM Standard-United States. Frequently Asked Questions About the National BIM Standard-United States [online]. Available at: https://www.nationalbimstandard.org/faqs#faq1

BIM is a process that involves creating and using an intelligent 3D model to inform and communicate project decisions. Design, visualisation, simulation and collaboration enabled by Autodesk BIM solutions provide greater clarity for all stakeholders across the project lifecycle. BIM makes it easier to achieve project and business goals.	Autodesk (2016)[9]

2.2.1.2 BIM uses in the AEC industry

The amount of information included in a model determines its value and its uses. Generally, BIM is categorised as 3D, 4D, 5D, 6D and 7D. The (D) in the term 3D BIM means dimensional, and it has many uses for the construction industry as Kacprzyk and Kępa (2014) stated that:

- 3D BIM: is the basic form of BIM. Its use is constrained only to making building documentation with some material take-offs or other schedules. It is important to differentiate it from CAD 3D. In BIM, the building must be divided into functional components with particular properties.
- 4D BIM: in addition to the functionality of 3D BIM, the fourth dimension added is time. Every component in a model contains information about its creation date and, possibly, destruction time.
- 5D BIM: information about the cost of each task is provided in the fifth dimension.
- 6D BIM: in addition to 5D BIM functionality, BIM at this level includes energy analyses.
- 7D BIM: the last dimension is use of the model in operation and maintenance of the building.

[9] Autodesk.co.uk. (2016). What's BIM | Building Information Modelling | Autodesk. [online]. Available at: http://www.autodesk.co.uk/solutions/building-information-modelling/overview

Table 2.2 describes the different uses of BIM in construction in detail.

Table 2.2 Details of BIM uses

Category	**BIM uses**	**Authors**
3D model	Model walkthroughs: for both designers and contractors to identify and resolve problems with the help of the model before walking on site.	Eastman et al. (2011)
	Clash detection: BIM enabled potential problems to be identified early in the design phase and resolved before construction begins.	Lu and Korman (2010)
	Project visualisation: provides a very useful and successful marketing tool by making a simple schedule simulation of the building, which can show the owner what the building will look like as construction progresses.	Kumanayake & Bandara (2012)
	Virtual mock-up models: on large projects, BIM modelling enables virtual mock-ups to be made for the owner to better understand and make decisions.	Staub-French et al. (2018)
	Prefabrication: can be enabled more easily with BIM, and more construction work can be performed offsite, cost efficiently, in controlled factory conditions and then efficiently installed in shorter time.	Pour Rahimian et al. (2019)
4D time	Construction planning and management: BIM tools can be used to enhance the planning and monitoring of health and safety precautions needed on site as the project progresses.	Ku & Taiebat (2011)
	Schedule visualisation: by watching the schedule visualisation, project members can make decisions based on multiple sources of accurate real-time information.	Lee & Kim (2017)
5D cost	Quantity take-offs: BIM model includes information that allows a contractor to accurately and rapidly generate an array of essential estimating information, such as materials, quantities and costs, size and area estimates. As changes are made, estimating information is automatically adjusted, allowing for greater contractor productivity.	Hasan & Rasheed (2019)
	Real-time cost estimating: in a BIM model, cost data can be added to each object enabling the model to automatically calculate a rough estimate of material costs, enabling designers to conduct value engineering.	Thurairajah & Goucher (2013)
6D sustainability	Data capture: sensors can feedback and record data relevant to energy performance to identify options optimising building energy efficiency during the life cycle.	Pučko et al. (2017)
	Sustainability assessment: 6D simulation model helps stakeholders to select the appropriate decisions in the early phases of the project and test alternatives	(Habib & Erzaij 2020)

	and compare them to reduce environmental and health impacts.	
7D facility management	Management of asset: tracking asset data such as its status, maintenance/operation manuals, warranty information, technical specifications, etc. to be used at a future stage.	(Howarth & Greenwood 2017)

Table 2.2 shows that BIM has a broad range of applications covering the design, construction, operation and maintenance processes. It would be idealistic for any single BIM user to have expertise in all areas; nevertheless, it is important to be aware of the areas of application and thus be able to select which BIM functions are most applicable to one's own business (Won et al. 2013). While BIM adoption at the firm level can be optional and subjective, BIM adoption at the project level requires changes in the forms of collaboration and contracts regulating the interaction between stakeholders (Miettinen & Paavola 2014). This raises the need for the further study of BIM adoption within and across firms which motivates this thesis.

2.2.1.3 Levels of BIM maturity

While 3D to 6D BIM present the width of adoption, BIM maturity level describes the depth of adoption. The purpose of defining the levels from 0 to 3 is to categorise types of technical and collaborative working to enable a concise description and understanding of the processes, tools and techniques to be used (Jayasena & Weddikkara 2013). The level definitions are provided through the work of Akbarieh et al. (2020) in Figure 2.2.

- Level 0 BIM: traditional drawings, which are either produced by CAD or by hand, are circulated between partners.
- Level 1 BIM: working with a mixture of 2D drawings for drafting and 3D CAD models for conceptual design is the common practice.
- Level 2 BIM: refers to collaborative work where stakeholders have their individual 3D models. Information is exchanged through a standard file format, e.g. Industry Foundation Classes (IFC) or Construction

Operations Building Information Exchange (COBie), to create a federated model.

- Level 3 BIM: full collaboration in one centralised model shared between all stakeholders signifies the highest level of maturity in BIM. Level 3 has the potential to manage the complete lifecycle information in an integrated workflow and open information exchange between project participants. Information can be reused through one model, since BIM is inherently a collaborative platform.

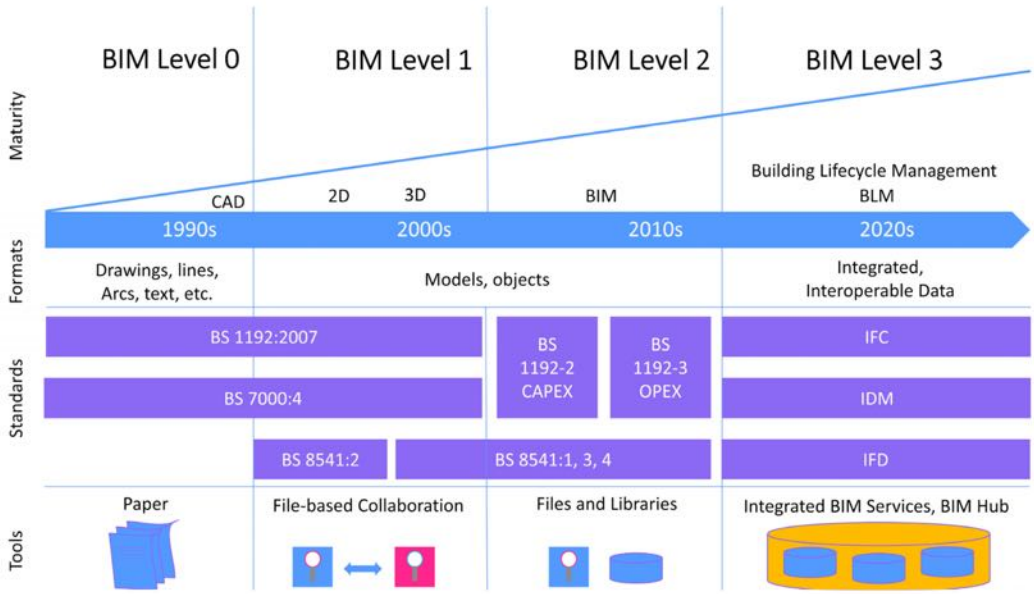


Figure 2.2 BIM maturity levels including codes of practice [BS...] following the UK BIM standards (Akbarieh et al. 2020)

Brief interpretation of terminologies used in Figure 2.2 provided by Kjartansdóttir et al. (2017) is repeated below:

- BS 1192-2007: Collaborative production of architectural, engineering and construction information
- BS 7000- 4: Design management systems
- BS 8541-1, 2, 3, 4: Library objects for architecture, engineering and construction

- BS 1192-2 CAPEX (Capital Expenditure): describes an expense that is incurred to create future benefit
- BS 1192-3 OPEX (Operational Expenditure): describes an expense needed on a daily basis for the functioning of a business or organisation
- IFC (Industry Foundation Classes): the rules for exchanging data
- IDM (Information Delivery Manual): the process of exchanging data
- IFD (International Framework of Dictionaries): the mapping of common terms.

It is important to note that some concepts of this BIM maturity model have not yet been validated and could be modified based on ongoing development and experiences in using BIM and trends of using BIM. For example, the terms used by the BIM community such as IFC, IFD and IDM are still unclear to the adopters (Wan et al. 2019). Even in the UK, considered to be a BIM champion nation, the characteristics of BIM level 2 remain explicitly undefined and this has created a degree of uncertainty amongst the promoters and those professionals charged with delivering projects (Bataw, Kirkham & Lou 2016). A large number of UK professionals acknowledge the value of BIM but are still unsure of what their organisation is planning to meet the challenges of adopting BIM level 2 in the near future to meet the UK government's decision to mandate level 2 BIM on all public sector projects by 2016 (Bataw, Kirkham & Lou 2016). In particular, to successfully implement BIM level 2, relevant costing framework, enabling 5D BIM cost protocol or standard significant to changing dynamics of cost functions within BIM environment is required to be embedded within design development stages; however, this 5D BIM cost protocol for industry implementation is currently lacking in UK (Moses, Heesom & Oloke 2020). Although some may be talking about level 3, there was little evidence to suggest that the industry has progressed beyond level 2 (Hardi & Pittard 2015). Qureshi and Al Hasani (2020) admitted that it may take a longer time to move the current UK construction practice towards BIM level 2 maturity requirements due to the lack of client demand, funding and BIM technicians.

Dainty et al. (2017) argued that the UK's BIM mandate has failed to engage small and medium-sized enterprises (SMEs) with BIM and has seemingly ignored the digital divide that will inevitably follow. The digital divide is also observed to be unequal across levels of maturity. For instance, the challenges encountered from moving between lower levels not only concern technical issues but may include social and political issues during the transition to higher levels (Ayinla & Adamu 2018). Recent case studies in Asian developing countries, including Vietnam, have found that AEC firms implement BIM at somewhere between level 1 to early level 2 (Bui 2019; Ismail, Chiozzi & Drogemuller 2017). However, it is very confusing to classify adopting companies as innovators or laggards under the lens of Diffusion of Innovation Theory because they may be proficient at performing some BIM tasks listed in level 2 but still have not fulfilled all requirements of level 1 (Ayinla & Adamu 2018). Besides, some companies were quickly catching up with state of the art technologies to jump from level 0 to level 1 but remained at a standstill (i.e. wait-and-see) for further transition (Juan, Lai & Shih 2017).

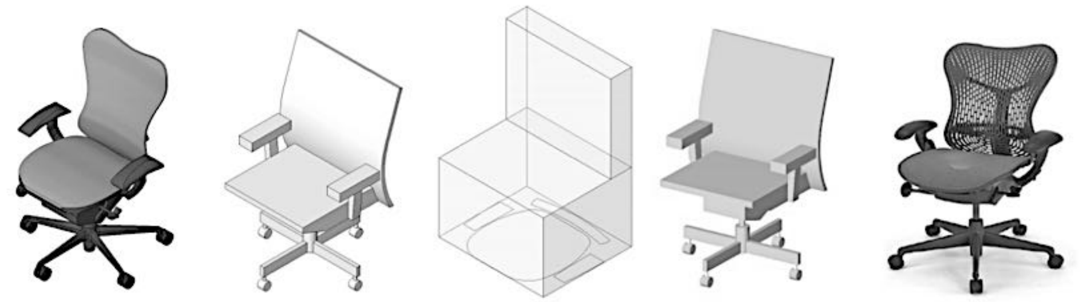
2.2.1.4 Level of Development (LODt)

Often, the terms Level of Development and Level of Detail are used interchangeably under the acronym "LOD" (Lu, Lai & Tse 2018). However, Level of Detail refers only to graphical details whereas Level of Development covers a broader concept associated with the reliability of shared information (NATSPEC 2013). For example, in addition to the level of graphic detail and precision of modelling, Level of Development includes the amount, quality and relevance of non-graphic information along with type of non-graphic information embedded in model elements, but linked to model elements or separated from (but cross-referenced to) model elements. Tolmer et al. (2017) proposed to differentiate LODt as Level of Development to reduce confusion with the simpler concept termed LOD. Level of Detail is presented in Table 2.3

which references geometric data only while Level of Development explained in Table 2.4 adds non-geometric information regarding analysis, cost, schedule, coordination and modelling authors' notes (NATSPEC 2013).

Table 2.3 Level of Detail (LOD) (NATSPEC 2013)

LOD 100	LOD 200	LOD 300	LOD 400	LOD 500



Concept (Presentation)	Design Development	Documentation	Construction	Facilities Management
DESCRIPTION: Office Chair Arms, Wheels WIDTH: DEPTH: HEIGHT: MANUFACTURER: Herman Miller, Inc. MODEL: Mirra LOD: 100	DESCRIPTION: Office Chair Arms, Wheels WIDTH: 700 DEPTH: 450 HEIGHT: 1100 MANUFACTURER: Herman Miller, Inc. MODEL: Mirra LOD: 200	DESCRIPTION: Office Chair Arms, Wheels WIDTH: 700 DEPTH: 450 HEIGHT: 1100 MANUFACTURER: Herman Miller, Inc. MODEL: Mirra LOD: 300	DESCRIPTION: Office Chair Arms, Wheels WIDTH: 685 DEPTH: 430 HEIGHT: 1085 MANUFACTURER: Herman Miller, Inc MODEL: Mirra LOD: 400	DESCRIPTION: Office Chair Arms, Wheels WIDTH: 685 DEPTH: 430 HEIGHT: 1085 MANUFACTURER: Herman Miller, Inc MODEL: Mirra PURCHASE DATE: 01/02/2013

Table 2.4 Level of Development (LODt) (NATSPEC 2013)

	LOD 100 Conceptual	LOD 200 Approx. geometry	LOD 300 Precise geometry	LOD 400 Fabrication	LOD 500 As-built
Analysis	Analysis based on volume, area and orientation by application of **generalised** performance criteria assigned to **other** Model Elements.	Performance analysis of selected systems by application of **generalized** performance criteria assigned to the **representative** Model Elements.	Performance analysis of selected systems by application of **specific** performance criteria assigned to the **representative** Model Element.	Performance analysis of systems by application of **actual** performance criteria assigned to the Model Element.	Performance measured from installed systems.
Cost Estimating	Development of a cost estimate based on **current** area, volume or similar **conceptual** estimating techniques (e.g., square metres of floor area, hospital bed, etc.).	Development of cost estimates based on **approximate** data provided and **quantitative** estimating techniques (e.g., volume and quantity of elements or type of system selected).	Development of cost estimates suitable for procurement based on the **specific** data provided.	Costs are based on the **actual** cost of the Model Element at buyout.	Operation and maintenance costs measured from installed systems.
Project scheduling	Project phasing and determination of **overall** Project duration.	For showing ordered, time-scaled appearance of **major** elements and systems.	For showing ordered, time-scaled appearance of **detailed** elements and systems.	For showing ordered, time-scaled appearance of **detailed specific** elements and systems **including construction means and methods**.	Maintenance scheduling derived from installed systems.
Coordination	N/A	**General** coordination with other Model Elements in terms of its size, location and clearance to other Model Elements.	**Specific** coordination with other Model Elements in terms of its size, location and clearance to other Model Elements including **general** operation issues.	Coordination with other Model Elements in terms of its size, location and clearance to other Model Elements including **fabrication, installation** and **detailed** operation issues.	N/A
Other authorised uses	Additional Authorised Uses of the Model Element developed to **LOD 100**, if any, including Authorized Uses identified or required by the uses set forth in Section 4.4 of *AIA E203-2012*.	Additional Authorised Uses of the Model Element developed to **LOD 200**, if any, including Authorized Uses identified or required by the uses set forth in Section 4.4 of *AIA E203-2012*.	Additional Authorised Uses of the Model Element developed to **LOD 300**, if any, including Authorized Uses identified or required by the uses set forth in Section 4.4 of *AIA E203-2012*.	Additional Authorised Uses of the Model Element developed to **LOD 400**, if any, including Authorized Uses identified or required by the uses set forth in Section 4.4 of *AIA E203-2012*.	Specific Authorised Uses of the Model Element developed to **LOD 500**, if any, including Authorized Uses identified or required by the uses set forth in Section 4.4 of *AIA E203-2012*.

2.2.1.5 Common Data Environment (CDE)

The Common Data Environment (CDE) is defined as "a single source of information for any given project or asset, used to collect, manage and disseminate all relevant approved files, documents and data for multidisciplinary teams in a managed process" (Mordue 2018, p. 3). In other words, the CDE represents a central space for collecting, managing, evaluating and sharing information. All project participants retrieve the data from the CDE and, in turn, store their data here. The CDE stores the coordination model, all domain-specific partial models, databases and documents which are necessary during the execution of the project (Preidel et al. 2016). The CDE is required as a means of providing a secure and collaborative environment for sharing work. Both benefits and challenges of CDE are presented below (Comiskey et al. 2017; Mordue 2018):

2.2.1.5.1 *Benefits of CDE*

- During design and construction stages:
    - providing greater reliability of data (e.g. consistency and compatibility) and reducing risk of data loss, leakage and corruption
    - supporting more efficient processes in the creation and management of information (e.g. data accessibility and retrieval)
    - reducing the time and effort required to revise and reissue information
    - reducing the time and cost of producing coordinated information
    - improving cross-disciplinary collaboration and outcomes
- During operational stage:
    - saving time to transfer accurate and complete information from construction to operational stages

- facilitating access to relevant and reliable information
- enabling improved estate planning, procurement and maintenance
- supporting improved analysis across portfolio of built assets

2.2.1.5.2 *Challenges to CDE*

- Complex IT procurement challenges with clear brief and compliance with existing IT procedures
- Varied CDE market offerings
- Cost and resources to procure a system
- Maintaining security of data
- Developing a system solution compatible with existing organisational systems.

2.2.1.6 Employer's Information Requirement (EIR)

Employer's Information Requirement (EIR) is defined as a "pre-tender document setting out the information to be delivered, and the standards and processes to be adopted by the supplier" (Ashworth, Tucker & Druhmann 2016, p. 3). The EIR helps designers and constructors to understand what information is needed by the client, in which format and when in the BIM process (Ashworth, Tucker & Druhmann 2016). It details roles and responsibilities, technical issues, submittals and the management of the model (Eastman et al. 2011). It also details team training, which was provided by BIM managers within each organisation (or by an external consultants) to all team members, to allow them to access, view and print from the model (Hafeez et al. 2016). The BIM managers are also responsible for establishing software protocols for the successful delivery of the project and the coordination of meetings on site, undertaking clash detection and proposing any required solutions (Eastman et al. 2011). The EIR is not incorporated as a contractual document but should be referenced in the building contract (Eynon 2016).

Often, the EIR is prepared by clients, or occasionally with support from a BIM manager or an externally appointed BIM consultant employed by clients (Pittard & Sell 2016). While the production of high quality BIM requirements which are feasible, understandable and customised could be outsourced to external BIM consultants, implementing an EIR requires a minimum of BIM knowledge and experience in client organisations (Silverio et al. 2017). This is because, in addition to clients having the ability to develop their requirements, clients also need to validate the outcomes of the BIM implementation process to ensure that the supply chain meets their requirements (Dakhil et al. 2019). It is important to note that clients should have the ability to effectively manage and control the validation process. This role demands a certain level of BIM knowledge and experience to enable clients to efficiently communicate with the supply chain and to be able to streamline the approval process of the expected outcomes. In other words, what is needed is an active client who is willing to "spend more time understanding their own requirements" and an intelligent client who demonstrates "understanding their own part in the BIM journey" such as responsibility, role and contribution (O'Sullivan & Behan 2017, p. 7). However, the relationship between a client's ability to validate the outcomes of a BIM implementation process and the required level of BIM knowledge and experience within a client's organisation is still not described clearly and explicitly in the literature (Dakhil et al. 2019). To date, BIM deliverables are presented in EIR but not clearly specified (Peters & Mathews 2019). Different contractors could also interpret them differently on what they need to deliver and hence the client does not receive consistent information for the revision of EIR (Hafeez et al. 2016). The problems of lack of client demand, unclear demand, and excessive demand are still considered as top barriers to wider BIM adoption by contractors (Dakhil, Underwood & Al Shawi 2016).

2.2.1.7 BIM Execution Plan (BEP)

In response to EIR, contractors, both designers and constructors, produce a BIM Execution Plan (BEP) that acts as a contractors' proposal. The BEP responds to the clients' requirements from the EIR and provides roles and obligations to meet them (Pittard & Sell 2016). This document is also referred to in the contract, but, due to its evolving nature, is not always included as a standard document (Eynon 2016). The BEP processes have revealed four important elements: BIM goals, BIM uses, responsible parties and decision making (Hadzaman, Takim & Mohammad 2016). The challenges in producing BEPs and managing BEP implementation arise from clients and contractors themselves. As mentioned previously, most barriers to preparing EIR (clients' duty) could negatively affect the production of the BEP (contractors' duty) because a proper EIR provides clear requirements for the supply chain to use for their corresponding BEPs and tender pricing (Ashworth, Tucker & Druhmann 2017).

Further, as BIM is new, a large proportion of practitioners reported a deviation (or gap) between the planned BIM processes and the actual BIM processes used in their projects (Bosch-Sijtsema et al. 2017; Bosdriesz 2018; Boton & Forgues 2018; Dong 2017). The BEP is a dynamic and living document rather than a fixed document and needs to be continually developed and refined throughout the project development to better cope with innovation required to manage uncertainties (McArthur & Sun 2015). Therefore, there should be a clear, concise and agreed procedure for the BEP's modification or updating (Ramírez-Sáenz et al. 2018). However, this iterative process challenges the traditional linear processes which are perceived as a norm of construction practice (Boton & Forgues 2018). Project parties may feel concerned about legal disputes when the BEP is still unstable before project commencement. This motivated the researcher to investigate this emerging issue when subjects have to work more collaboratively to achieve "collective" objectives of a dynamic activity which is innovative and uncertain as Engeström (2009, p. 303) defined as a "runaway object".

2.2.2 BIM brings new elements to the AEC industry

2.2.2.1 BIM as a new profession

2.2.2.1.1 *New tools and processes*

New tools. BIM models, such as Architectural, Structural and MEP, can be created through several software products. Some of these products are from vendors such as Autodesk (Revit Architecture, Revit MEP, AutoCAD MEP); Graphisoft (ArchiCAD, ArchiCAD MEP) and Bentley (BIM). Associated functions of 4D scheduling or 5D costing can be supplied as interoperable software. Table 2.5 lists the major software products available in the market (Kalfa 2018). The difference between BIM tools and traditional design tools (e.g. CAD drafting tools) are advanced functions enabled by BIM such as automation (for data sync and update), interoperability (potential to import and export data between different tools), accessibility (real-time and cloud-based) and data retrieval (e.g. search, store, reuse and modification), see Figure 2.3 (Kovacic et al. 2013).

Table 2.5 Common BIM software (Kalfa 2018)

Architecture software		MEP software	
▪ Revit Architecture ▪ ArchiCAD ▪ Allplan Architecture ▪ Digital Project Designer ▪ Vectorworks Architect	▪ IDEA Architectural Design (IntelliCAD) ▪ Bentley Architecture ▪ CADSoft Envisioneer ▪ Softtech Spirit ▪ RhinoBIM (BETA)	▪ Revit MEP ▪ Bentley Hevacomp Mechanical Designer ▪ FineHVAC + FineLIFT + FineELEC +FineSANI	▪ Digital Project MEP Systems Routing ▪ CADMEP (CADduct / CADmech)
Structure software		**Sustainability software**	
▪ Revit Structure ▪ Bentley Structural Modeler ▪ Bentley RAM, STAAD, and ProSteel ▪ Tekla Structures ▪ CypeCAD	▪ Graytec Advance Design ▪ Structure Soft Metal Wood Framer ▪ Scia ▪ Strad and Steel ▪ Robot Structural Analysis	▪ Ecotect Analysis ▪ Green Building Studio ▪ EcoDesigner ▪ IES Solutions Virtual Environment VE-Pro	▪ Bentley Tas Simulator ▪ Bentley Hevacomp ▪ DesignBuilder
Construction software		**Facility management**	
▪ Navisworks ▪ Solibri Model Checker ▪ Vico Office Suite ▪ Vela Field BIM ▪ Bentley ConstructSim	▪ Tekla BIMSight ▪ Glue (by Horizontal Systems) ▪ Synchro Professional ▪ Innovaya	▪ Bentley Facilities ▪ FM: Systems FM: Interact ▪ Vintocon ArchiFM (For ArchiCAD)	▪ Onuma System ▪ EcoDomus

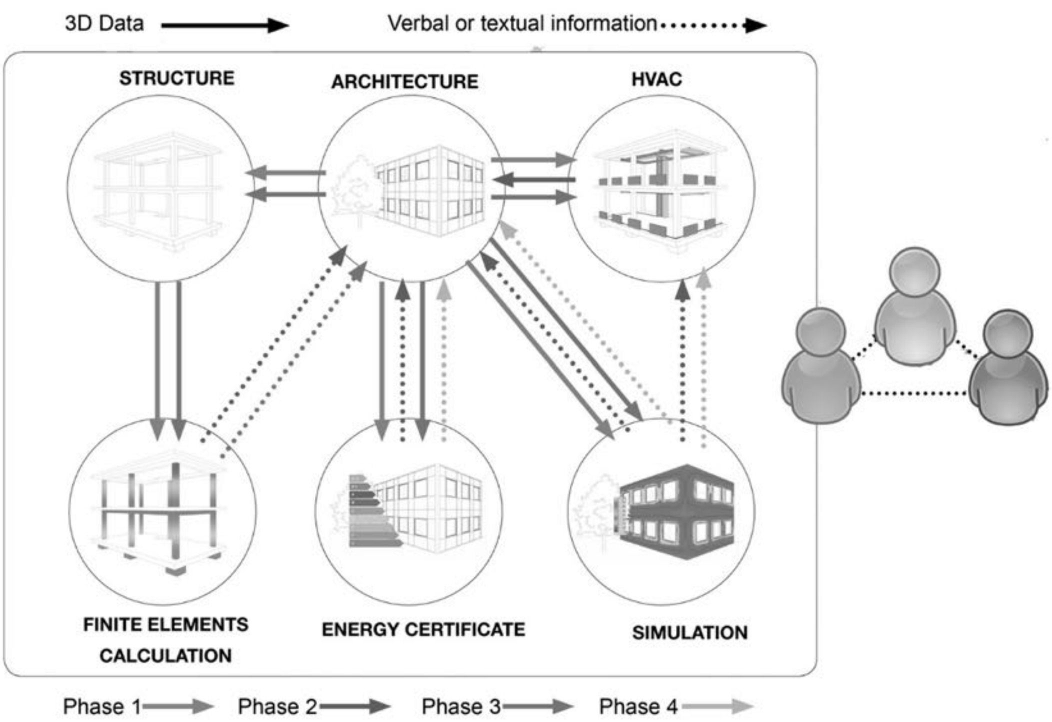


Figure 2.3 Modelling and data transfer between multidisciplinary teams (Kovacic et al. 2013)

New process. The constructability review process using a BIM model provides some advantages over the traditional process using 2D drawings where the contractors often suffer from various changes on site, especially unexpected and late scope changes (Liao et al. 2020). This unpredictability can lead to the need for extensive coordination of time, costs and increased safety risk, resulting in potential miscommunication of expectations or outcomes between the project teams (Swallow & Zulu 2019). Wang and Leite (2012) described the shift from verbal discussions and use of 2D drawings to manage design changes, and argued that this change potentially helps designers and contractors to better manage design changes and to avoid designs that are inefficient to build or that even cannot be built, see Figure 2.4.

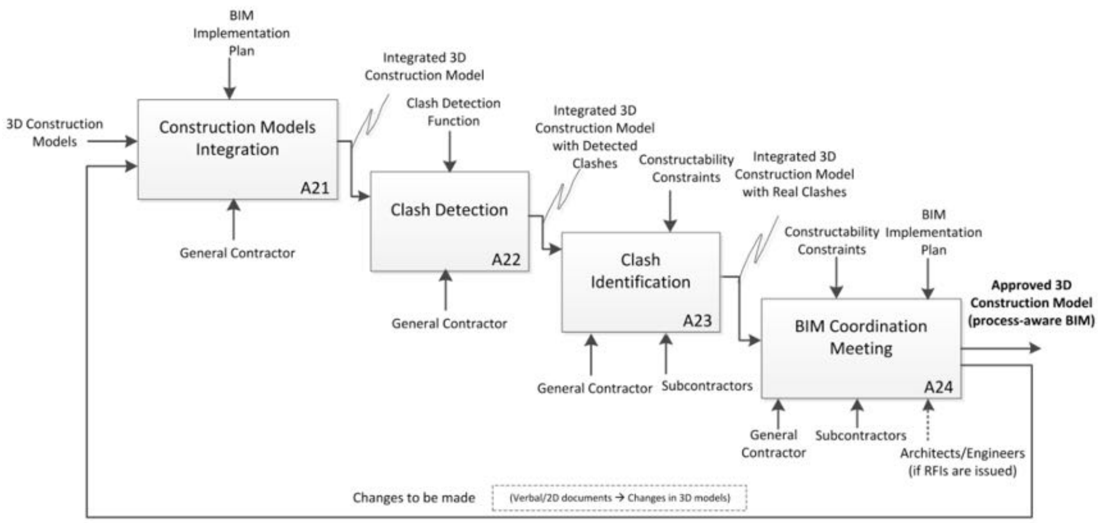


Figure 2.4 Model-based constructability review (Wang & Leite 2012)- Refer to Appendix 12 for full page figure

According to Figure 2.4, clashes and constructability issues are solved through the construction models. Before approving the subcontractors to generate shop drawings, the general contractor goes through a model-based constructability review process by combining all the construction models developed by different subcontractors into one integrated model, checking existing conflicts or constructability issues among different trades and resolving all potential problems. If there were major changes to be made, an request for information (RFI) was issued. The architects and engineers then confirmed if the changes could be made. After each meeting, the subcontractors addressed the identified changes, updated their model and sent the revised model to the general contractor again. Another iteration of design review was then held until there were no additional changes to be made. Once the coordinated model was approved by the project team, the model and related drawings and specification were ready to be used for fabrication.

However, visual checking using a BIM model is challenging to implement because it depends on users' experience and observational capability. Often, designers do not have the same executing experience as the contractors have, thus a constructible design solution requires the exchange of tacit knowledge between designers and contractors (Wang & Leite 2012). In addition to the collective uses of IT tools, communication channels such as verbal conversations, meetings and peer networks play an important role in promoting the adoption of innovation in terms of transferring tacit knowledge (Jayasena et al. 2019) and becomes another focus of this thesis.

2.2.2.1.2 *New roles*

The shift to BIM brings with it a shift in job titles and job descriptions. There are many different BIM specialists, each with a specific set of responsibilities which are described in Table 2.6.

Table 2.6 BIM roles

BIM role	Description	Authors
BIM modeller	Creates, develops and extracts 2D documentation from BIM models	Barison & Santos (2010)
	May occupy the position of the CAD draftsperson	Batarseh (2018)
BIM analyst	Performs analyses and simulations based on the BIM model such as building performance analysis, circulation and security analysis	Barison & Santos (2010)
BIM-supporting technician	Contributes to the data exchange process as IT professional but not directly involved in modelling activities. Develops IFC extensions, and familiar with the IFC data structure and modelling concepts	Barison & Santos (2010)
	Responsible for mapping Exchange Requirements to IFC classes	Weise, Liebich & Wix (2009)
BIM researcher	Works in universities, research institutes or governmental organisations, and usually teaches, coordinates and conducts research on BIM	Barison & Santos (2010)
BIM manager	Responsible for the development and delivery of the BIM execution plan, and establishing BIM protocols for the project	Davies, Wilkinson & McMeel (2017)
BIM coordinator	Performs secondary role under the leadership of the BIM manager	Barison & Santos (2010)
	Responsible for the exchange of BIM models within the organisation or discipline, including ensuring models created by their team adhere to the agreed BIM standards and follow exchange protocols	Barison & Santos (2010)
	Often includes model coordination and clash detection	Davies, Wilkinson & McMeel (2017)
Information manager	Employed by the client to have oversight of the information requirements of the entire project	Davies, Wilkinson & McMeel (2017)
	Responsible for establishing and managing the information processes, protocols and procedures for the project, including the common data environment for the project, file management and information exchange	Davies, Wilkinson & McMeel (2017)
	Does not get involved in design-related functions such as clash detection or model coordination	Qaravi (2018)
BIM facilitator	Assists other professionals, not yet skilled in operating BIM software, in visualising the model information	Barison & Santos (2010)
	Works with those going to physically construct the building, assisting the engineer's work to communicate with foremen or contractors	Kymmell (2008)

In Vietnam, BIM specialists were commonly categorised as a BIM manager or a BIM coordinator (Nguyen, Dau Thi & Dao 2020). However, in practice, a BIM specialist may execute the tasks of one or more of the specialists named in Table 2.6 depending on the project and the size of the company they are working for. This is examined further in Chapters 4, 7 and 8.

2.2.2.1.3 *New business in the AEC industry*

BIM consultant. Companies such as AEC firms or real estate developers that have adopted or are planning to adopt BIM, but do not have an experienced BIM expert, can hire a BIM consultant to guide their BIM implementation (Barison & Santos 2010). BIM consultants can provide services such as training, advising, helping BIM projects to start or leading the entire BIM adoption process (Construction Industry Federation 2018).

BIM outsourcing. Some AEC firms investigate specialised BIM applications such as BIM detailing, clash detection, BIM family creation, time and cost simulation and become outsourcing BIM partners for companies participating in the project. They act as third parties and are not directly involved in the project like BIM consultants (Fountain & Langar 2018).

BIM education. Adoption of BIM in educational programs is a relatively new trend in Vietnam (Nguyen Bao et al. 2018). Programs teaching BIM are being offered in many Vietnamese universities, however, they usually have a narrow scope similar to software training (Nguyen Bao et al. 2018). There is growing interest and demand to implement BIM in academic programs and to offer entire courses or programs focused on BIM at all levels (undergraduate, postgraduate or on-the-job-training) of the AEC specialties (Abbas, Din & Farooqui 2016). The need to teach BIM as a collaborative process rather just a software tool has also been highlighted by Panuwatwanich et al. (2013).

2.2.2.1.4 *Potential to integrate with other applications*

BIM not only creates new business opportunities within the AEC industry (e.g. BIM consultant, BIM outsourcing and BIM education/training) but can integrate with other applications to form a new discipline. For example, laser scanning technology, which is commonly used for geological survey, is being used with BIM. The creation of 3D models directly from laser scanner data represents one of the new uses of this technology which is currently widely used in archaeological and cultural heritage assets evaluation (Pica & Abanda 2019). One application of laser scanning helped facility management at the Sydney Opera House (see Figure 2.5). Mitchell and Schevers (2005) found that maintenance at the Sydney Opera House is complicated due to the aging nature of the building and a high level of building services and operational requirements which severely limit access to operational areas. Using laser scanning to create a digital model of the World Heritage listed building without physically touching it could be an appropriate approach to protect cultural property.

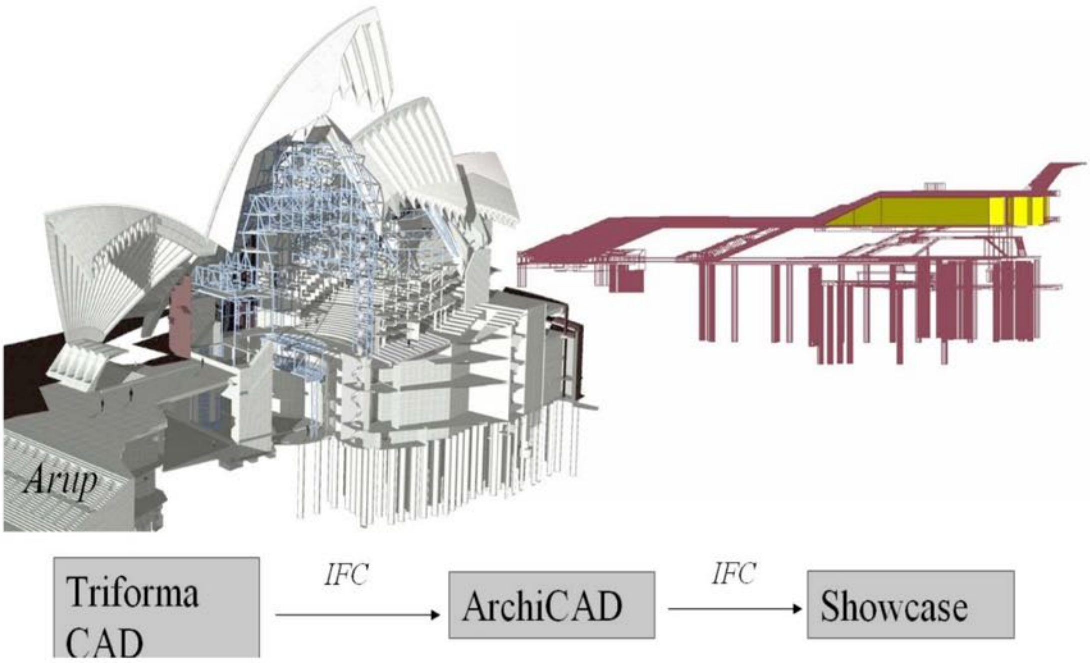


Figure 2.5 Using laser scanning to create 3D model of Sydney Opera House for facility management (Mitchell & Schevers 2005)

A Geographical Information System (GIS) is a computer system that displays stored digital data on a map representing the Earth's surface (Jebara 2007). GIS is used for various applications such as biodiversity conservation, resource availability and vulnerability maps, such as flood or earthquake prone areas (Ondieki & Murimi 2001). The integration of BIM and GIS in construction management is a new and fast developing trend (Zhao, Liu & Mbachu 2019).

2.2.2.2 Potential BIM benefits

Several research studies on BIM's adoption in construction projects have reported many advantages over traditional construction practices (Ullah, Lill & Witt 2019). Table 2.7 shows BIM benefits in different phases of the building lifecycle.

Table 2.7 BIM benefits through the building lifecycle

Phases	Benefits of BIM uses
Pre-construction	- Better concept and feasibility (Eastman et al. 2011) - Effective site analysis to understand environmental and resource-related problems (Azhar et al. 2011) - Improves effectiveness and accuracy of existing conditions documentation (Kjartansdóttir et al. 2017) - Effective design reviews leading to sustainable design (Sandvik & Fougner 2019) - Enhances energy efficiency (Eastman et al. 2011) - Resolves design clashes earlier by visualising the model (Mehrbod et al. 2019) - Enables faster and more accurate cost estimation (Thurairajah & Goucher 2013)
Construction	- Evaluates the construction of complex building systems to improve planning of resources and sequencing alternatives (Kjartansdóttir et al. 2017) - Effective management of the storage and procurement of project resources (Eastman et al. 2011) - Efficient fabrication of various building components offsite using design model as the basis (Abanda 2017) - Allows better site utilisation (Chong et al. 2016) - Reduces site congestion and improves health and safety (Shah & Edwards 2016)
Post-construction	- Helps in decision making about operations, maintenance, repair and replacement of a facility (Kjartansdóttir et al. 2017) - Makes asset management faster, more accurate and with more information (Husain, Razali & Eni 2018) - Helps schedule maintenance and provides easy access to information during maintenance (Fargnoli et al. 2019)

2.2.2.3 New skills required

2.2.2.3.1 *Hard skills (e.g. technology and engineering)*

A requirement for operating knowledge is inevitable when acquiring a new IT application, such as BIM, to integrate it into a business process (Furneaux & Kivvits 2008). New BIM skillsets that employees need to acquire include basic BIM skills and understanding of how the software works, 3D modelling and detailing, simulating construction means and methods, collaboration and coordination procedures, clash detection, and estimating or quantity take-offs from a 3D model (Pena 2011). Instead of detailing specific skills, Arayici and Coates (2013) proposed new knowledge areas required to implement BIM (see Figure 2.6) that can be developed into new skills.

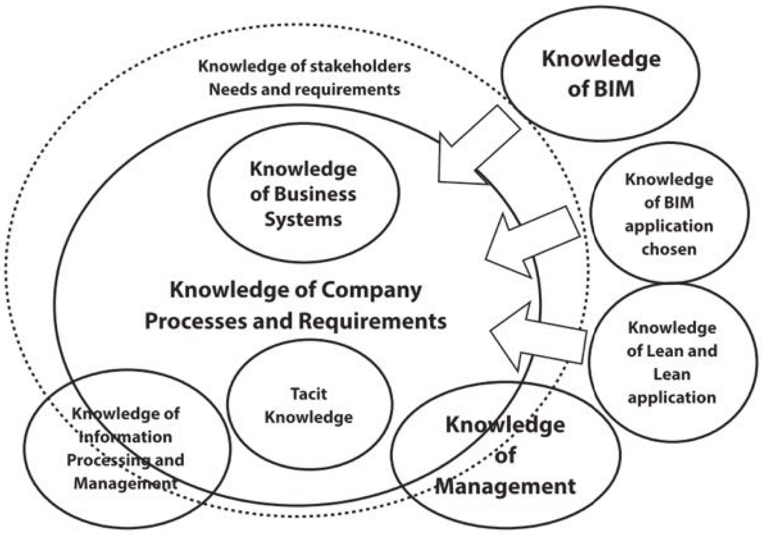


Figure 2.6 Knowledge required to implement BIM (Arayici & Coates 2013, p. 8)

Not only employees but also senior managers need to upskill in the area of BIM technology. Rahman et al. (2016) demonstrated unique and shared skills between traditional project managers and BIM managers (see Table 2.8). Their results implied that project managers and BIM managers require more shared skills than unique BIM skills because project managers need more expertise in engineering matters while BIM managers potentially add value to a project after construction such as facility management and to the environment through sustainable design (Rahman et al. 2016).

Table 2.8 Unique and shared skills between project managers and BIM managers (Rahman et al. 2016)- Refer to Appendix 13 for full page table

Project manager	Project manager and BIM manager		BIM manager	
Metal fabrication	3D	Drawing	3D modeling	MEP
Modeling	Architectural design	LEED	3D studio max	MicroStation
New business development	Architectural drawings	Mixed-use	Construction safety	Piping
Steel	AutoCAD	Navisworks	Facilities management	Sketchup
Steel structures	BIM	Revit	High rise	Urban design
	CAD	Space planning	Interior design	
	Comprehensive planning	Steel detailing		
	Construction drawings	Submittals		
	Design research	Sustainable design		

2.2.2.3.2 *Soft skills (e.g. teamwork and negotiation)*

It is argued that soft skills in a BIM project team are as important as hard skills (Davies, McMeel & Wilkinson 2015). Soft skills may include effective time management practices, the ability to provide effective solutions to conflicts, the ability to maintain good relationships, and ease in helping to solve personal problems (Sumner & Slattery 2010). Some researchers have also considered additional soft skills such as emotional (Saini & Soni 2016) or managerial skills and leadership skills (Adams 2016) while others have included "communication and negotiation skills" (Davies, McMeel & Wilkinson 2015, p. 109). Milivojevic and Ahmed (2018) have a different view of soft skills and BIM by suggesting that soft skills are not necessarily interpersonal skills such as talents but may refer to a change of attitudes towards more openness, such as openness to new ideas and learning or willingness to share (see Figure 2.7).

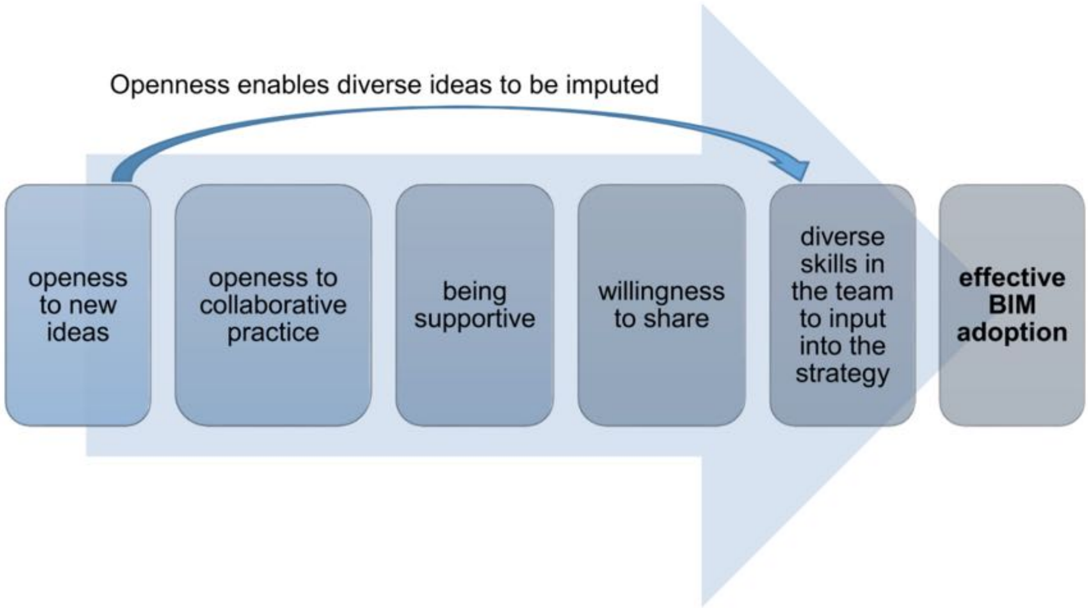


Figure 2.7 Essential skillsets for effective BIM adoption (Milivojevic & Ahmed 2018)

2.2.3 Enablers of BIM adoption

Four major enablers of BIM adoption have been proposed. The first is the enhanced IT infrastructure (internet speed) and capability of computers (both hardware and software) to develop and display 3D models with supporting large databases. The second is the effort of creating a unified digital format such as Industry Foundation Classes (IFC) for interoperability. The third is the increasing worldwide support for BIM. The fourth is support from the national government. These enablers are explained in detail below.

2.2.3.1 Enhanced IT infrastructure and computer capacity

Improved accessibility to the internet, consistent service and high speed broadband have facilitated the exchange and sharing of large files across time and space (Kivits & Furneaux 2013). This has meant that firms separated across geographical locations can operate in separate time zones, with the internet enabling these firms to collaborate on major projects. Continuous innovations in internet technology and IT infrastructure have in turn improved the performance of BIM (Furneaux & Kivvits 2008).

Additionally, enhanced computer capacity in processing power and graphics, storage and memory (Brodlie et al. 2005), and better compression algorithms, means that larger and more resource intensive files can be created and shared (Furneaux & Kivvits 2008). The current trend in IT infrastructure, with the latest innovation of fibre optic cables, gives rise to the possibility of sharing even larger data files among users all over the world (Kivits & Furneaux 2013). BIM is heavily reliant on this infrastructure, since BIM files are large, at hundreds of Gigabytes, and need to be accessible at all times (Ding & Xu 2014).

BIM software has rapidly evolved to adapt to varying users' demands. BIM applications are often programmed on the Windows operating system as it is the most widespread operating system family on the market (Bouška 2016). There are three major tools for model creation written in this platform: Autodesk Revit, Graphisoft ArchiCAD and Nemetschek Allplan (Hatem, Abd & Abbas 2018; Staub-French et al. 2018). The Mac OS operating system is second in popularity. While Mac OS has been the platform of choice for graphic designers and artists, there are not many powerful software tools for architects and civil engineers in Mac (Bouška 2016). Currently, there are very few BIM tools for this platform, except ArchiCAD which was originally developed for Mac OS (Onur & Nouban 2019). BIM tools which are being used with Mac OS are not tied to the operating system, but are cloud computing (Bouška 2016). For open source operating systems like Linux and Unix, the choice for BIM tools is rare because these systems are not popular among civil engineers and architects (Logothetis & Stylianidis 2016). However, open sources for BIM have recently attracted the attention of government bodies who may not need to edit data but only be able to read it. Systems that can read only are less complicated to develop and cost relatively less (Bouška 2016).

The BIM ecosystem refers to a wide range of programs that work seamlessly according to BIM standards. These programs are often developed by one software vendor and its partners. For example, Autodesk is a world leader in the field of industrial and civil construction software development. Autodesk solutions are sold, integrated and serviced by five distributors, 110 partners and more than 70 training centres (Vysotskiy et al. 2015). With Autodesk BIM ecosystem, users can:

- make the concept of a building in Vasari
- design the architecture, construction and engineering in Revit, preparing the general layout
- design the external site plan network in AutoCAD Civil 3D
- make sophisticated equipment and technological lines in Inventor
- use Navisworks to verify the model and check calendar graphics, mistakes and the progress of the construction on an iPad using the apps BIM360Glue, Buzzsaw and Autodesk 360.

While the BIM ecosystem promotes interoperability between varying programs (Vysotskiy et al. 2015), if users rely heavily on a certain software ecosystem, their innovation could be limited. For example, some BIM tools are not conducive to exchanging data outside their "product family". In this study, the problems of software interoperability and compatibility are addressed in Chapters 7 and 8 in the theme of mediating tools.

2.2.3.2 Unified digital format

The Industry Foundation Classes (IFC) are a set of rules and protocols that describe and store built asset information (Furneaux & Kivvits 2008). IFC is considered as a vendor-independent, open and neutral file format which facilitates BIM software interoperability. "The Industry Foundation Class (IFC) file type represents a means for sharing construction and facility management data across various software packages used in the architecture, engineering and construction industry and facility management industry" (Yousefzadeh et al. 2015, p. 714). According to Thein (2011), IFC facilitates cross-discipline coordination of building information models, including architecture, structural and building services, data sharing and exchange across IFC-compliant applications, and handover and reuse of data for analysis and other downstream tasks.

However, since IFC facilitating interoperation focuses on data itself and not on tools (Amoah & Nguyen 2019), the software vendors are unlikely to put more effort into developing their products to meet this format. Rather, software vendors encourage clients to use their native file formats such as Autodesk Revit file ".rvt" to get better support from in-house product lines (Hernández et al. 2018). Often, household name companies (e.g. Autodesk and Tekla) still provide the option of exporting native files into IFC for "read only" but with less support for (re-)importing IFC files created by other applications (Ibrahim et al. 2016). Papadonikolaki, Leon and Mahamadu (2018) found a similar result, noting that the import and export functionality of current BIM tools using IFC protocols is underdeveloped, thus hindering interoperability among users of such software. The challenge to bidirectional IFC data transfer can be the fragmentation of software packages due to their different interests in specialised solutions (Papadonikolaki, Leon & Mahamadu 2018). For example, Autodesk BIM solutions favour architectural and mechanical design while Tekla BIM solutions mainly support structural and prefabricated design (Hergunsel 2011; Madsen & Madsen 2017). Another challenge is the dominance of a single software vendor who wants to tie AEC firms to their product line to sustain their existing industry power (Borrmann et al. 2018).

2.2.3.3 Worldwide support for BIM

As BIM aims to reduce the fragmentation in construction supply chains, BIM data integration includes not only information from AEC firms' tasks (e.g. design models) but also geospatial information from council databases on buildings, transport, vegetation and water bodies and product information such as specifications, user manuals and maintenance services from manufacturers' webservers (Hor 2015; Niknam, Jalaei & Karshenas 2019). Traditional web service technology, i.e. World Wide Web (www) standard, allows computer applications to communicate information over the internet (Utiome 2010). However, these web services have a number of limitations: they provide syntactic interoperability which requires data to be transferred in a specific format, interfaces of a web service must not change, otherwise, applications communicating could encounter a service break, and the content of a message exchanged with a web service may not be interpreted properly by computers, which prevents workflow automation (Niknam & Karshenas 2015). Currently, geospatial and product information presented on websites of councils and manufacturers are embedded in downloadable PDF formats to mediate consistent data retrieval (Niknam, Jalaei & Karshenas 2019). The problem with an attached PDF is that its content cannot be automatically interpreted by a computer and serves as "read-only". Another solution to data transfer interoperability is manually inputting data from websites into BIM platforms (e.g. Autodesk Revit) but this is very time consuming and error prone (Niknam, Jalaei & Karshenas 2019).

As data sharing standards on the internet are considered an effective way to increase efficiency and interoperability, the World Wide Web Consortium (W3C), a group of 430 organisations that develops web standards, has collaborated to develop the semantic web, a linked data web or web of data (Utiome 2010; World Economic Forum 2018). The semantic web represents a major development potential in linking information, that is, building information can effectively be linked from one source to another source, and the information can be understood by computers, and used to perform more and more advanced tasks (Godager 2018). For example, the semantic web makes it possible to refer to a specific piece of information contained in a document or program, instead of having to connect to the document or program itself; and if this information is updated, users can take advantage of this update (Godager 2018). In short, it enables the transition from the traditional web (Web of Documents) to a Web of Data: "an extension of the current web in which information is given well-defined meaning, better-enabling computers and people to work in cooperation" (Patsias 2019, p. 3).

Regarding direct support for BIM adoption in Vietnam from overseas, the UK government has assigned their consultants to organising BIM workshops (i.e. engagement stage), training on UK best practice methodologies such as policies, standards and working processes towards BIM collaboration (i.e. training stage) and running pilot BIM projects (i.e. rollout stage) in Vietnam (Matthews & Ta 2020). This support can shorten the learning curve and help the Vietnamese agents to revise current standards (as applicable) to align with international standards such as e-submission, data exchange and data storage structure (Matthews & Ta 2020). Software vendor Autodesk has signed an MOU with the Vietnamese Ministry of Construction in 2017 to work hand in hand towards Vietnam's 2021 goal of implementing nationwide BIM guidelines[10]. A recent infrastructure public project, Thu Thiem 2 bridge, has been completed using BIM through the support of Finnish engineering consultants who were introduced by the Embassy of Finland in Hanoi, Vietnam to contribute to Finnish–Vietnamese relations (Bui 2019).

2.2.3.4 Government support

2.2.3.4.1 *Policy*

Government policies can potentially influence both the process and direction of innovation through their impact on industrial, consumer and public service demands (Liu et al. 2015b). The United Kingdom government, for example, mandated that all UK government projects should use BIM by 2016 (Ganah & John 2014). Despite not mandating the use of BIM at the national level in the United States, many US public sector bodies at different levels have established BIM programs, set up BIM goals and implementation roadmaps, and published BIM standards (Cheng & Lu 2015). Although BIM adoption came later to Asia, BIM use has now developed rapidly in Asian regions. For instance, Singapore and Hong Kong have established their own BIM

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[10] Source: https://adsknews.autodesk.com/pressrelease/the-bim-steering-committee-ministry-of-construction-and-autodesk-sign-mou-to-collaborate-in-implementing-building-information-modeling-bim-in-vietnam

committees and published several BIM guidelines (Liu et al. 2015b). The Mainland Chinese government also included BIM-related strategies in its 12th National Five Year Plan in 2012 (Liu et al. 2017).

The Institute of Construction Economics has developed a BIM roadmap with the aim of requiring all public projects and first class projects to deliver BIM by year 2020 (Nguyen Viet 2015). In December 2016, the Deputy Prime Minister of Vietnam, Trinh Dinh Dung signed and approved a framework on "Applying Building Information Modelling for construction and project operation & management activities", at an event hosted by the Institute of Construction 50, Ministry of Construction (Ismail, Chiozzi & Drogemuller 2017; Vietnam Prime Minister's Decision No. 2500/QD-TTg 2016). It was followed by a series of forums, seminars and meetings to create a network amongst government agencies, design consultants, project management consultants, BIM solution providers, contractors and research institutes to jointly develop the national BIM standards, strategy and roadmap (Matthews & Ta 2020).

2.2.3.4.2 *Government funding*

In addition to mediating policies, government subsidy is effective in promoting BIM adoption because the subsidy can both bring forward the joining time and at the same time enhance BIM adoption efficiency by offsetting firms' setup costs (Yuan & Yang 2020). Liu et al. (2015b) recommended that governments can provide financial support in both direct and indirect ways by taking on multiple roles such as public project owner/client, R&D investor and innovation funding founder (e.g. incentive and reward). In Vietnam, the government will pay consultancy fees for some selected public projects registered in the national program for pilot BIM projects including expenses of preparing BIM contracts and selecting BIM-savvy contractors (Bui 2019; Matthews & Ta 2020).

2.2.3.4.3 *Formal training and education programs*

BIM funding for formal education and training to produce skilled personnel was the basis for BIM projects and equally important for the industry (Liu et al. 2015b). Chegu Badrinath, Chang and Hsieh (2016) emphasised the important role of government financial assistance in encouraging BIM education providers and researchers to design BIM education frameworks, curricula and courses. There are two options for developing and designing BIM courses: either offering new BIM courses in conjunction with existing construction management programs or integrating BIM aspects into existing curricula (Abbas, Din & Farooqui 2016). However, transitioning to BIM education is time consuming and costly. In Vietnam, where undergraduate and postgraduate educational curricula have no current plans for developing professional courses related to BIM, it is better to deliver short-term courses with the aim of improving both quantity and quality of BIM human resources to cope with industry demand (Nguyen Bao et al. 2018). In October 2017, the Vietnamese Ministry of Construction issued Decision No. 1056/QD–BXD announcing the pilot phase of the BIM educational framework for agencies and organisations to apply in the BIM implementation process (Nguyen Bao et al. 2018). This policy enabled the creation of a sustainable network connecting higher education institutions and AEC firms in Vietnam (Matthews & Ta 2020), and significant outcomes were the increasing awareness of academia and industry regarding training courses and materials to develop BIM human resources for Vietnam (Nguyen Bao & Nguyen 2018). Most BIM courses in Vietnam are currently provided by certified private training centres as short, custom made and distance learning supportive (Nguyen Bao et al. 2018).

2.2.4 Misconceptions of BIM

2.2.4.1 A single BIM model or a variety of BIM models used together with other software and tools

The technological promise of BIM has its basis in the idea of interoperability and integrated wholly sharable information allowed by ICT and standards (Miettinen & Paavola 2014). In particular, BIM is expected to represent a full collaboration between all disciplines whereby all parties can access and modify a single, shared project model through a centralised repository (i.e. Open BIM), reducing risks arising from conflicting information (Dakhil et al. 2019). Howard and Björk (2008, p. 273), however, suggested that a comprehensive single BIM "has been the holy grail but it is doubtful whether there is the will to achieve it". Similarly, other researchers argued that while the use of one single detailed model prevents errors arising from mixing up older and newer versions of a plan, a tightly integrated model restricts users from exploring alternative designs (Furneaux & Kivvits 2008; Holzer 2007). While there are aspects of knowledge such as finance, marketing and administration that are usually not directly reflected in a BIM model, they do have an impact on the BIM modelling of a design project, thus requiring the use of other non-BIM tools to support BIM adoption (Arayici, Egbu & Coates 2012).

An alternative way of defining BIM is to view it as a multifunctional set of instrumentalities for specific purposes that will increasingly be integrated (Miettinen & Paavola 2014). This is because it is unrealistic to put every data item into a single model which may result in an unmanageable file exceeding the ability of computer processing and human administration. Howell and Batcheler (2005) maintain that BIM is only one of many purpose-built models, with software constructed to be used in the specific task of functions such as architectural design, modelling of lightning or fire simulation. On large projects, various discipline models may be split into multiple, smaller models to cater for internal processes and make file sizes more manageable (State of Queensland 2017).

In addition, while a single integrated model can theoretically be created, this is rare in practice (Kuiper & Holzer 2013) because the standard practice in the construction industry of design–bid–build procurement presents a linear workflow which possibly prevents multiple parties from working collaboratively (Mota et al. 2020). Further, it is challenging to create a full integrated model at the early design stage (e.g. conceptual design) where project information is inconsistent and constantly changing (Holzer 2007). Thus, each party still needs to work on their specialised model before considering aggregation of models. Also, the power of BIM lies in its capability of relationship management of a building's components, in order to guarantee model consistency during the design process (Luciani, Garagnani & Mingucci 2012). BIM tools are weak in supporting conceptual design activities which, by nature, require a certain level of flexibility, abstraction and creation (Gu et al. 2008). It was suggested that physical models and sketching and drafting tools will continue to have a place in the creation process as the fluidity of the sketching process facilitates the thought process of designers (Coates et al. 2011). Therefore, rather than having a single model, having a single project environment containing multiple models and all associated project information to work together seems to be more effective (Baldwin 2019).

2.2.4.2 BIM should be used during project lifecycle

The promise of BIM use during the whole lifecycle of the building is "a dream far from being realised" (Miettinen & Paavola 2014, p. 86). Kivits and Furneaux (2013) claimed that while BIM is applicable to all stages of construction, there is very little evidence of a single project using BIM in all phases of construction. One reason for this is the immaturity of the BIM market due to reasons such as incompetent BIM practitioners, underdeveloped BIM tools and insufficient client demand (Ahmad Jamal et al. 2019). Further, more time is needed to prepare for dealing with the disruptive process caused by BIM, not only due to new technology but also its impact on social and economic issues (Ahmad et al. 2016). Small-scale trials are required to give users the opportunity to examine different benefits of BIM without risking a company's bottom line (Panuwatwanich & Peansupap 2013).

In addition, it does not make business sense to commit organisational resources such as personnel, equipment, time and effort to a full lifecycle BIM project, which are often long complex projects. In particular, the construction industry is dominated by small and medium sized companies (Hosseini et al. 2016) whose appetite for BIM is considered to be too risky due to the limited resources (Li et al. 2019). Often, small companies have only subcontracting roles with low profit margins on a project compared to big companies (Belayutham & Ibrahim 2019). To survive, smaller companies undertake multiple projects at once and try to avoid getting stuck in one project. This requires frequently moving resources on and off projects to optimise the use of scarce resources. However, the productivity and fluidity of the entire BIM process may decline due to work disruption or time lag when crews move from one area or work assignment to another (Intergraph 2012). For example, information updating for as-built models is likely to be either interrupted or inconsistent due to personnel rotation which frequently occurs within and across projects.

Operation and maintenance (O&M) costs of a building are often overlooked at the design phase by owners and project stakeholders even though these costs could add up to over half of the total building lifecycle costs (Patacas et al. 2015). This is due to the lack of awareness of owners (i.e. lack of knowledge) and the lack of interest of AEC professionals (i.e. out of design and construction scopes). As a result, information handover for O&M is left until the completion of the deign–construction phase and is typically in non-digital formats and contains inaccuracies, such as unavailability or inconsistency of as-built models (Kelly et al. 2013). Currently, BIM implementation stops at the early construction phase and the achievement of complete as-built models has been a problem, limiting BIM data use in the post-construction phase for O&M (Heaton, Parlikad & Schooling 2019).

2.2.4.3 BIM tools disrupt drafting and sketching tools

BIM should not be seen as a "one-size-fits-all" solution as BIM practitioners (e.g. designers or software vendors) often exaggerate its advantages for commercial reasons (Kjartansdóttir et al. 2017). In reality, BIM capabilities seem to be valuable for design documentation and post-design rationalisation rather than for creating new opportunities for new design solutions (Holzer 2007). In other words, as more information is added to a BIM model, it is less likely to remain flexible for creating alternative versions (Holzer 2007).

The design process is often not linear or straightforward but iterative and flexible (Knotten et al. 2015). Further, design development reflects a personal design method of a designer. For example, some designers like to design projects from the inside out while others prefer to design from the outside in. However, BIM tools do not allow for these personal nuances in the design process. Few BIM tools can accommodate the ambiguities of early design (Coates et al. 2011). Researchers have claimed that "BIM is a methodology to integrate digital descriptions of all the building objects and their relationships to others in a precise manner, so that stakeholders can query, simulate and estimate activities and their effects on the building process as a lifecycle entity"(Arabica, Egbu & Coates 2012, p. 76). BIM concentrates too much on providing a means of representing the final form of the design, i.e. object-oriented design. In other words, it is more a language of materiality or a language of parts while the language of architectural design is more abstract and holistic, containing values, meanings, anthropometrics and aesthetics (Coates et al. 2011). Similarly, Çavuşoğlu (2015) noted that in the early stages of architectural design, sketching or drafting, either manual or CAD-based, still has a significant role in exploring possible design alternatives, evaluating ideas and communicating internally and with other project stakeholders.

2.2.4.4 BIM clients: owners or end-users?

Several BIM studies have emphasised the role of clients as a driving force of BIM implementation in the AEC industry (Bosch-Sijtsema et al. 2017; Hosseini et al. 2016; McGraw Hill 2014; Moreno, Olbina & Issa 2019; Yuan, Yang & Xue 2019). The common barriers to BIM adoption arising from client factors are lack of clients' knowledge (Bosch-Sijtsema et al. 2017); lack of clients' demand (Hosseini et al. 2016); low level of clients' involvement in terms of support, commitment and decision making (Fadeyi 2017; Moreno, Olbina & Issa 2019; Yuan, Yang & Xue 2019); and lack of clients' capability to leverage BIM at the post-adoption stage (O&M) regarding skilled staff, IT infrastructure and funds (McGraw Hill 2014). However, the terms clients and owners seem to be used interchangeably as most researchers above referred to clients as the people owning or sponsoring a project (e.g. investors, developers or government bodies) while the role of end-users, the occupants of a completed building, is not well understood in the BIM process. Many researchers have explored the benefits of BIM, but very few have reported benefits for the occupants of constructed facilities (Gurevich, Sacks & Shrestha 2017). Most studies have focused on the benefits of BIM for AEC professionals, suppliers, regulators and developers (Eastman et al. 2011; Herr & Fischer 2019; Moayeri 2017).

Occupants of facilities created using BIM are more concerned with long-term values than with short-term benefits. Values such as potentially reduced cost and construction duration might benefit owners and developers (Eadie et al. 2015; Hardin & McCool 2015) but such values are not very relevant to occupants of a building. Safety, security, accessibility, thermal comfort and energy performance, lighting, acoustics and aesthetics are all aspects of building performance which improve occupants' wellbeing, enhance their productivity or provide other specific values (Gurevich, Sacks & Shrestha 2017). In a study of BIM uses for educational facility projects, Moreno, Olbina and Issa (2019) found that it is important to include the end-users, the school students and teachers, in the process of design, construction and maintenance of the buildings to achieve a higher quality project, such as engaging students in the evaluation of daylight design for visual comfort as daylight is very beneficial for student wellbeing and learning of course material (Koti & Munshi 2009). In particular, post occupancy evaluations with review and feedback are critical for renovation projects or project upgrades or projects focusing on performance optimisation such as energy consumption.

2.2.5 Barriers to BIM adoption

2.2.5.1 Legal concerns

2.2.5.1.1 *Intellectual property*

As BIM typically involves architects and engineers in the co-creation of the model, it raises the issue of who owns the intellectual property (IP) of the model. With 2D drawings, the copyright and related IP for a drawing is clear as this is asserted on each page of the drawings (Furneaux & Kivvits 2008). However, in a BIM model, numerous professionals contribute their expertise and intellectual property together in the development of the single model. An issue that needs to be addressed is whether a distinction can be made between the overall model, and the elements of which the model is comprised (Currie 2014). Often, owners (e.g. government bodies and developers) may want to share or reuse information in models many times; and therefore develop a large database of building elements, perceived as a valuable commodity in its own right (Kivits & Furneaux 2013). This leads to a debate on whether designers need to be paid royalties every time their original elements are used or if the entire model and its associated elements should be fully purchased by clients in a one-off payment (Furneaux & Kivvits 2008).

It is argued that the ownership of model outputs should vest in project owners as they are financial sponsors of a project (Currie 2014) but there could be sensitive data embedded in the model whose access rights for reusing, amending or further transmitting data to third parties require the agreement of the model authors. This includes confidential information and trade secrets such as construction techniques and sequencing (Manderson, Jefferies & Brewer 2015). Upstream users (e.g. main contractors) providing transparent information also add value to a project, facilitating interpretations of downstream users (e.g. subcontractors) regarding design intents or executing processes in order to plan responses accordingly, yet imposing the risks of losing competitive advantages on upstream users due to potentially leaking commercial data (Smith 2014). Further, downstream beneficiaries also do not pay compensation upstream for additional cost and effort (Li et al. 2019). Also, current policies on intellectual property of digital models are still subjective and superficial in developing countries such as China and Malaysia (Jiang, Ma & Zhang 2018; Jo, Ishak & Rashid 2018). It is recommended that the clauses of a collaboration arrangement should allow flexibility for model contributors to be able to choose between shared or joint leadership across disciplines. However, this is likely to challenge traditional disciplinary boundaries in determining ownership of work (Alwash, Love & Olatunji 2017).

Generally, the new terms collective objects or outcomes of collaboration, where a federated digital model is jointly aimed and owned by contributors and clients, upset traditional industry practices and challenge existing intellectual property regulations based on physical materiality of paper-based documents (Alwash, Love & Olatunji 2017). This adds to the unwillingness of AEC professionals to share information and collaborate (Herr & Fischer 2019; Wang, Gosling & Naim 2019).

2.2.5.1.2 *Professional liability*

As noted above, intellectual property is relevant to the issues of payment arrangement (e.g. royalties) and defined authorship of models (e.g. permission of transmitting, extracting and reusing the model in whole or in parts). Despite its challenges, intellectual property disputes may not escalate into litigation due to early internal settlement among project stakeholders, through open negotiation and bespoke contracts (Currie 2014; Kuiper & Holzer 2013). The legal issues arise from the reliability and validity of information which can be further reused directly from the handed-over model (Foster 2008). Present regulations in the United States and the United Kingdom do not allow model authors to give owners unrestricted licenses to reproduce the model's content for other purposes beyond the current project's contract (Fan et al. 2018). If model authors do not get involved each time the model's elements are reused, there is a risk of inaccurate interpretation of information or incorrect application of information by owners and third parties they hired which could reduce safety, create design and/or construction errors, and lead to insurance claims (Olatunji & Sher 2010). However, it would be challenging to gather the original creators of a model every time it was reused due to the nature of a project as a temporary organisation (Dossick & Neff 2010).

It should also be noted that the model's authors (e.g. architects) are not only held responsible and accountable for any defects that occur during the implementation (Furneaux & Kivvits 2008) but are also concerned about how much liability they have to bear if other parties (e.g. owners or contractors) start reusing their models (Foster 2008). Further, model authors could also be liable to exposure due to data corruption, sabotage and loss which may be inadvertently caused by software incompatibility (Manderson, Jefferies & Brewer 2015). The level of responsibility among project teams also becomes unclear if any inaccuracy or mistake is detected since they may have "touched up the information in the same data model" (Mat Ya'Acob, Mohd Rahim & Zainon 2018, p. 6).

2.2.5.1.3 *Contract*

As noted early, intellectual property may put downstream users (e.g. clients and subcontractors) at risk of copyright infringement while professional liability creates the risk of errors such as design errors, non-compliant design, transition errors, data loss or data misuse on upstream users (e.g. designers). This means that contractual relations between parties in the AEC industry need to address these emerging concerns. However, a widely accepted contractual governance for BIM-enabled projects has not yet been established

(Jiang, Ma & Zhang 2018). Therefore, it is necessary to develop collaborative and integrated contracting methodologies to avoid disputes among project teams involved (Jamil & Fathi 2019). It has also been suggested that future contractual forms should consider design delegation to non-professionals and subcontractors, as well as the effect of software on design updates and automatic changes (Jamil & Fathi 2019).

2.2.5.2 Expense of BIM implementation

2.2.5.2.1 *Cost*

Training costs. Organisations need new skills to drive BIM. To develop these skills, personnel must be trained to deploy new technologies. Because organisations have different structures, they may require different training packages to manage BIM in line with varying business interests of disciplines involved with BIM (Wood, Davis & Olatunji 2011). Therefore, different categories of staff will require different training to adapt to specific functions (Wood, Davis & Olatunji 2011). Such custom designed courses may incur high expenses to meet unique demands (Shepherd 2016). BIM training for an organisation is normally conducted in two ways: start-up and in-line training. While start-up training precedes implementation and is usually for new recruits, in-line training can be periodic or continuous for experienced personnel working on projects in on-the-job-training (Liu et al. 2015a).

Equipment costs. The up-front cost of BIM is seen as a financial burden by adopting companies (Moreno, Olbina & Issa 2019). This involves the cost for purchasing new software and hardware and also the cost for operation and maintenance such as electric power, internet access, frequent updates and continuous technical support, e.g. consultancy and research (Hasan & Rasheed 2019). It is also very common that old and new tools are used in parallel as the completed transition may be time consuming and costly (Byun & Sohn 2020). This could result in incompatibility between software packages (Hatem, Abd & Abbas 2018) adding to the cost for developing plug-ins, add-ins or for procuring third party apps to facilitate interoperability when problems arise (Chandra & Zhou 2014).

Consulting fees. It is also likely that adopting companies may not have in-house BIM champions to lead the BIM initiative. Hiring external BIM experts or contracting with BIM consulting firms, therefore, would be necessary to ensure that an organisation is on the right track with BIM adoption (Barison & Santos 2010). However, Purba (2018) questioned the cost effectiveness of hiring BIM experts because small companies cannot afford extra overheads on experts' salaries. Further, the loyalty of outside talent may be lower than that of employees developing in-house because they are likely to move on due to better offers from competitors lacking such expertise (Agustine & Ssemugenyi 2014).

Also, a case study in Vietnam revealed that low-paid salaries of the client teams of public projects (i.e. the state officers) compared to the consultant teams (i.e. private sector employees) negatively affect recruiting qualified BIM champions to the client teams (Bui 2019). This causes the lack of BIM experts in the client teams which may, in turn, increase BIM consultancy fees because the consultant teams have to do extra-work (e.g. convert outputs from BIM model in compliance with traditional 2D-drawing-based documentation) to assist the client teams to meet project deadlines (Bui 2019).

2.2.5.2.2 *Time*

In addition to money, BIM adoption takes time, creating an unavoidable learning curve (Hardin & McCool 2015). Similarly, Mondrup, Karlshøj and Vestergaard (2012) stated that many organisations rush into BIM adoption expecting great benefits immediately but BIM adoption requires a learning curve which imposes additional stress on employees. There will also be some productivity loss during the time employees are learning BIM (Akintola et al. 2016). It was also found that employees feel exhausted when learning on-the-job due to pressure created by the time constraints of their daily tasks (Matthews et al. 2018). Some companies may provide full-time training courses to facilitate the concentration of learners but this imposes heavier workloads on non-learners who have to fill positions temporarily left by learners (Leung, Chan & Cooper 2015). In a Vietnamese infrastructure project, hiring foreign BIM experts is expected to speed up BIM process, however, the existing paper-based tradition is considered as the most time-consuming issue in implementing BIM since the BIM experts had to modify manually outputs exported from the 3D model to meet the local requirements (Bui 2019).

2.2.5.2.3 *Effort*

Adding work to designers. While designers (e.g. architects and engineers) in Asian developing countries were initially expected to adopt BIM, they have not done so on a large scale to date, presenting a "wait-and-see" attitude to the adoption of higher levels of BIM practices (Ismail, Chiozzi & Drogemuller 2017; Juan, Lai & Shih 2017). The development of an integrated multidisciplinary model, with fully attributed objects, involves significantly more information than is currently required in 2D drawings provided by the designers (Kong et al. 2020). While automated functions of BIM can save time for manual and repetitive design tasks (Lu & Wong 2018), working on a 3D model would prolong the additional processes required to carry out non-design activities such as the creation of computable parameters and cross-disciplinary collaboration (Kong et al. 2020).

2.2.5.3 Technological issues

2.2.5.3.1 *Interoperability*

The lack of interoperability between applications or software incompatibility is considered a major risk in implementing BIM (Ratajczak et al. 2015). This problem exists due to the heterogeneous nature of applications and software systems used across multiple disciplines (Mat Ya'Acob, Mohd Rahim & Zainon 2018). Each project participant prefers tools which are specialised and tailored to their individual roles or business interests (Walasek & Barszcz 2017).

However, many tools are not designed for multiple users, and work only for one specific use.

Further, due to the restricted capabilities of immature BIM tools, non-BIM tools continue to be used in conjunction with them. For example, BIM was mostly used and restricted to 3D modelling and visualisation (Ismail, Chiozzi & Drogemuller 2017) while offering less support to sketching design or advanced engineering analysis compared to specialised tools such as SketchUp[11] and ETABS[12] (Coates et al. 2011; Herr & Fischer 2019). This could exacerbate the interoperability issue likely to arise due to data exchange between the software providing these additional capabilities and BIM software (Harding et al. 2014).

2.2.5.3.2 *Standards of data exchange formats*

The development of BIM tools for specific solutions and professions has resulted in a series of programs that do not interface well with each other. This led to the introduction of the Industry Foundation Classes (IFC) as "an open source international standard developed by the building SMART alliance" (Walasek & Barszcz 2017, p. 1229). IFC aims to facilitate sharing of information in a common language and easing the data exchange focusing on the geometry of objects and metadata attached to them regardless of the software package or BIM platform being used (Pour Rahimian et al. 2019). However, the complexity added to meet IFC has made software vendors reluctant to integrate it into their products (Howard & Björk 2008). While the applications of IFC have been tested (Stapleton, Gledson & Alwan 2014), to date, IFC does not support the entire object information library of proprietary software, resulting in data loss through each import and export, degradation of

[11] SketchUp: a 3D model design software was initially developed by Google but it does not include a parametric modelling function (Graham, King & Hopson 2018).
[12] ETABS: an engineering analysis software provides linear structural analysis including both static loads and dynamic loads but it does not support the importing or exporting files directly to BIM tools (Ren, Zhang & Dib 2018).

information, and in some instances loss of semantic, descriptive and parametric functionality (Lai & Deng 2018).

In addition, AEC professionals tend to use traditional AutoCAD formats (i.e. DWG files) adapted to local regulations and standards in order to facilitate document approvals (Herr & Fischer 2019). Particularly in Vietnam, the government bodies remain slow to change towards supporting international standards for BIM data sharing (Bui 2019; Nguyen Quoc et al. 2020). The mismatch between new BIM software and existing standards results in the manual and ad hoc exchange of information when users need to import data from CAD tools into a BIM model for analysis and export BIM outcomes back to CAD tools for regulatory compliance (Heaton, Parlikad & Schooling 2019). Using several intermediate steps to process information not only reduces productivity but also increases the possibility of human errors such as incorrectly entering data and inadvertently leaking data that could negatively affect trust among parties often leading to litigation (Preidel, Daum & Borrmann 2017; Stapleton, Gledson & Alwan 2014). Thus, it is argued that technical issues and social issues (e.g. legal disputes and mutual trust) are difficult to separate and need to be investigated together in a holistic manner (Okakpu et al. 2019; Papadonikolaki 2017).

2.2.5.3.3 *Technological capabilities of practitioners*

It is vital for the success of BIM that all participating parties of the project use the same versions of programs and the same standards (e.g. IFC), which has to be agreed before starting the project. In the initiation stage, all participants will have to agree on switching to the new standards if they are not using these yet (Furneaux & Kivvits 2008). However, Kong et al. (2020, p. 5) challenged this view and argued that "a chain is only as strong as its weakest link" where the inefficiency or weakness of just one party can cause the entire project to slow down even though the other parties are efficient.

Another option would be to only enter arrangements with partners that already comply with the requirements (Kivits & Furneaux 2013). In this way interoperability challenges could be addressed and delays due to lack of interoperability avoided. However, this option requires a proper project delivery mediating the establishment of BIM competent project teams. Therefore design–build procurement is considered the best fit when BIM is applied (Kjartansdóttir et al. 2017). This delivery method empowers a main contractor to select the most suitable subcontractors for the project based on the talent (or the best value) instead of the basis of lowest price in design–bid–build procurement (Akintan & Morledge 2013). Design–build enables better trust-building among parties than design–bid–build where each party works in disciplinary silos and reports directly to the owner (Aibinu & Papadonikolaki 2016). Despite its suitability for BIM adoption, design–build is not popular because most public entities may be required by law to use design–bid–build (Shrestha et al. 2007). Further, clients with less experience in design–build may fear to take an additional risk by selecting a procurement system which is not familiar to them, e.g. putting all trust into one single entity (Joseph & Jayasena 2008). Also, a main contractor in design–build could deliberately drive designs which are fast, simple and consistent to serve their own constructability purposes rather than being innovative and provide flexible design solutions (New Zealand Government Procurement 2019).

A recent case study of a Government-funded infrastructure project also indicated that the challenge faced by Vietnamese construction companies for BIM adoption is the lack of technological capacity. That is, the foreign BIM consultants found difficult to collaborate with local companies because while the staff members are busy with other projects and do not have time to learn about BIM, the management board preferred taking on more projects to adopting new technologies (Bui 2019).

2.2.5.4 Social issues

BIM adoption requires more than technological and legal enablers. BIM is most likely to require to be accompanied by changes to the way AEC firms relate to each other and interact (Furneaux & Kivvits 2008). Miettinen and

Paavola (2014) have also argued that the technological visions in particular tend not to take fully into account the social and human conditions of the implementation of a technology. On the other hand, Barra (2013, p. 3) referred to this underestimated social interaction as "design fancy", when designers assumed that builders can construct any proposed design thanks to 3D BIM visualisation. Yet, there are many social factors affecting the ability to transform a digital model into a physical building including new attitudes toward digital information, the re-distribution of power structures, new organisational forms, and re-definition of terms and territories (Furneaux & Kivvits 2008).

Also, job titles related to BIM were found to be diverse and overlapping (Davies, Wilkinson & McMeel 2017) and were classified based on subjective interpretation rather than being standardised (Gathercole & Thurairajah 2014). This problem could create a confusion of 'who does what?' among project teams which lessens their motivation of intensive using BIM tools (Kouider, Sykes & Hamma-adama 2019). However, much of the work on BIM today has focused on addressing the technical issues involved in creating a viable product (Herr & Fischer 2019; Hochscheid & Halin 2018) and recently it has become clear that inter-organisational issues (i.e. social interactions) must also be considered (Camposano & Smolander 2020; Li et al. 2019).

2.3 Government BIM mandate in Vietnam as the catalyst for the research

In December 2016, Vietnam's Deputy Prime Minister Trinh Dinh Dung signed Decision No. 2500/QD-TTg approving the scheme on "Applying Building Information Modelling for construction and project operation & management activities", which has been hosted by the Institute of Construction Economics, Ministry of Construction (Ismail, Chiozzi & Drogemuller 2017; Vietnam Prime

Minister's Decision No. 2500/QD-TTg 2016). According to this scheme, work content and schedule follow a roadmap:

- From 2017 to 2019, prepare necessary conditions and skill training sessions for application of BIM, including duties such as improve awareness and encourage entities, institutions or enterprises to implement BIM; outline the legal framework for application of BIM, system of technical regulations, standards or economic and technical norms where relevant; build instructions for BIM and develop the framework for training of knowledge about BIM and make arrangements for providing training to construction authorities exercising their delegated powers.
- From 2018 to 2020, initiate pilot application of BIM at several projects, including duties such as conduct utilisation of BIM in project design, construction and management operations for at least 20 new construction packages ranging from the first to higher level in investment and construction projects financed by the state and other sources (on a voluntary basis); use BIM for operation management of at least 10 important projects which are subject to technically complicated requirements and developed by state funds.
- From 2021 onwards, based on the review and evaluation report on application of BIM, the Ministry of Construction will introduce the Circular and Detailed Guidance on universal use of BIM in facility construction and operating management activities.

Although the Vietnamese government issued its nationwide BIM application roadmap, there are very few studies with empirical evidence of either success or failure case studies on how the AEC professionals in Vietnam can implement BIM in collaborative design and construction to facilitate an adoption decision making process by key stakeholders such as the public sectors, management boards and project owners. To date, BIM research on the Vietnamese context is rare and (if any) only focuses on software-learning courses (Nguyen Bao et al. 2018), the legal framework for BIM adoption (Matthews & Ta 2020) and methods proposed to tailor BIM deliveries (e.g. quantity take-off and costs estimation) to meet Vietnamese regulations (e.g. standard rules of measurement) (Nguyen Quoc et al. 2020).

Study on the collaborative behaviour of BIM users is necessary to gain more knowledge on the performance of BIM-based collaboration platform (Forcael et al. 2020), particularly when the Vietnamese government encourages key stakeholders to carry out pilot BIM projects before mandating the use of BIM from 2021 onwards. Okakpu et al. (2018) affirmed that the adoption of BIM requires a more multidisciplinary collaboration effort of different disciplines to facilitate information sharing, without this, it is only "scratching the surface" (p. 468). Singh, Chinyio and Suresh (2018) also argued that BIM projects may fail due to ineffective social interactions between the project stakeholders (e.g. inconsistency in setting common goals or miscommunication with non-technical stakeholders) rather than lacking project management practises. This gave rise to this research which aims to investigate social interactions in BIM collaboration activities covering specific areas: how project stakeholders perceive their BIM roles on a new collaborative working platform, in Chapter 4; how project stakeholders cooperate, communicate and negotiate objectives and outcomes in BIM collaboration activities, in Chapter 7; and how project stakeholders respond to contradictions which emerge in BIM collaboration activities, in Chapter 8.

2.4 Diffusion of Innovation Theory and BIM research

2.4.1 Overview of Diffusion of Innovation Theory

2.4.1.1 The process of adopting an innovation

Diffusion of Innovation Theory seeks to explain how innovations are accepted and adopted by social groups (Rogers 2003). Innovations can be ideas, behaviours or objects that the social groups perceive to be new and will in some manner create social change (Dearing 2009; Sahin 2006). Rogers (2003) developed a framework that describes the adoption process within a society (see Figure 2.8). The diffusion of an innovation in a social group occurs as a five-stage decision making process. It occurs over a period of time through a series of communication channels among individual members of the group. As an increasing number of individuals within the social group adopt the innovation, the innovation becomes more palatable for the rest of the group. The stages of adoption decision are summarised by Rogers (2003) as below:

- Knowledge: the individual is first exposed to an innovation but lacks information about the innovation and is not inspired to seek any more information
- Persuasion: the individual is interested in the innovation and actively seeks out more information about the innovation
- Decision: the individual takes the concept of the change and weighs the perceived advantages and disadvantages. The individual also makes a decision about adopting the innovation or rejecting the innovation.
- Implementation: the individual employs the innovation to varying degrees depending on the situation. This is a testing stage and the individual is determining the usefulness of the innovation and may need further information about it.

- Confirmation: the individual finalises their decision about continuing to use the innovation. This stage is both intrapersonal and may cause the individual to be conflicted about deviating from the status quo and interpersonal, with the group to which the individual belongs confirming that the innovation is the better choice.

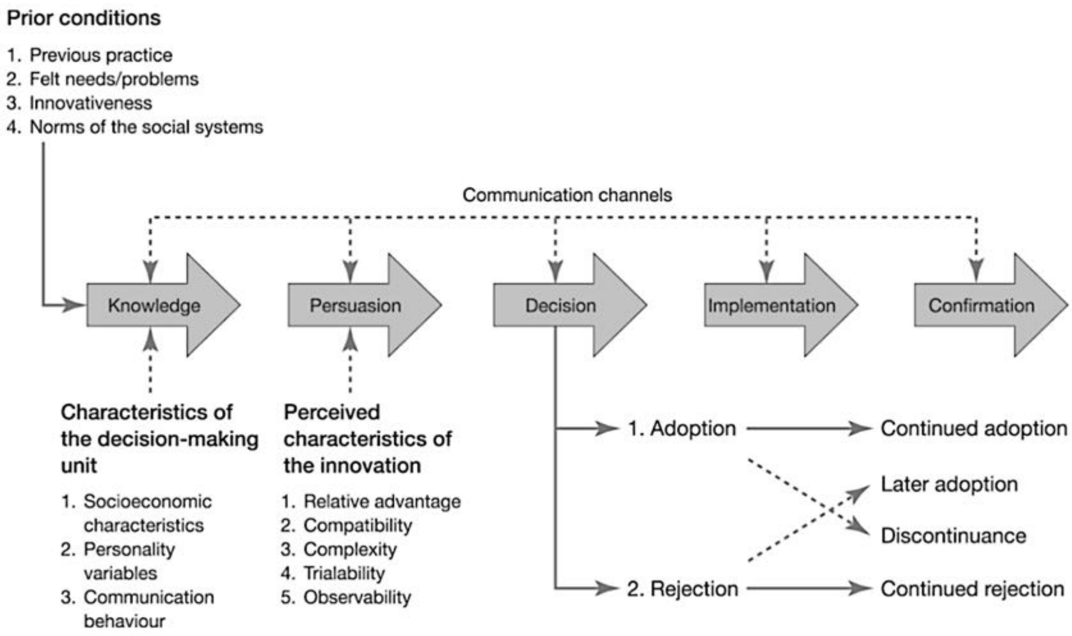

Figure 2.8 Innovation adoption decision process (Rogers 2003)

As shown in Figure 2.8, the first three stages including knowledge, persuasion and decision (pre-implementation stages) were explained using a number of factors affecting the organisational decision of taking innovation into practice such as prior conditions, characteristics of the decision making units and perceived characteristics of the innovation. The implementation stage and confirmation stage, however, were not fully taken into account because they depend on the context of the application in each organisation. Innovation practices in general and BIM implementation in particular lack empirical evidence within the construction fields and in a developing country context (Bui, Merschbrock & Munkvold 2016; Sahil 2016).

2.4.1.2 Characteristics of an innovation

Diffusion of Innovation Theory explains the possibility of an innovation being adopted by potential adopters through its attributes (Dearing 2008) as below:

- **Relative advantage** is described as how individuals perceive an innovation in regard to its predecessor. If they view the innovation as having more advantages than the previous innovations, the rate of its adoption will be faster.
- **Compatibility** is defined as the extent to which the innovation is consistent with the existing values, past experiences and needs of potential adopters.
- **Complexity** is the degree to which an innovation is perceived as difficult to understand and use.
- **Trialability** is the degree to which an innovation may be experimented with on a limited basis.
- **Observability** is the degree to which the results of an innovation are visible to others.

The influence of each attribute on the decision of adoption varies based on the different ability of adopters and their adopting conditions but the more attributes the innovation has, the greater its likelihood of adoption (Musa, Ezra & Monsurat 2015).

2.4.1.3 Characteristics of adopters

Diffusion of Innovation Theory categorises adopters according to their innovativeness – the degree to which an individual adopts new ideas earlier than other members of a system (Scott & McGuire 2017).

- **Innovators:** They are risk takers who are willing to experience new ideas despite a certain level of uncertainty about the innovation or a risk of unprofitable and unsuccessful innovations (Sahin 2006). Innovators play an important role in the diffusion process of launching the new idea in the social system by importing the innovation from outside the system's boundaries (Rogers 2003). As they are ahead of the norm, few others may decide to copy them. In particular, they may not be respected by other members of the social system because of their venturesomeness and close relationships with those outside the social system (Sahin 2006). Their venturesomeness also requires innovators to have complex technical knowledge (Kee 2017).

- **Early adopters:** While innovators adopt because a product is new and exciting, early adopters adopt when they see potential value of the innovation which is compatible with the adopting community (Umberger 2016). Early adopters are more likely to hold leadership roles in the social system and other members come to them to get advice or information about the innovation (Rogers 2003). Unlike innovators, early adopters are a more integrated part of the local system and are respected by peers. Their degree of innovativeness is relatively limited by the boundaries of the social system, and culture and practice norms (Sahin 2006). Thus, early adopters perform adopting activities at a slower pace but in a more consistent manner than innovators to ensure the alignment of the innovation with the social system's norms (Rogers 2003).
- **Early majority:** They adopt a new idea just before the average member of the society adopts it and interact frequently with their peers (Sahil 2016). Although the early majority have a good interaction with other members of the social system, they do not take on the leadership role that early adopters have (Rogers 2003). However, their interpersonal networks are still important in the innovation diffusion process. In particular, their unique position between the very early and the relatively late adopters makes them an important link in the diffusion process. Their innovation decision period is relatively longer than that of the innovators and the early adopters (Kant et al. 2018).
- **Late majority:** They adopt an innovation with caution and wait until most of their peers adopt the innovation by observing and collecting enough successful evidence (Sahil 2016). Although they are sceptical about the innovation and its outcomes, economic necessity and peer

pressure may lead them to adopt the innovation (Ayinla & Adamu 2018). Interpersonal networks of close peers may help to reduce uncertainty and persuade the late majority to adopt an innovation because they may feel that "it is safe to adopt" (Rogers 2003, p. 284).

- **Laggards:** Laggards have a more traditional view and they are more sceptical about innovations than the late majority. They have almost no opinion leadership (Sahil 2016). Their interpersonal networks may be narrow and many of them are nearly isolated in social networks (Kant et al. 2018). Due to the limited resources available to them and the lack of awareness knowledge of innovations, they want to make sure that an innovation works before they adopt it (Umberger 2016). Thus, laggards tend to decide after looking at whether the innovation has been successfully adopted by other members of the social system (Sahil 2016). Due to all these characteristics, laggards' innovation decision period is the longest of all adopters (Rogers 2003).

2.4.1.4 Innovation adoption rate (S-shaped curve) by adopter categories (Bell-shaped curve)

Based on the five adopter categories defined by innovativeness (innovators, early adopters or opinion leaders, early majority, late majority and laggards), Diffusion of Innovation Theory depicts the percentage of each adopter group in the target population and expects adopter distribution to follow a Bell-shaped curve over time (Rogers 2003). An underlying theme of the theory is that the rate of innovation spread starts off slowly, accelerates through the mid-range of the graph, and then slows down and levels off, forming an S-shaped curve (Rogers 2003). The S-shaped curve represents the cumulative rate of adoption (or diffusion curve) over time (Dearing 2009). S-shaped curves have a critical 'take-off point', at between 10% and 20% of the system (usually 16%), where a sufficiently large number of people in the community have adopted (or been infected) to make the rate of growth turn upward and continue climbing until the system begins to run out of unaffected members

(Briscoe, Trewhitt & Hutto 2011). In recent studies on diffusion prediction such as Bech, Shimizu and Wong (2017), Dube and Gumbo (2017) and Lambert (2019), the S-shaped curve for cumulative distribution of adopters and Bell-shaped curve for frequency distribution of adopters are presented together to better demonstrate the rate of adoption (see Figure 2.9).

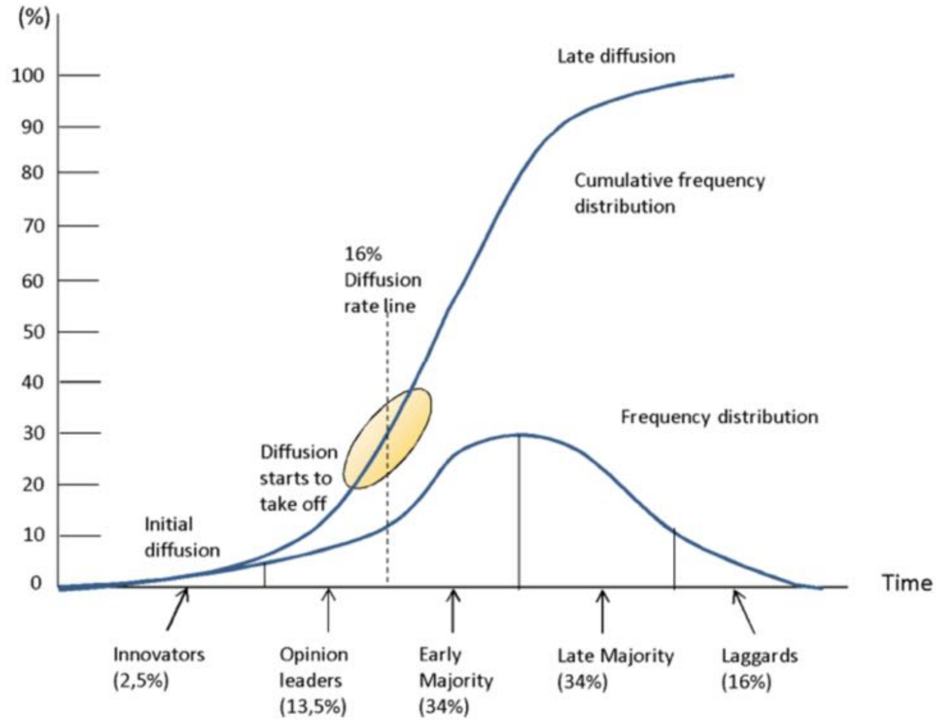

Figure 2.9 Model of innovation adoption rate by adopter categories, adapted from Rogers (2003)

2.4.1.5 Communication channels

In addition to the attributes of innovation and the nature of adopters, communication channels facilitating the broadcast of knowledge and the information exchange of innovation are perceived as determinants of adoption success (Rogers 2003). Communication channels could be influential people (e.g. an opinion leader), external expert (e.g. a change agent), social network (e.g. peer network) and means of communication (e.g. mass media).

- Opinion leader: The adoption of new products or behaviours involves the management of risk and uncertainty. Therefore, the majority of potential adopters require a role model to follow. Robinson (2009, p. 3) noted that the source of trust comes from people "who we personally know and trust; who we know have successfully adopted the innovation themselves; and who can give us credible reassurances that our attempts to change will not result in embarrassment, humiliation, financial loss or wasted time". Opinion leaders can be this role model because they often stand out in a community in terms of social status, wealth or skills, and are thus respected by social members and have the ability to influence others' attitudes and knowledge (Feder & Savastano 2006). Opinion leaders are most likely to become early adopters (Sahil 2016), however they may be in alignment with traditional behaviour and norms—adhering to local values and practices; and, in some cases, could even be strongly against changes or external influences (Rogers 2003). In practice, change agents should first target opinion leaders and cooperate with them to enhance the impact of their diffusion activities in a social system (Tuan et al. 2010).

- Change agents: A change agent is anyone who has the skill and power to stimulate, facilitate and coordinate the change effort (Rogers 2003). Change agents may be either external or internal (Lunenburg 2010). Dearing (2009) defined change agents as external experts hired to facilitate the diffusion of innovation into a social system. On the other hand, Seeger and Wilson (2019) argued that change agents may be most effective when they are opinion leaders within the adopting community.
- Social network: Diffusion of Innovation Theory assumes that the diffusion of innovation process starts with a few early innovators, and then diffuses to some early adopters in their social network, primarily as a result of peer modelling of the innovation and positive iterative feedback (Rogers 2003). Then the innovation is further adopted by more and more individuals in the community, which finally results in a change in general practice, or behaviour norm change, in the population (Li et al. 2012). Such widespread adoption is enabled by

many activities such as word of mouth, social learning or network externality (Xiong, Wang & Bobashev 2018). Word of mouth is particularly effective when used by opinion leaders to recommend the adoption of a product or service without the expectation of commercial reward and therefore has credibility in the social network (Mazzarol 2011). Social learning such as distant education and online courses can save time and cost for adopters to gather information from observing outcomes of prior adopters (DiMaggio & Garip 2012). Network externality serves as a peer-to-peer information sharing platform such as email, the telephone system or social networking sites such as Facebook (DiMaggio & Garip 2012). The value of network externality strengthens as the number of subscribers increases. The large community of users not only influences other peers to adopt the platform, but the users also attract more innovation promoters to introduce their new products on the platform, which then attracts more adopters to join the platform to seek information about this product (Hejazinia & Bruce 2016).

- Media channels: The mass media, both print (books, magazines and newspapers) and broadcast (cinema, radio and television), have been seen as more effective than interpersonal communication (e.g. word of mouth) in spreading information and creating awareness about innovations (Barnett & Vishwanath 2017). While early adopters (e.g. innovators) may be more influenced by mass media communications, later adopters are likely to prefer interpersonal communications such as word of mouth or observation, supporting the notion that later adopters are imitators of the innovators (Fry, Ryley & Thring 2018).

2.4.2 BIM research using Diffusion of Innovation Theory

Diffusion of Innovation Theory was designed to investigate the diffusion and adoption of a new technology across communities (Rogers 2003) and digital innovations, such as BIM, are not exceptional (Shibeika & Harty 2015). BIM studies using the theory have focused on diverse subjects, including but not limited to barriers, cultural issues, maturity and awareness, change, drivers and diffusion prediction (Ahmed & Kassem 2018). Table 2.9 summarises examples of concepts and models of Diffusion of Innovation Theory to study BIM as an innovation.

Table 2.9 Examples of BIM studies using Diffusion of Innovation Theory

BIM studies	Authors/years	Main focus	Use of Diffusion of Innovation Theory
Barriers	Hamma-adama, Kouider & Salman (2018)	- Social and habitual resistance to change - Legal and contractual constraints - High cost of training	Uses the categories of adopters such as early majority, late majority etc. to explain slow adoption
	Panuwatwanich & Peansupap (2013)	- Unavailability of BIM tools - Lack of market demand - Complicated and time consuming modelling process	Uses the characteristics of innovation such as complexity, relative advantage etc. to explain slow adoption
Cultural issues	Ali & Miraz (2016)	- Sensitive adherence to culture is key in the opening of more reserved societies to new innovative technologies	Identifies opinion leaders and cooperates with them to understand cultural and religious norms of target population
	Shibeika & Harty (2015)	- Cultural diversity in BIM workforce	Uses communication channels and network development
Maturity and awareness	Froise & Shakantu (2014)	- Lack of awareness by clients, the government and industry bodies	Uses the categories of adopters such as early majority, late majority etc. to classify the levels of maturity and awareness of BIM adoption
	Hochscheid & Halin (2019)	- Level of maturity of BIM adoption	Uses the model of innovation adoption

			decision process to predict the levels of maturity
Changes	Ishak & Newton (2016)	- Key resistance factors to change	Uses the characteristics of innovation to establish resistance indicators
	Merschbrock & Munkvold (2014)	- Organisational changes	Uses the concept of "change agents" to facilitate digital collaboration process
Drivers	Singh (2013)	- Innovation champions	Uses the concept of "opinion leaders" to drive the change
	Panuwatwanich & Peansupap (2013)	- BIM professional network	Uses the concept of "social network" to prove the importance of online professional networks (e.g. LinkedIn) to diffuse BIM
Diffusion prediction	Hamma-adama, Kouider & Salman (2018)	- Predict adoption rate	Uses the model of adopters' categories based on innovativeness to estimate the adoption rate
	Froise & Shakantu (2014)	- Predict BIM uptake trends	Uses the model of innovation adoption curve (S-shaped) to predict BIM uptake trends

2.5 Theoretical gaps that require further study

The literature review in Section 2.2 revealed that BIM research generally focuses on barriers to BIM adoption at the macro level with little concern for the consequences of these barriers to end-users at the micro level. For example, studies on AEC professionals' perspectives on BIM jobs affected by these barriers are rare.

Section 2.4 reviewed the basic principles of Diffusion of Innovation Theory and its implementation as a theoretical framework for BIM research. A common theme in this review highlighted the units of analysis as either BIM specialists (e.g. BIM consultants) or non-BIM specialists (e.g. owners or government bodies). Currently there are very few studies which extend their application of the theory to investigate the interactions between BIM specialists and non-BIM specialists.

Bui, Merschbrock and Munkvold (2016) noted that there are limited BIM studies that consider the developing country context. In particular, previous reviews of BIM diffusion in Asian developing countries were fragmented with very limited research in some regions such as Vietnam. This highlights the need for detailed, meaningful investigations into BIM applied to less developed countries rather than merely highlighting BIM's potential benefits in developed countries (Ismail, Chiozzi & Drogemuller 2017).

2.6 Summary

This chapter provided a comprehensive review of the literature on the relevant aspects of BIM innovation from its definitions and applications to enablers and barriers. The Vietnamese government's BIM mandate which sets the context for this study was also reviewed.

One of the most common theories applied in BIM research, Diffusion of Innovation Theory, was critically reviewed. The theory has demonstrated its strengths in studying the pre-adoption stage and individual adoption process. Thus, it was proposed to be used to initially guide the design of the first round of case studies, formulating priori-codes to incorporate into interview questions and the interpretation of findings (see Chapter 4). The next chapter (Chapter 3) outlines the methodology used to conduct the study including how the case companies were selected and how respondents' data was collected, categorised, coded and analysed.

CHAPTER 3 Methodology

3.1 Chapter objectives

This chapter outlines the research methodology followed in the study. It first provides the research philosophy which is a belief about the way in which data about a phenomenon should be gathered, analysed and used. Research philosophy is classified as ontology, epistemology, theoretical perspective, form of inference and research approach. Second, the multiple case study research design chosen for the purpose of this study and the reasons for this choice are described. Third, prior to commencing research activities, ethical processes adopted in the study are described.

When ethics approval for this study has been obtained, the research is conducted. Research methods are then introduced, including the criteria for inclusion in the study, how participants were sampled and information on the participants. The instruments used for data collection are also described and the procedures followed to carry out this study are explained. The data analysis method and the computer-aided analysis software used are discussed.

3.2 Research design

Figure 3.1 presents an overview of the elements of a research design, providing a range of choices from which a researcher can select and put together a coherent framework or research design. The elements presented on both sides indicate the most common uses of elements according to research type. For example, quantitative research often adopts a survey data collection method while qualitative research prefers an ethnography method of building rapport with participants to observe their behaviours, thoughts or language uses and taking field notes. The middle line implies a more flexible research process where a researcher can choose elements from the left or right sides, or even a mix of them.

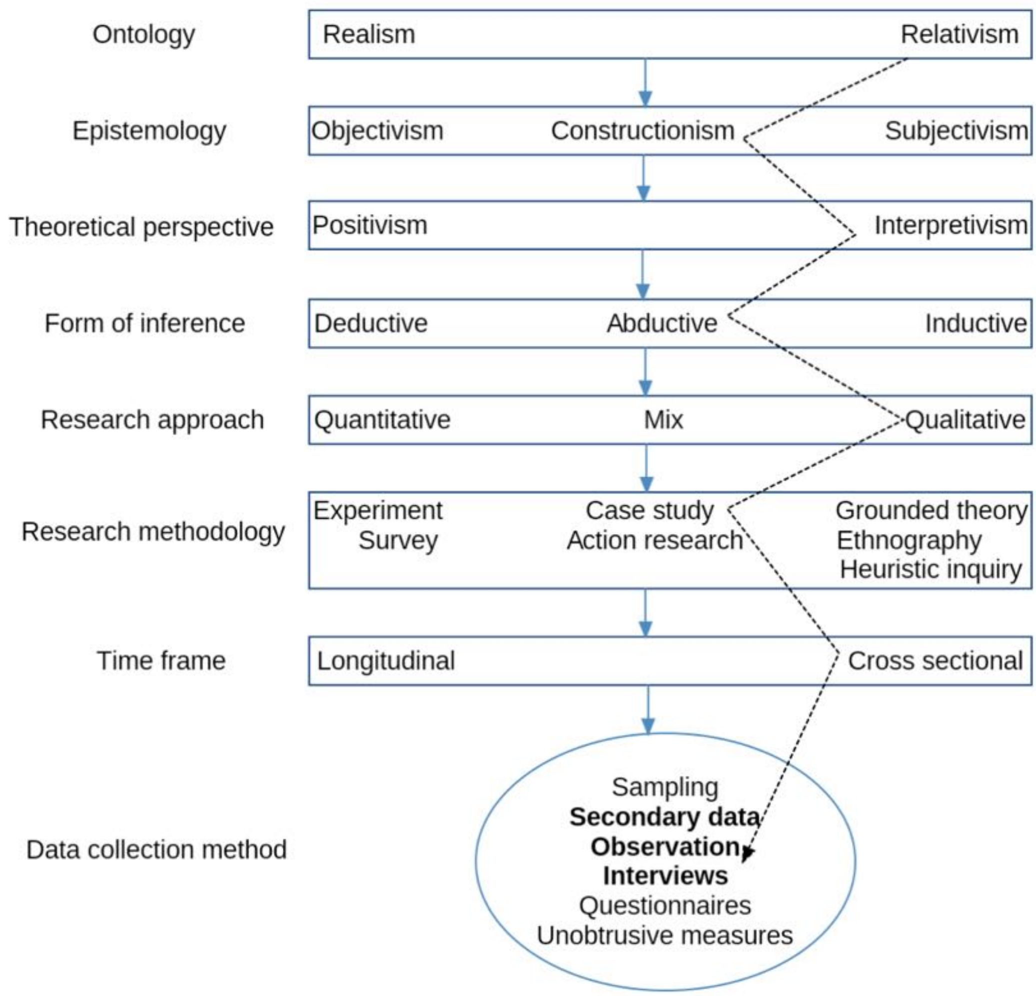

Figure 3.1 Elements of research design (Gray 2013, p. 35)

In this study, the elements for the research design chosen are relativism, constructivism, interpretivism, abductive, qualitative, case study, interview, observation and secondary data. The rationale for the research design is explained below.

3.3 Research philosophy

3.3.1 Ontology

Ontology refers to the study of being, that is the nature of existence and what constitutes reality (Gray 2013). For realism, the world is independent of our knowledge of it (or it exists out of our minds and perceptions) while for relativism, there are multiple realities and ways of accessing them because the reality is constructed subjectively in the mind of each person depending on context (Willig 2016). With the aim of investigating BIM adoption through varying views of project participants, the thesis falls within a **relativist ontology**, where the experiences of individuals are recognised as unique and context specific.

3.3.2 Epistemology

Epistemology refers to the philosophical view held by the researcher into how we can create knowledge or how we can know the reality (Gray 2013). According to objectivism, meaning exists within an object which is independent of the subjects, for example, in natural law gravity exists out of human control. Subjectivism, in contrast, advocates that the subject imposes meaning on an object whereas constructivism argues that meaning is created from interplay between subject and object, that is, the subject constructs the reality of an object (Braun & Clarke 2013). This thesis uses **constructivist epistemology** because the research is concerned with BIM – an innovation which offers a new way for people to collaborate, share and develop a single integrated model throughout the project lifecycle (Eastman et al. 2011). Knowledge of a social reality, the BIM model, is not passively received but built up by subjects, the multiple team members, using their cognitive skills. The social reality of BIM adoption is thus interpreted based on the constructed meanings and interpretations of project participants. The researcher was also involved in the process of constituting the meaning by linking new ideas with his existing knowledge such as prior theories or industry experience.

3.3.3 Theoretical perspective

Positivism insists that reality exists external to the researcher and must be investigated through the rigorous process of scientific inquiry, for example experiment (Gray 2013). In contrast, interpretivism rejects this view of human knowledge. Truth and meaning are created by the subject's interactions with the world or object (Wahyuni 2012). Meaning is constructed and not governed by any natural law or causality, so subjects construct their own meaning in different ways, even in relation to the same phenomenon. Hence, multiple contradictory but equally valid accounts of the world can exist. In other words, the human interpretations of reality are culturally derived and historically situated (Crotty 1998).

This study seeks to examine how the adoption of BIM is socially constructed, dialogued, experienced or perceived by project participants. The **interpretivist theoretical perspective** was found to be relevant. By accepting this theoretical stance, researchers acknowledge that the findings may not match their expectations and predictions, with a surprising outcome or new information contradicting prior knowledge or beliefs. Reality is a mental construct and multiple realities can exist that are incompatible and conflicting (Creswell 2009; Guba & Lincoln 1994).

The key tenet of the interpretivist paradigm is that reality is socially constructed, which is why this paradigm has also been referred to as the social constructivist paradigm (Kivunja, Ahmed & Kuyini 2017). **Social constructivism** emphasises the importance of culture and context in understanding what occurs in society and constructing knowledge based on this understanding. Several researchers have contributed to the social constructivist approach. In this study, three widely recognised perspectives on social constructivism were reviewed, including Piaget [13], Papert [14] and Vygotsky [15] (Ackermann 2001; Lee 2016; Mensah 2015). This study is particularly guided by Vygotsky's social constructivism because the Vietnamese participants may have prior knowledge of BIM through in-house applications but lack experience in joint working to create a new meaning such as a digital, shared, integrated and interoperable Building Information Model. That is, the construction of new knowledge is achieved through communicating, sharing and negotiating socially constituted knowledge (Kim 2001).

Social constructivism was further developed by Vygotsky under the name **socio-cultural theory** or **cultural-historical theory** (Shabani 2016; Veraksa & Veraksa 2018). Vygotsky stated that the human mind is constructed through a subject's interactions with the world or is an attribute of the relationship between subject and object (Verenikina 2010). Furthermore, Vygotsky advocated that humans do not act directly on the physical world without intermediary tools (Turuk 2008). These tools can be any artefacts, whether physical or mental materials, created by humans under specific cultural and historical conditions (Shabani 2016). Hence, Vygotsky argued that human actions and psychological functions could only be understood if we understand the tools and signs that mediate them. "When an individual performs an activity, his or her relationship with the object is mediated mainly by tool and the history and culture that have shaped his or her understanding and interpretation of the properties of the tool and object" (Wiredu 2014, p. 54).

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[13] **Piaget's social constructivism**: knowledge is "self-initiated discovery" and mediated by social interaction. An individual's knowledge is gradually developed due to biological maturation and interaction with the environment (e.g. gained experience).

[14] **Papert's social constructivism**: knowledge is better constructed by "making things to learn" or hands-on project-based methods. Together people produce a product and, as a group, impose meaning on it through the social learning process.

[15] **Vygotsky's social constructivism**: knowledge is not a self-sufficient entity. Rather, people "make meaning" of the world by co-participating in a collective with others. People share understandings concerning what they are doing and what that means for their lives and their communities.

Vygotsky distinguished between technical tools that work on the object and psychological tools that mediate the relationship with the environment, action and thought (Thompson 2013). In this thesis, the technical tool refers to BIM software and hardware while the psychological tool is the concept of being built twice – first virtually (on models) and then physically (on site). The adoption of Vygotsky's cultural-historical theory is one of the reasons for choosing Activity Theory as part of the theoretical framework along with Diffusion of Innovation Theory. This is because Activity Theory adopts the basic tenet of Vygotsky's cultural-historical theory that tools occupy a mediating role in human reaction and interaction with the world (Verenikina 2010). In addition, Activity Theory has gained increasing importance in the application of human–computer interaction (Kuutti 1996; Nardi 1998) and BIM is seen as a computer-aided design methodology in construction projects that uses human–computer interaction (Sampaio 2017).

3.3.4 Form of inference

An inference is a process of drawing conclusions based on the evidence. Deductive inference takes predefined theories to test the empirical data (i.e. hypotheses) and then confirms or rejects the theories (Gray 2013). On the other hand, inductive inference brings researchers to the field (empirical work) without theoretical backup; through a process of gathering data, it attempts to establish patterns, consistencies and meanings to generate a theory (Lincoln & Guba 1985). Inductive inference is often associated with grounded theory as Glaser and Strauss (2009) noted that grounded theory is the systematic development of theory in social settings and it depends on inductive approaches which is appropriate for study that mainly aims to develop theory. However, the inquiry concern of this thesis is neither theory building (induction) nor theory testing (deduction). An alternative inference method of **abduction** was therefore used. Abduction refers to the 'inference to the best explanation', a concept coined by Peirce (1839–1914) in his work on the logic of science. Peirce treated abduction as the use of a known rule to explain an observation. For example, it is a known rule that if it rains the grass is wet; so, to explain the fact that the grass is wet, one abduces that it has rained (Bellucci 2018). Abduction, however, can lead to false conclusions if other rules explaining the observation are not taken into account, such as if sprinklers were recently on the grass that is wet. Research employing abduction thus requires the use of multiple theories to comprehensively interpret various aspects of a reality or social phenomenon. In this thesis, the combination of Diffusion of Innovation Theory and Activity Theory was applied to explain the adoption of BIM in the Vietnamese construction industry context.

The key difference between abduction and other methods of drawing an inference (deduction and induction) is how the theory is employed. Deduction uses theory as a source deriving logically valid conclusions: "A truth statement about a model when the model is fully specified in its units, laws of interaction, boundary, and system states" (Dubin 1969, p. 205). Induction, on the other hand, sees theory as an outcome of the research process, with a universally valid conclusion about a whole population which is drawn from a number of observations (Eastwood, Jalaludin & Kemp 2014). Abduction considers theory as a tool which mediates the most likely explanation for the observations: "abduction relies heavily on theories as mediators for deriving explanations" (Modell 2009, p. 213). The differences between the three types of inferences are illustrated in Figure 3.2.

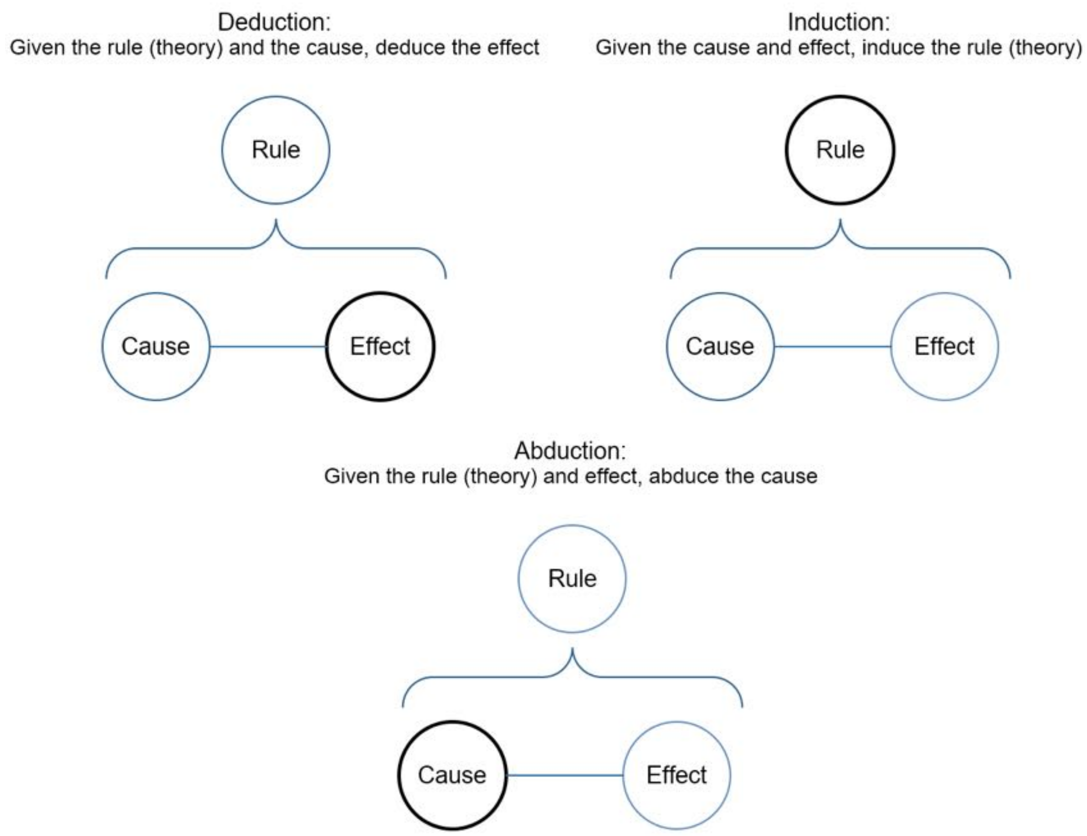

Figure 3.2 Deduction, induction and abduction (Svennevig 2001)

Deductive inference is not applicable due to the lack of valid data on BIM diffusion and adoption on which the researcher could rely to formulate a hypothesis. There are relatively few instances of practical BIM use reported in the developing country context (Bui, Merschbrock & Munkvold 2016; Ismail, Chiozzi & Drogemuller 2017). In Vietnam in particular there are very few cases of BIM use and, if ever used, it is by foreign consultants working on the projects (Bui 2019). Inductive inference is also not suitable for use in this study. It was difficult to develop a conclusion directly from empirical data in the absence of a popular theoretical framework serving as a base for data analysis. Similarly, Hussein et al. (2014, p. 5) embraced the notion that "researchers can become inundated at the coding level with induction, as open coding is a time consuming, tiring and laborious process. The process of abstracting and encompassing concepts is not an easy task".

Abduction was thus adopted in this study instead of using deduction or induction. Abduction lies in between deduction and induction (Dubois &

Gadde 1999; Kovács & Spens 2005). Abductive researchers begin fieldwork with an initial theoretical framework (theory) but keep a very flexible attitude. Through the interactions with empirical data, the initial framework can be modified to better explain anomalies or surprising observations which emerge in the research process. At the same time, the scope of fieldwork (e.g. boundaries of case study or units of analysis) can also be redefined, either being broadened or narrowed to match the theory.

In this study, the researcher observed the phenomenon of BIM adoption and implementation in the Vietnamese AEC industry context, attempting to identify factors affecting such activities such as the barriers or contradictions, and concluded the most likely explanation of when these factors emerge and how they take effect during the interactions of project participants. This intention justifies the selection of abductive inference.

3.3.5 Research approach: quantitative or qualitative

Quantitative research generally uses numerical data and hard facts, by employing statistical, logical and mathematical techniques to test a relationship (negatively or positively related) as well as the magnitude of the relationship between variables, whereas qualitative research develops understanding of human and social sciences to find the way people think and feel (Creswell 1994).

The Vietnamese government mandated the use of BIM for all public and first category projects (buildings which are 20 floors and more or with a floor area over 20,000 square metres) by the year 2020 (Ismail, Chiozzi & Drogemuller 2017). In terms of economic development, Vietnam is considered a periphery country (Chase-Dunn, Kawano & Brewer 2000) and, typical of most developing countries, it has a low level of technological knowledge. To date the impact of this government's requirement on the construction industry in Vietnam has not been explored. A qualitative approach appeared logical as there are very few studies of BIM adoption in the context of Vietnam (Bui, Merschbrock & Munkvold 2016), resulting in the limitation of predefined variables for developing hypotheses for quantitative studies. BIM awareness is increasing in Vietnam, but actual adoption and implementation are still low (Nguyen, Luu & Ngo 2020). There are almost no fully implemented BIM based projects recorded in Vietnam, making it difficult to obtain an adequate number of participants experienced in using BIM for a large-scale quantitative survey (Nguyen Minh & Tran Thanh 2019). Further, the aim of this research is to understand the interactions between social and technical factors affecting BIM adoption and implementation within and between organisations. Thus, qualitative in-depth interviews with key stakeholders such as non-BIM specialists (e.g. top managers and owners) and BIM specialists (e.g. BIM team members) were used to collect people's knowledge, experiences, opinions or behaviours as interviews offered the opportunity to capture rich, descriptive data about how people think and behave, and unfolding complex processes.

3.4 Research methodology

3.4.1 Qualitative case study methodology

Case study methodology is widely used in the social sciences, and there is a growing confidence in its applicability as "a rigorous research strategy in its own right" (Hartley 2004, p. 323). A case study facilitates exploration of a phenomenon within its context using a variety of data sources. This ensures that the issue is not explored through one lens, but a variety of lenses are used to observe and understand multiple facets of the phenomenon (Baxter & Jack 2008). In this thesis, the **case study methodology** is justified as the researcher aims to examine the adoption of BIM in the Vietnamese context where the government has recently developed the BIM roadmap requiring all public projects and projects classified as level 1 to deliver BIM by year 2020; the research on BIM is Vietnamese conditions is limited; and there is a lack of evidence of successfully implementing BIM practice in Vietnam. The rationale for case study suggested by Yin (2014, p. 16) is that case study is an empirical inquiry which appropriately "investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". The adoption of BIM in the Vietnamese context is a contemporary phenomenon that is changing as BIM is being adopted to comply with the government's mandate.

There is also considerable support for a case study approach within BIM adoption research, for example: measuring benefits of BIM through separate case projects (Barlish & Sullivan 2012), BIM for facility management of a large case project (Kassem et al. 2015), and the overview of BIM adoption in developing countries (Ismail, Chiozzi & Drogemuller 2017). As BIM is seen increasingly as a means of facilitating collaborative working, the interactions between adopters and context are vital. The case study approach can provide in-depth insightful information into organisational behaviours. It also offers a particular richness of detail of processes in context, providing an opportunity to analyse how human behaviours or processes influence context and context might influence behaviours or processes (Hartley 2004).

3.4.2 Multiple cases versus single case

Case studies can be conducted in the form of a single case or multiple cases. A single case enables an in-depth understanding of that particular case. It is not representative of other cases, and does not shed light on phenomena or build theory, rather it simply illustrates a particularly interesting case (Stake 1995). In contrast, multiple cases involve a study of collective cases to examine the differences or similarities between the cases (Stake 1995; Yin 2014). In this thesis, **multiple cases** were chosen to be studied because "understanding them will lead to better understanding, perhaps better theorizing, about a still larger collection of cases"(Stake 2005, p. 446).

Further, if a researcher wants to study a specific phenomenon arising from a particular entity, then a single case study is warranted and will allow for an in-depth understanding of the single phenomenon (Easton 2010; Flyvbjerg 1998). It would involve collecting several different types of data and spending a relatively large period of time on a case. Engaging in a full BIM project from start to finish could be a possible choice for single case study. However, this is not applicable for this study because the widely adopted spontaneous deployment of BIM by Vietnamese construction companies makes BIM adoption partial and fragmented (Bui 2019). Doing research full-time on a single project in Vietnam is also difficult due to study requirements in Australia, and restrictions imposed by a case company such as not allowing a non-contractual person to have long-term access to the site.

Typically, evidence arising from multiple case studies is considered to be stronger and more reliable than from single case research (Eisenhardt 2007), although some researchers have argued that it is possible to conduct a single case in-depth reliably to contribute to theory (Flyvbjerg 2006; Mariotto, Zanni & de Moraes 2014). There are also a few situations where the multiple case study is not really applicable because it offers little or no improved robustness to the results. These situations are the extreme and unique case, the critical case and the revelatory case (Bengtsson 1999). First, in the extreme and unique case, a phenomenon is so rare or extreme that any single case is worth documenting. For example, Shanghai Tower was the first high-rise building in China using BIM from design to construction stage (Ge 2012). Second, the critical case is a case that may challenge, confirm or extend the hypothesis formulated. For example, the One Island East office building project in Hong Kong was pre-designed virtually in BIM software by assembling up to 300,000 building components in one master file (Holzer 2007). It is assumed that the BIM model containing integrated data like site conditions, climate and geography could provide a basis for the final performance and the aesthetics of the final outcome at the early conceptual design (Çavuşoğlu 2015). The critical case, by contrast, showed that the more information is added to a BIM model, the less likely one will be able to remain flexible in the creation of alternative versions (Holzer 2007). BIM adopters in this case project concluded that for design explorations in the earlier design stages, where changes occur due to the input of a variety of reasons, lighter datasets and models for project representations are required. Third, in the revelatory case study the goal is to explore a phenomenon that has never been studied before and hence, all information on the case is welcome. For example, the National Cancer Institute Putrajaya was launched as the first BIM project initiated by the Malaysian government (Ismail, Chiozzi & Drogemuller 2017). As selected cases of this thesis do not align with any type of single case discussed above, multiple cases were adopted.

3.4.3 Abductive approach to case study research

As abductive inference was chosen, it is necessary to develop a 'systematic combining' where theoretical framework, empirical fieldwork and case analysis evolve simultaneously to improve the explanatory power of case studies (Dubois & Gadde 2002). Figure 3.3 illustrates the basic ingredients in systematic combining.

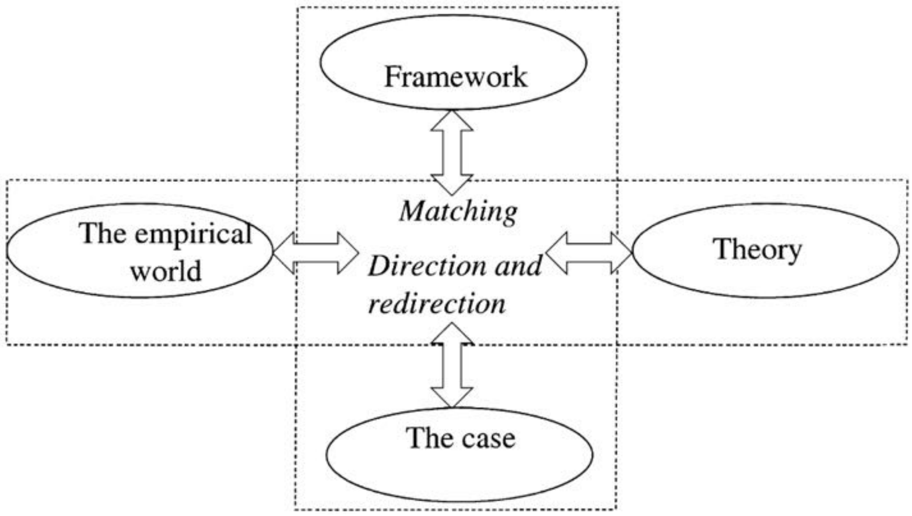

Figure 3.3 Systematic combining based on abduction (Dubois & Gadde 2002)

Case study research is commonly described as a linear process characterised by the term 'phase' or 'process' or 'step'. The most popular case study designed by Yin (2014) involves three phases: 'define and design', 'prepare, collect and analyse' and 'interpret and conclude'. Other researchers conduct case study research following a typical general process: plan, collect data, analyse data and disseminate findings (Neale, Thapa & Boyce 2006). Similarly Stake (1995) has proposed a series of necessary steps for completing the case method, including posing research questions, gathering data, data analysis and interpretation. Dubois and Gadde (2002, p. 555) nevertheless argue that "a standardized conceptualisation of the research process as consisting of a number of planned subsequent 'phases' does not reflect the potential uses and advantages of case research". By constantly going 'back and forth' between cases and theoretical framework, the researcher is able to expand the understanding of both theory and the empirical world of practice (Dubois & Gibbert 2010). The rationale for abduction is that the researcher enters the field not with 'empty' thoughts (induction, no theory backup) or 'consistent' thoughts (deduction, a fixed theory) but 'flexible' thoughts (abduction, evolving theory).

As shown in Figure 3.3, **analytical framework** refers to the preliminary theoretical lens containing pre-conceptions which are used in the initial analysis stage, for example Diffusion of Innovation Theory. Over time, this framework is developed according to what is discovered through the empirical fieldwork, as well as through analysis and interpretation. Empirical observations from currently selected cases might result in identification of unanticipated yet related issues that may require **additional cases** to justify capability for replication. It is time to temporarily stop analysing data and return to the **empirical world** (e.g. the field) to search for more cases (or participants) or redefine the cases (e.g. change other means of data collection, expand or reduce boundary conditions of cases). If the existing framework is unable to explain the anomalies, this might bring about a further need to redirect the current theoretical framework through expansion or change of the theoretical model. The framework is not tight and pre-structured (deduction) or loose and emergent (induction) but evolving during the study (abduction). The fieldwork is paused to refer back to the **theory** (literature review). The aim of **abduction** is not theory development or theory testing but rather theory matching. Abduction deals with matching theory and reality through empirical evidence, which means seeking more cases to support the initial framework, or complementing the initial framework with a second theory, Activity Theory, to establish the combined framework to comprehensively explain unexpected findings which were insufficiently interpreted by the initial framework. In brief, abductive case study involves the process of continuously travelling back and forth between the cases and theory where the cases and the framework simultaneously evolve (Dubois & Gadde 1999, 2002; Dubois & Gibbert 2010).

3.5 Ethics

To ensure compliance with UTS ethics requirements, the researcher has considered and incorporated the university's guidelines[16] for human research ethics in this study. According to the guidelines, the following actions have been taken.

First, prior to data collection, the research proposal was subject to formal scrutiny by the UTS Human Research Ethics Committee (HREC), and no ethical issues were raised. The ethics approval has been granted with reference number UTS-HREC REF NO. ETH17-1421 (see Appendix 1).

Second, an invitation letter was sent to potential participants. The letter would explain the purpose of the research and the participants' obligation (see Appendix 2). Importantly, it pointed out the participants have the right to not participate or withdraw from the study at any time (see Appendix 3).

Third, the participants were informed that their personal information and data given would be kept confidential (see Appendix 4 and Appendix 5). The thesis and its relevant published papers will also be available for all

[16] Source: https://gsu.uts.edu.au/policies/research-ethics-integrity-policy.html

interested participants who may want to confirm their data protection and participant anonymity.

3.6 Research process

Adopting the 'systematic combining' approach (Dubois & Gadde 2002; Dubois & Gibbert 2010; Huhtala et al. 2014), Figure 3.4 represents how the research moved between cases, theories and subjects as the study progressed.

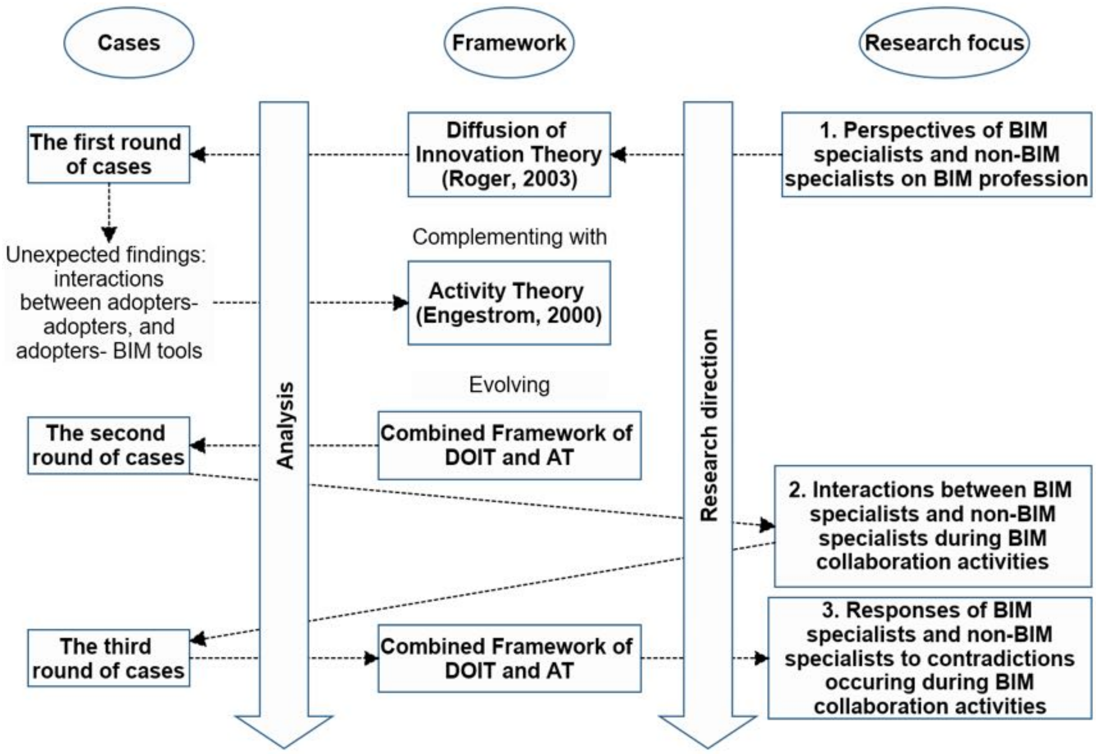

Figure 3.4 Systematic combining research process

The early intention of research was to examine research question 1: How do BIM specialists and non-BIM specialists in the Vietnamese construction industry perceive the new BIM profession? Diffusion of Innovation Theory was initially chosen as the theoretical framework to guide analysis due to its popularity in studying adoption of information technologies. First, the researcher conducted the first round of case studies to gain deeper understanding of AEC professionals' perspectives on BIM as a new career. Four cases were selected, mostly those working in design disciplines (e.g. architectural, structural or engineering companies) because they are upstream users and are among the first groups impacted by BIM in the change of roles and responsibilities. Three more cases including a real estate developer, a construction firm and a government agency were added to gain insights to designers' concern of the unequal contribution to BIM from those with opposing views. Unexpected findings emerged, due to the interaction between adopters and non-adopters, and adopters and BIM tools. This required the modification of the existing framework by returning to the literature to search for theoretical support. Activity Theory was adopted, together with Diffusion of Innovation Theory, to construct the combined framework for better analysis of the anomalies.

The next step was to use this combined framework to move to the second round of case studies. The research direction shifted from understanding of the human mind (e.g. attitudes toward BIM) to human activities (e.g. BIM coordination) by exploring research question 2: How do BIM specialists and non-BIM specialists in the Vietnamese construction industry carry out BIM collaboration activities? During the interviews, it was found that project team members were very different in their socioeconomic characteristics and live in separate business habitats. This made them behave in relatively different ways in order to adapt and succeed, and they require different types of technology and knowledge to sustain themselves and perform well. At this point, the researcher realised that it is not the BIM constraint itself that the researcher should be focusing on, but should also take into account the participants' adaptation to this constraint. The research thus turned its attention to research question 3: How do BIM specialists and non-BIM specialists in the Vietnamese construction industry respond to contradictions emerging during BIM collaboration activities?

Returning to the fieldwork was necessary to seek additional cases, the third round of case studies, to validate the findings in the second round of case studies for research question 2. The researcher also applied the combined framework of Diffusion of Innovation Theory and Activity Theory to interpret the participants' reactions to conflicts arising through their collective activities for research question 3.

3.7 Conducting multiple case studies

Figure 3.5 demonstrates the implementation of multiple case studies adopted from Yin (2014). The researcher conducted three rounds of case studies one by one- following the similar process as shown in Figure 3.5. This is an iterative process in which the initial theoretical framework used to examine the first round of cases will be revised and developed to better interpret emerging themes in the second and third round of cases respectively. Each round aims to answer a separate research question. Each round of case studies includes multiple organisations adopting BIM and having experiences in BIM collaboration activities.

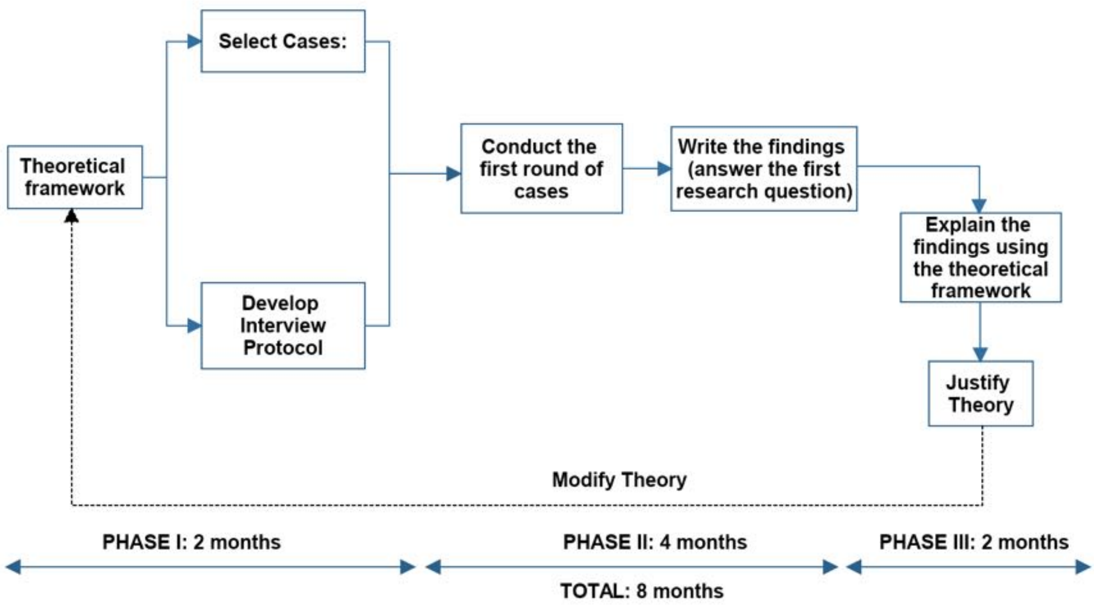

Figure 3.5 Conducting multiple case studies adapted from Yin (2014)

3.7.1 Theoretical framework: using Diffusion of Innovation Theory to analyse the first round of case studies

As discussed above, the original framework was Diffusion of Innovation Theory (see Figure 3.6). This framework focused on the five stages of the adoption process: knowledge, persuasion, decision, implementation and confirmation (Rogers 2003). Diffusion of Innovation Theory was chosen at the early research stage during the first round of cases because it has provided a generally accepted conceptual framework to explain how new ideas and technologies are diffused and adopted in a community (Sahin 2006). Recent studies on BIM adoption have confirmed that BIM adoption in the construction context is closely aligned with the innovation adoption process (Hochscheid & Halin 2018; Jayasena et al. 2019; Papadonikolaki 2017). In addition, dealing with BIM adoption through the lens of Diffusion of Innovation Theory is recommended as the most effective approach for exploring BIM adoption in construction companies (Hosseini et al. 2016). Therefore, Diffusion of Innovation Theory is well placed for framing research questions on the processes of adoption of BIM in construction organisations (Davies & Harty 2013; Gledson & Wardleworth 2016).

On the adoption of abductive approach (see section 3.4.3), it is possibly that Diffusion of Innovation Theory evolves by adding new elements from extending literature and empirical evidence in the field (e.g. the first, second and third round of case studies).

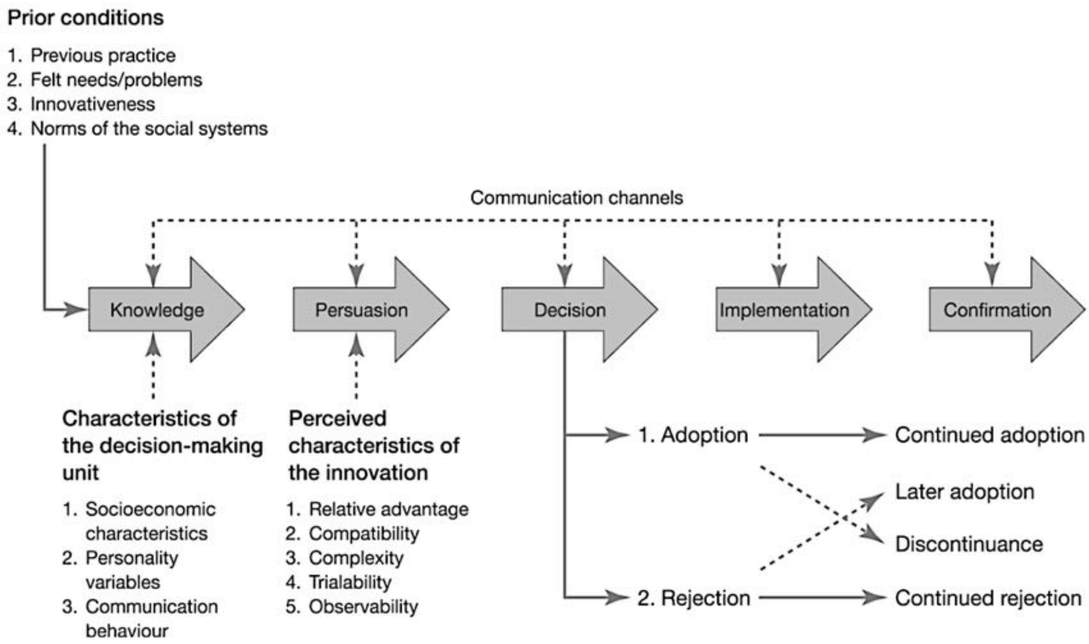

Figure 3.6 Diffusion of Innovation Theory (Rogers 2003) (replication of Figure 2.8)

3.7.2 Time frame of case studies

Case study research involves a detailed and intensive analysis of a particular event, situation, organisation or social unit (Schoch 2020). Typically, a case has a defined space and time frame: "a phenomenon of some sort in a bounded context" (Miles, Huberman & Saldaña 2014, p. 28). In this research, three rounds of case studies were conducted in succession. Each round takes 8 months (total 24 months from 2017 to 2019) to provide an in-depth investigation of a contemporary phenomenon within its real-life context. In December 2016, the Vietnamese government approved a BIM adoption plan that set a goal of completing at least 20 BIM pilot projects in 2018 to 2020 as a preparation to mandate BIM uses for all public projects from 2021 onwards (Vietnam Prime Minister's Decision No. 2500/QD-TTg 2016).

As shown in Figure 3.5, the first round of case studies was undertaken within 8 months in three phases. Phase I (2 months) involved the selection of cases, the preparation and revision of case study protocol, and the modification of the theoretical framework. Phase II (4 months) comprised face-to-face interviews, site visits and summary of findings. Phase III (2 months) included the development of explanations of findings and justification of theories. When the first round of case studies was completed, the second and third round of cases were carried out respectively- following the same process (see Figure 3.5).

Due to time constraints, only key project stakeholders including design companies, main contractors, owners and the government agency, not subcontractors, suppliers and BIM software vendors, were selected for study. The researcher also could not conduct a longitudinal case study (requiring a long period of time) to examine the improvement of BIM practices or the changing behaviours of the same project team members from day-to-day. This study, hence, uses cross-sectional case study in which different individual AEC professionals with experience in BIM collaboration activities in various stages of different projects are compared at a single point of time. The constrained time frame also impacts the selection of case organisations in close geographical proximity, in the same city, to optimise travel time.

3.7.3 Selecting cases

According to Yin (2014, p. 57), each case must be carefully selected so that it either predicts similar results (literal replication) or predicts contrasting results but for anticipatable reasons (a theoretical replication). “The ability to conduct 6 to 10 case studies, arranged effectively within a multiple case design, is analogous to the ability to conduct 6 to 10 experiments on related topics; a few cases (2 or 3) would be literal replications, whereas a few other cases (4 to 6) might be designed to pursue two different patterns of theoretical replications” (Yin 2014, p. 57). In this study, the researcher used 17 cases of organisations adopting BIM to identify consistent patterns of behaviour and to uncover new and/or divergent themes.

In any construction project whether using BIM or not, there are five key project stakeholders: the architecture firm, engineering firm (either structure or MEP discipline), main contractor, owner and the government agency (e.g. the local council where the project will be built). Thus, these stakeholders are considered to be primary targets for case studies.

It should be noted that BIM adoption and implementation in Vietnam is fragmented and spontaneous (Nguyen Bao et al. 2018), thus it is very difficult to select a full BIM project as a "holistic" case doing BIM from the design stage to construction stage in order to examine the interaction among BIM specialists and non-BIM specialists within project teams. The researcher changed strategy for selecting cases by re-focusing on organisations within the Vietnamese BIM network as they all know each other and have experience in BIM collaboration activities in various stages of different projects.

Two methods of selecting cases were adopted: searching databases and using inter-relationships. First, the researcher searched databases with key words about the topic (BIM projects, BIM departments, BIM services etc.), geographic locations (Ho Chi Minh City, Da Nang City etc.), and the specific disciplines (architects, engineering, contractors, developers, etc.). LinkedIn was chosen for general searching as it is one of the largest online business directories providing business listings, phone numbers, maps, email addresses and websites of companies in Vietnam.

At the earlier stage, companies experiencing BIM or offering BIM services were selected. The boundary of cases was those working in large and developing cities because the researcher assumed that BIM activities are more applicable in places having advantages of capital centralisation, technologies and human resources. Moreover, BIM may be applicable to address construction in compact cities (e.g. high residential density) where the requirements of safety, environment, schedule and complexity are at a higher level than projects located in rural areas. The researcher sent emails to potential companies to ask for their permission to access their employees. The researcher also searched for key people in professional networks through LinkedIn with the focus on their BIM experience, positions in the company, and contribution to the BIM community through research papers, seminars, conferences and workshops. The researcher then asked them to introduce him to their organisations.

Secondly, the researcher established relationships with companies to request permission to access. The connections of the supervisors of the researcher were also helpful in contacting senior managers of companies. Table 3.1 illustrates selected cases in the thesis.

Table 3.1 Cases selection (total 17 cases)

First round of cases	Second round of cases	Third round of cases
D_1: Architecture **D**esign	**D_5**: Architecture **D**esign	**D_7**: Architecture **D**esign
D_2: Engineering **D**esign	**D_6**: Engineering **D**esign	**D_8**: Engineering **D**esign
D_3: Engineering **D**esign	**C_2**: General **C**ontractor	**C_3**: General **C**ontractor
D_4: Architecture **D**esign	**O_2**: **O**wner	**O_3**: **O**wner
C_1: General **C**ontractor	**GA**: **G**overnment **A**gency	**GA**: **G**overnment **A**gency
O_1: **O**wner		
GA: **G**overnment **A**gency		
7 cases	**5 cases**	**5 cases**

The abbreviations **D, C, O and GA** stand for **D**esign company, **C**ontractor, **O**wner and **G**overnment **A**gency respectively.

The first round of case studies involved seven organisations working in various disciplines such as design companies, contractor, owner and government agency. Diffusion of Innovation Theory was applied to guide the analysis of the first round of cases. Subsequently, the proposed framework combining Diffusion of Innovation Theory and Activity Theory was used to examine data from the second round of cases with five new organisations. To validate the findings in the second round of cases, an additional five cases in the third round of cases were analysed using this combined framework. In the meantime, the third round of cases were used to answer the third research question which was generated during the analysis of the second round of cases.

3.7.4 Selecting units of analysis

The units of analysis are AEC professionals including BIM specialists (e.g. designers and engineers) and non-BIM specialists (top management, clients, and government agents). The 'snowball technique' was used to find additional research participants. This method yields a study sample through referrals made among people who share or know of others who possess some characteristics that are of research interest (Moser & Korstjens 2018). This technique is particularly useful when the focus of study is not widely known at the research site (e.g. BIM has not been widely used in Vietnam); or when the researcher is not familiar with the field and thus lacks connections and knowledge required to recruit participants by identifying eligible participants, gaining access to participants and retaining participants until study completion (Biernacki & Waldorf 1981).

The participants were very open in their responses to questions and their descriptions of topics were candid and detailed. This could have been a direct result of having been introduced to the interviewees by a common personal contact.

The researcher started with a small sample of research participants who were readily available and easy to contact and then expanded the sample by asking each participant to recommend other potential participants. Normally, people with a high position in the company (e.g. senior managers) were contacted first because they are not only key influencers in the company but also have a wide network of informed and interconnected contacts to help facilitate access to participants. For example, one director of an architecture company was approached by means of personal invitation (including letters from my supervisors); after the interview, the participant was asked to pass on the invitation to other eligible candidates. The units of analysis were selected according to three criteria: research participants are long-term members of case organisations who understand the culture and hierarchical system of their company; all research participants have an architecture, engineering or contractor background; and all research participants have some experience in BIM collaboration activities. Through referrals made by those already selected as matching the target research criteria and based on their interpersonal knowledge of other professionals in the same field, there is increased potential for matching subjects of interest, both in the relevance of interviewees and the data collected.

Table 3.2 shows an example of the participants' selection in the first round of case studies. To maintain confidentiality, names of companies and respondents were coded. The abbreviations TM, MM and E stand for the position of the participant in the company as top management, middle management or employee, whereas D, C, O and GA refer to the type of organisation such as design company, contractor, owner or government agency. For instance, the full code TM_1D_1 means person 1 at top management level working at design company 1.

Table 3.2 Example of participants' selection in the first round of case studies

Company	Participant	Position	BIM role
D_1 (Design)	- TM_1D_1, TM_2D_1 - MM_1D_1, MM_2D_1, MM_3D_1 - E_1D_1, E_3D_1 - E_2D_1	Top management Middle management Employee Employee	Non-BIM specialist BIM specialist BIM specialist Non-BIM specialist
D_2 (Design)	- TM_1D_2	Top management	Non-BIM specialist
D_3 (Design)	- MM_1D_3	Middle management	BIM specialist
D_4 (Design)	- TM_1D_4	Top management	Non-BIM specialist
C_1 (Contractor)	- TM_1C_1 - MM_1C_1 - MM_2C_1, MM_3C_1 - E_1C_1, E_2C_1, E_3C_1, E_4C_1, E_5C_1, E_6C_1, E_7C_1 - E_8C_1, E_9C_1, $E_{10}C_1$, $E_{11}C_1$	Top management Middle management Middle management Employee Employee	Non-BIM specialist BIM specialist Non-BIM specialist BIM specialist Non-BIM specialist
O_1 (Owner)	- TM_1O_1	Top management	BIM specialist
GA (Government Agency)	- GA_1, GA_2	Government agents	Non-BIM specialist

Total: 7 organisations with 15 BIM specialists and 14 non-BIM specialists

3.7.5 Data collection methods

3.7.5.1 Semi-structured interview

Semi-structured interviews were used as the main data collection instrument in the research because they are more flexible than standardised methods such as the structured interview or survey (Alshenqeeti 2014). Surveys are a popular form of data collection, especially when gathering information from large groups, where standardisation is important (Kelley et al. 2003). However, a survey is often associated with a close-ended approach in which respondents select from a range of predetermined answers, thus, limiting respondents from answering in a free flowing narrative form (Hyman & Sierra 2016). As a result, a survey may not allow researchers to develop an in-depth understanding of individual circumstances or the local culture that may be the root cause of respondent behaviour. Similarly, a structured interview is not flexible. A structured interview usually consists of the same questions posed in the same sequence to all participants (Jong & Jung 2015). New questions cannot be asked impromptu during the interview as an interview schedule must be followed (Owen & Noonan 2013). The answers from structured interviews also lack detail as only closed questions are asked which likely generates quantitative data (Owen & Noonan 2013). This means a researcher may not know why a person behaves in a certain way. Because this study aims to provide insight into how BIM specialists and non-BIM specialists perceive, interact and collectively address conflicts in the specific context of the Vietnamese construction industry, surveys and structured interviews are not appropriate options.

Semi-structured interviews were chosen as they are conducted with a fairly open framework which allows focused, conversational, two-way communication (Pathak & Intratat 2012). The interviewer follows a guideline but is able to follow topical trajectories in the conversation that may stray from the guide when it seems appropriate.

The semi-structured interview method allows for the exploration of emergent themes and ideas rather than relying only on concepts and questions defined in advance of the interview (Raworth et al. 2012). The interviewer would usually use a standardised interview schedule with set questions to be asked of all respondents. The questions tend to be asked in a similar order and format to allow comparison between answers. However, there is also scope to pursue and probe novel, relevant information through additional questions often noted as prompts on the schedule (Zulu 2009). The interviewer frequently has to formulate impromptu questions in order to follow up leads that emerged during the interview (Zulu 2009). Also, the interviewer can prepare some open-ended questions to encourage respondents to give full, meaningful answers using the subject's own knowledge or feelings (Leech 2002). Usually the interviewer's role is engaged and encouraging but not personally involved. The interviewer facilitates the interviewees to talk about their views and experiences in depth but with limited reciprocal engagement or disclosure (Alsaawi 2014). However, when the respondents tend to deviate from the topic, the interviewer could refocus the respondent towards the key subject (Jamshed 2014).

In this study, 67 face-to-face interviews were conducted in total. The guiding interview questions for the semi-structured interviews are in Appendix 6.

3.7.5.2 Observation

Observation technique is defined as the method of viewing and recording the actions and behaviours of participants in their natural settings such as the workplace (Kawulich 2005). Researchers have a chance to see what actually goes on by themselves rather than what is being informed by the respondents' narrative stories (Baker 2006). For example, researchers can discover discrepancies between what participants say, and often believe should happen and what actually does happen. The unobstrusive observations are made without disturbing, influencing or altering the environment or the participants in any way. Researchers simply use all of their senses to observe participants in either a natural setting or a naturally occurring situation. In this thesis, the researcher directly observed the interactions between BIM specialists and non-BIM specialists in a coordination meeting, BIM practices (e.g. modelling BIM), and the execution of projects using BIM (e.g. BIM for site management) with field notes and photographic images recorded. The findings from observation are used to confirm those from interviews, and generate additional follow-up questions for further information (Jamshed 2014).

3.7.5.3 Secondary data

Secondary data is data collected or reported by someone else for other purposes. However, researchers may find some use for secondary data for their studies. The use of this existing data provides a viable option for researchers who may have limited time and resources (Johnston 2014). Secondary data can be a reliable supporting source for the comparison and confirmation of findings from primary data. Examples of secondary data include documents, drawings, graphic models or surveys conducted by research participants.

3.7.6 Thematic analysis with NVivo support

Data was analysed with the assistance of the qualitative data analysis software package NVivo v12 produced by QSR. NVivo was chosen due to the features of the software such as searchable annotations and hierarchical categories, the availability of software from the university, and the availability of textbooks and online support (QRS Free Resources 2019; Richards 2005; Wong, Medicine & Lumpur 2008). Moreover, the strength of NVivo lies in its high compatibility with research designs. The software is not methodology specific as it works well with a wide range of qualitative research designs and data analysis methods such as thematic analysis, discourse analysis, grounded theory, conversation analysis, ethnography, phenomenology and mixed methods (Zamawe 2015).

Thematic analysis was adopted as a method of discourse extraction from the data because it provides a way of looking for patterns in the data and trying to connect them together into meaningful groups and themes that capture the topic being investigated (Braun & Clarke 2006). Thematic analysis is one of the most common forms of analysis to examine and record themes in qualitative data (Guest 2012). Thematic analysis differs from grounded theory or discourse analysis because it is not attached to a specific theoretical perspective or epistemological position and it is therefore a more accessible approach with the ability to be used with a wide variety of frameworks (Braun & Clarke 2006; Maguire & Delahunt 2017). As the theoretical framework of the research evolved from a single Diffusion of Innovation Theory model to a combined model of Diffusion of Innovation Theory and Activity Theory, the flexibility of thematic analysis was vital and justifies its adoption. This type of analysis has also been highlighted as particularly useful when exploring new or under-researched areas (Braun & Clarke, 2006) and, for this reason, it is appropriate for this thesis because no previous study has described the phenomenon of BIM adoption in a holistic manner in the Vietnamese context.

The objective of thematic analysis is to identify themes that arise from the coding process (Maguire & Delahunt 2017). A theme is defined as a coherent integration of repeated patterns of meaning in the information (Vaismoradi, Turunen & Bondas 2013). It captures something important or interesting about data in relation to the research questions, and represents some level of patterned response or meaning within the dataset (Braun & Clarke 2006). This thesis follows six phases of thematic analysis based on the work of Braun and Clarke (2006):

- Phase 1: Familiarising with the data
- Phase 2: Generating initial codes
- Phase 3: Searching for themes
- Phase 4: Reviewing themes

- Phase 5: Defining themes
- Phase 6: Reporting themes.

It is noted that the thematic analysis process is not linear, simply moving from one phase to another phase, but the process can move forward and back between phases, perhaps many times, particularly if dealing with a lot of complex data (Maguire & Delahunt 2017; Vaismoradi, Turunen & Bondas 2013). A reiterative data analysis process is recommended, to "reassure the reader that the interpretation is representative of the data and the expectation of the finding as something unpredictable and innovative in the data has been enhanced" (Vaismoradi & Snelgrove 2019, p. 4). This feature of thematic analysis naturally matches the abductive approach characterised by a constant flow back and forth between the cases (data) and theories (analysis) (Gold et al. 2011).

3.7.7 Doing thematic analysis

3.7.7.1 Familiarising with the data

The researcher was immersed in the collected data to become familiar with it. All verbal data recorded from face-to-face interviews was transcribed into Vietnamese text which then was translated to English. The formats of text documents should be in popular 'pdf' or 'docx' for better compatibility with NVivo. The textual files were imported into the software to facilitate the process of searching, sorting, coding, noting and commenting directly on files for later analysis.

The researcher read and re-read all transcriptions before coding and searching for meanings and patterns. By getting close to the data, the researcher could capture underlying ideas of participants which would be used as discussion topics in following interviews. When no additional data was found or similar responses kept repeating, the researcher became empirically confident that a topic was saturated and stopped collecting further information on this topic and started analysing it.

3.7.7.2 Generating initial codes

Prior to entering the field, the researcher built a pre-structured coding scheme. This coding scheme served to guide the interview topics and questions. The coding scheme was composed to reflect the most salient aspects of Rogers' Diffusion of Innovation Theory (Rogers 2003). The initial codes thus mirrored topics as follows:

- **Innovation's features:** relative advantage, complexity, compatibility, trialability and observability, etc.
- **Environmental features**: social influence, client demand, industry norms, and government regulations and policies, etc.
- **Organisation's features:** training, leadership and social network etc.
- **Individual's features:** motivation, attitude, capacity to adopt, etc.

3.7.7.3 Creating free codes

The coding scheme was not limited to a preliminary set of codes as the study was also shaped by the participants' standpoints. Additional free codes were used to label other topics that emerged during the face-to-face interviews. The participants' words were coded to carefully preserve their original senses. Two techniques of gathering all statements (or texts) about a particular theme or case into a code were used such as '*Word Frequency Query*' and '*Compare and Contrast*'.

3.7.7.3.1 *Word Frequency Query using NVivo*

A Word Frequency Query was run on all selected documentation such as interview transcripts and field notes. Words that occur more frequently are often seen as being salient in the minds of participants (Feng & Behar-horenstein 2019). Word repetitions can be analysed to know how frequently people express themselves through the same network of ideas. The researcher examined the context associated with the uses of common words to identify recurring themes. This technique is based on a simple observation: if you want to understand what people are talking about, look at the words they repeatedly use in various contextual settings.

Figure 3.7 represents an example of a Word Frequency Query in the first round of cases listing common words including their stemmed variants (e.g. contracts, contracting, contractual, contractor, etc.) and synonyms (e.g. contract, bid, agreement, deal, clients' requests and requirements etc.). By scanning the most frequent words, the researcher considered whether similar words could be grouped into a code which covers significant meanings of participants' statements in a broader context. The results from Word Frequency Query in the second and the third round of case studies are presented in Appendix 7 and Appendix 8 respectively.

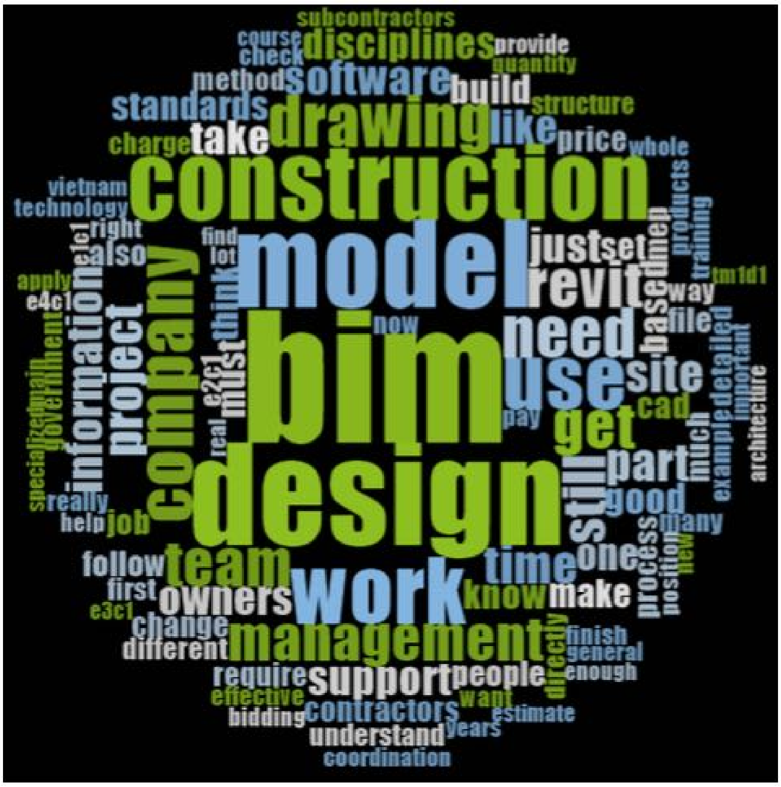

Figure 3.7 Example of Word Frequency Query result by NVivo in first round of cases

As an example, Table 3.3 illustrates how some codes were created by gathering and tagging words with high frequency counts with a label which the researcher devises.

Table 3.3 Examples of grouping frequent words into codes

Coded as	Common words	Stemmed variants	Synonyms
Copyright issues	Unlicensed		Work around, fake copyrights, pirated, piracy, tricky, stolen, unauthorised
	Liability		Infringement, illegal, penalties, financial and reputational damages
	Software		BIM tools, Revit, CAD, add-in, plugins
Lack of IT infrastructure	Software cost	Costly, cost, costs	High up-front cost, luxurious, expense, over-budget, high investment, update costs
	Hardware cost		Powerful desktop and laptop, strong computers
	Connection	Connected, connection, connect	Cloud BIM technologies, stable internet connections, mobile devices, portable devices
Contractual issues	Contract	Contractors, subcontractors contractual, contracting	Bidding, agreement, deal, clients' request, clients' demand, project requirements
Unfair compensation			Lower design fees, unfairly paid, less money, unsatisfactory salary
Extra workload	Work	Working, works, workload	Additional work, burdens, work pressure, quit jobs, employee turnover
	Time	Timely, on-time	On-time delivery, not enough time
Late payment	Pay	Paid, payment, paying, get paid	Not timely payment, late payment, delayed payment

3.7.7.3.2 *Compare and Contrast*

The compare and contrast approach is based on the idea that themes represent the ways in which texts are either similar to or different from each other (Rubin & Rubin 1995). The researcher conducted a careful line-by-line analysis to compare pairs of texts by asking:

- How is this text different from the preceding text?
- What kinds of things are mentioned in both texts?

- What if the participants who produced this text had been non-BIM specialists instead of BIM specialists?
- Is the demographic information of participants (e.g. ages, roles, positions and specialty) relevant to their responses?
- How similar is this text to my own experience?
- To what extent do the texts match the existing theory, either Diffusion of Innovation Theory or Activity Theory?

The themes thus may not necessarily be the topics or subjects which participants repeatedly referred to but represent their key thoughts, behaviours and experiences of a specific phenomenon. In particular, the researcher paid more attention to the responses (e.g. statements) which are different from or complementary to the researcher's experiences and pre-defined theories. Table 3.4 represents how some codes were generated through comparing and contrasting participants' statements with the researcher's experiences (e.g. observed, heard, read or participated in) and the prior theory such as Diffusion of Innovation Theory.

Table 3.4 Examples of grouping compatible or contrasting ideas into a code

Coded as	Compare & Contrast	
	The participants' experiences	*Diffusion of innovation theory*
Overstating BIM capability	People may overstate the technological superiority of an innovation to make it spread more quickly.	The negative message (e.g. failed BIM project) may spread quickly and impede the adoption or prevent it altogether. BIM hype leads to a loss of trust among users.
Lack of client demand	Actually, the market does not lack client demand but knowledgeable clients who are educated regarding BIM benefits and willing to pay for qualified BIM services.	The benefits of BIM are not clearly observed. Construction practitioners do not know how to take advantage of BIM.
Being replaced by new BIM professionals	Companies employ construction people trained in BIM rather than BIM people trained in construction such as BIM champions.	Companies should hire innovation champions (i.e. frequent users or problem solvers) to guide staff members by pushing adoption, managing resistance to change, and ensuring implementation of a new technology or process.

The code 'overstating BIM capability' captures the response of companies to the digital trend of exaggerating the technological superiority of an innovation to speed up its adoption. Diffusion of Innovation Theory, nevertheless, warned that the wrong or negative message from a failed BIM project may also spread quickly and impede adoption or prevent it altogether (Rogers 2003). Treating BIM as hype can even lead to a loss of trust among users as the cost effectiveness of BIM adoption does not meet their expectation.

The code 'lack of client demand' has been mentioned in literature as a major barrier to BIM adoption and this can arise from the lack of information on BIM technology (Ismail, Chiozzi & Drogemuller 2017; Ratajczak et al. 2015). However, Diffusion of Innovation Theory affirms that, although information of innovation is available via communication channels such as professional networks, software vendors, academia and the government agency, BIM adoption could fail if its benefits are perceived as intangible or not clearly observed (Peansupap & Walker 2006).

The code 'being replaced by new BIM professionals' refers to a concern of current staff members that their jobs or roles would be taken over by BIM proficient professionals. The researcher, however, experienced the different views of senior managers who confirmed that the companies prefer to employ construction people trained in BIM rather than BIM people trained in construction such as BIM champions. This finding also differs from Diffusion of Innovation Theory which proposed the recruitment of innovation champions or external experts to guide other adopting members by pushing adoption, managing resistance to change and ensuring implementation of a new technology (Dearing 2015).

3.7.7.4 Reviewing codes and searching for themes

The researcher revised the codes and gathered codes having possible relationships, either containing similar or different ideas on a specific subject, into a sub-sub-theme which is a word or a phrase that captures something important or captures the essence of the data in relation to the research question (Braun & Clarke 2006). A sub-sub-theme can be a component of a sub-theme which is a more abstract or descriptive concept of what the respondents said about their experiences and their reality. After several sub-themes have been noted, the data was revised again to see how the themes fit into every individual experience. The sub-themes were linked together to establish a main theme which creates a meaningful explanation of the topic (Rubin & Rubin 1995). Figure 3.8 represents an example of theme hierarchy for sub-sub-theme 'welfare concern' found in the first round of cases.

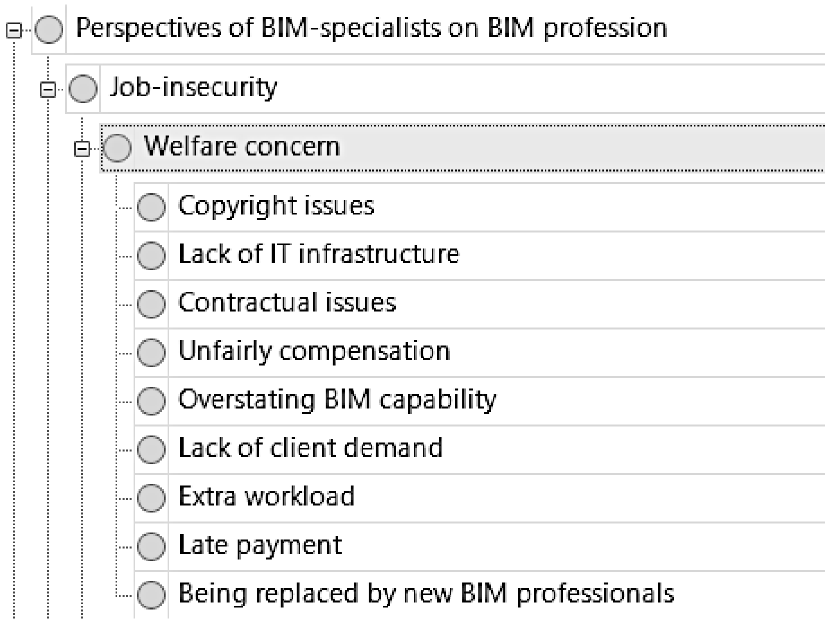

Figure 3.8 Example of sub-theme hierarchical structure by NVivo in the first round of cases

The sub-sub-theme 'welfare concern' links nine codes found by *word frequency query* and *compare and contrast* techniques and is a child of sub-theme 'job insecurity' which inherits the parent or main theme 'perspectives of BIM specialists on BIM profession'. The main theme is a salient abstract idea which represents the most interesting aspects of interview data, in particular, how BIM specialists perceive the new BIM profession in relation to their daily business. Repeating the coding process guided above, a number of sub-sub-themes and sub-themes were generated which together developed a main theme (see Figure 3.9). The details of themes structure of the first, the second and the third round of case studies are presented in Appendix 9, Appendix 10 and Appendix 11 respectively.

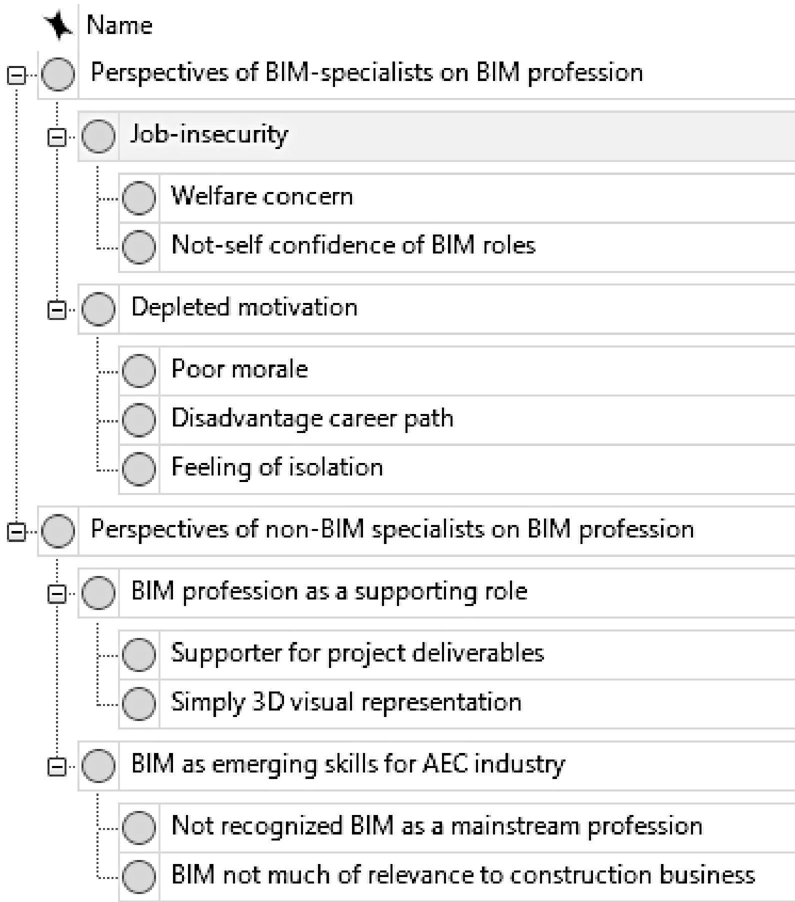

Figure 3.9 Example of main theme hierarchical structure by NVivo in the first round of cases

3.7.7.5 Defining and reporting themes of case studies

Two main themes were defined and reported. The first theme explains how BIM specialists individually perceive the BIM profession whereas the second theme interprets how non-BIM specialists perceive the role of BIM with regard to their business. These two themes were brought together to understand the 'holistic view' of BIM adoption in Vietnam. Each main theme is represented as a group of sub-themes. An individual sub-theme is gathered by a number of 'sub-sub-themes' linking directly to the codes which contain interview data (e.g. verbatim quotations). Table 3.5 demonstrates the hierarchy of theme structure (i.e. theme development).

Table 3.5 Theme development in the first round of cases

Main themes	Sub-themes	Sub-sub-themes
Theme 1: Perspectives of BIM specialists on BIM profession	Job insecurity	- *Welfare concern* - *Not self-confident of BIM roles*
	Depleted motivation	- *Poor morale* - *Disadvantage career path* - *Feeling of isolation*
Theme 2: Perspectives of non-BIM specialists on BIM profession	BIM profession as a supporting role	- *Supporter for project deliverables* - *Simply 3D visual representation*
	BIM as emerging skills for AEC industry	- *BIM not recognised as a mainstream profession* - *BIM not of much relevance to construction business*

3.8 Method of validating findings

Qualitative research methods, particularly those which use social constructivism, assume that reality is socially constructed, multi-dimensional, and ever-changing; there is no such thing as a single, immutable reality waiting to be observed and measured (Merriam 1995). Thus, there are varying interpretations of a reality, in which the researcher offers his or her understandings of a reality through experiences described from the viewpoint of the participants. A qualitative researcher is usually not a person who has a direct experience of what is being studied (e.g. BIM adoption); and thus, has no control over behavioural events. Qualitative research work is frequently criticised by quantitative researchers for lacking control over the trustworthiness of the findings (Noble & Smith 2015). However, the two types of research are not contradictory but distinct regarding their target. Qualitative research is concerned primarily with 'process' rather than 'outcome' like quantitative research. Qualitative researchers, therefore, are interested in understanding how people make sense of their lives, experiences and their structures of the world, whereas quantitative researchers aim to test the findings to discover whether they are statistically significant or due to chance (Atieno 2009). Quantitative research attempts to confirm the findings by numbers, rates or trends (Atieno 2009). Qualitative research, on the other hand, gains the trustworthiness of the findings by using several interviews or observations (e.g. visual or written evidence) during fieldwork to reduce the potential bias (Patton 1999). By doing so, it provides means to assess more directly the reliability and validity of the data obtained.

Qualitative researchers also have methods to increase research credibility such as triangulation by using different sources of knowledge to cross-check the qualitative findings (Merriam 1995). In addition to the analysis of interview data, this research study used member checking, secondary data and direct observation to strengthen the internal validity of the qualitative research.

3.8.1 Using member checking to validate findings

The member checking technique, also known as member validation, was used to reconfirm the accuracy of the findings and the appropriateness of representing the participants' stories (Birt et al. 2016). The researcher returned to the sites and conducted follow-up interviews with participants who previously provided information. In particular, participants were provided with relevant sections of a research report and were invited to comment on the accuracy of the report.

Typically, the focus of this validation is on the content of the participant's experiences, emotions and thoughts such as whether the findings match what actually happened in the participants' context, how the participants feel about the findings and whether there are any supplements to the findings (Koelsch 2013). Further, the participants can also be asked to comment on the analysis such as alternative interpretations of findings, and recommended solutions for problems. The main purpose of member checking is to access the validity of qualitative results by taking into account the static responses of participants (e.g. consensus about the themes), but it is not limited to the opportunities of exploring new or alternative explanations of the findings.

3.8.2 Using secondary data to validate findings

As the products in and of environments are inseparable parts of the social world (Saldana & Omasta 2017), the researcher not only took people's thoughts into account but also what they produced and worked with. Artefacts are considered as historic remains of behaviour in an organisation such as design drawings, graphic models and BIM documents. (Reischauer 2015). Artefacts serve as secondary data to assist the examination of products of human actions to better understand its creators (e.g. BIM adopters) and the social, cultural and historical context in which it typically exists.

3.8.3 Using direct observation to validate findings

Direct observation involves observing without interacting with the objects or people under study in the setting (Kawulich 2012). The researcher comes into the field and looks at the events happening in front of their eyes in the moment of them occurring. This type of observation gives a researcher the ability to collect data about social practices – what and how people are doing – in a context that is natural to them (Ciesielska, Boström & Öhlander 2018). Data from direct observation was recorded in field notes and photos which were later used to triangulate the findings from the interviews.

3.8.4 Case study design validity and reliability

To increase the validity and reliability throughout the process of conducting case studies, the researcher consistently adopted the guideline proposed by Yin (2014) and Merriam (1995). According to Yin (2014), the quality and validity of any case study design can be judged by four design tests, which can overcome much criticism. Those are construct validity, internal validity, external validity and reliability. The use of these principles in this study is illustrated in Table 3.6.

Table 3.6 Validity and reliability of case study design

Phases of case study	Validate/test	Description	Applications in the study
Research design (Yin 2014)	External validity	Establishing the domain to which findings can be generalised	Use literal replication logic in multiple case study
Data collection (Yin 2014)	Construct validity	Establishing correct operational measures	Use multiple sources of evidence (described above - see triangulation methods such as member checking, secondary data and site visits)
	Reliability	Demonstrating that the operations of the study can be repeated with same results	Use case study protocol - Apply 45-60 minute semi-structured interview for all research participants - Pilot test interview questions with the supervisors' verification - Use template letter to invite participants in the formal form of the University in Appendix 2 - Use template consent form to explain the aims of research and reach agreement with participant on the uses of data collection methods (interviews/recording/take notes/confidentiality) in Appendix 3 - Use template interview questions to guide data collection in Appendix 6
Data analysis (Yin 2014)	Internal validity	Empirically based pattern is logically compared against a predicted pattern	- Compare themes found in case studies with existing literature - Compare themes found in previous case studies with themes found in additional case studies using the same theoretical framework
Report findings (Merriam 1995)	Internal validity	Peer examination	The researcher has published four papers which describe the key findings of this study – see list of research papers (page xii).

3.9 Summary

This chapter outlined the logical selection of the qualitative multiple case study methodology as an appropriate choice to conduct this research. The data collection method of snowball sampling and data analysis method of thematic analysis with support of NVivo software were explained. The selection of Diffusion of Innovation Theory as an initial theoretical framework is rational because the theory has been widely used to facilitate data interpretation in studies on innovation adoption.

Following the research design outlined in this chapter, the next chapter (Chapter 4) reports the findings and analysis of the first round of case studies using Diffusion of Innovation Theory. Perspectives of BIM specialists and non-BIM specialists on BIM professionals are explored. However, emerging themes related to post-adoption behaviours are insufficiently explained through the lens of Diffusion of Innovation Theory which require the revision of the literature review in Chapter 5 and Chapter 6. The proposal of combining Diffusion of Innovation Theory and Activity Theory is made to develop a more comprehensive framework to guide data analysis of the second round of case studies in Chapter 7 and the third round of case studies in Chapter 8.

CHAPTER 4 Findings from the first round of case studies

4.1 Chapter objectives

The purpose of this chapter is to investigate the relatively new BIM profession in the Vietnamese construction industry from the perspectives of both BIM specialists and non-BIM specialists. A multiple case study methodology was adopted to collect data for the study and compare perspectives of participants in the context of different case organisations. Common themes were accordingly identified and reported using thematic analysis. The validity of themes is also discussed using the triangulation methods of the use of secondary data, direct observation and member checking. Diffusion of Innovation Theory was used to interpret the collected data (see Figure 4.1):

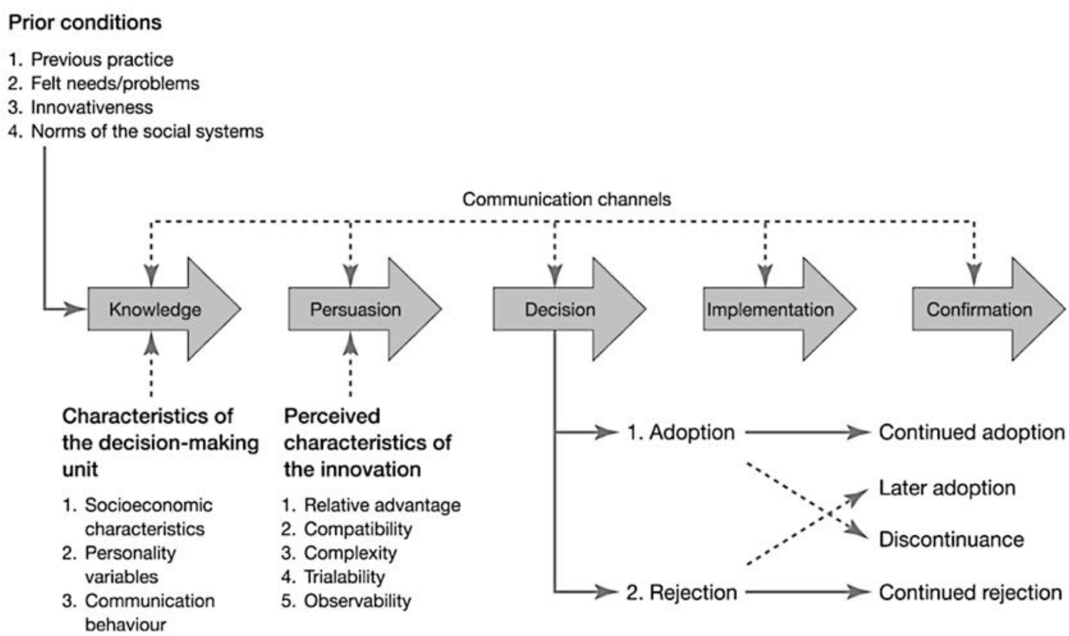

Figure 4.1 Diffusion of Innovation Theory (Rogers 2003) - replication of Figure 2.8

According to this theory, there are three main determinants of success of an IT innovation: characteristics of the innovation, characteristics of the adopters, and prior conditions of the social system (e.g. the organisation adopting IT innovation), The effects of these determinants on adopters' attitudes toward the new career created by the introduction of BIM by Vietnamese AEC companies are discussed in this chapter. In addition, some inconsistencies between Diffusion of Innovation Theory and the evidence have been found, leading to the proposal of theory modification, enhancement and complementarity by Activity Theory.

4.2 Context of organisations adopting BIM in the first round of case studies

Table 4.1 provides the context of organisations adopting BIM in the first round of case studies including their name, size and scope of business, BIM tools being used, and current BIM uses.

Table 4.1 Context of case organisations in the first round of case studies

Company	Size and scope of business	BIM tools being used	BIM implementation
D_1 - Architectural design company - Local private owned enterprise	- 150 employees - Designs architecture, structure and MEP engineering of residential, office and commercial buildings	- Architecture design: Revit and Navisworks - Structural and MEP design: on the research and development - Design management: BIM 360	- In-house design management - Outsources BIM objects and designs - Mandatory BIM application for all architecture design (since 2012) - Provides BIM services, solutions and consultants
D_2 - Engineering design company - State owned enterprise)	- 450 employees - Designs structure and MEP engineering of public buildings such as hospitals, schools and government offices	- Architecture design: None - Structural and MEP design: Autodesk Civil 3D - Design management: Trimble Connect	- In-house design management - Not mandatory to use BIM - Not including BIM in business scope

D_3 - Engineering design company - Local private owned enterprise	- 350 employees - Designs architecture, structure and MEP engineering of residential, office and commercial buildings	- Architecture design: Grasshopper - Structural and MEP design: Tekla - Design management: Trimble Connect	- In-house design management - Mandatory BIM application for structural design - Not including BIM services in business scope - Cooperates with public sector clients in 6D BIM pilot projects
D_4 - Architectural design company - Foreign private owned enterprise	- 30 employees - Designs architectural, interior, and landscape	- Architecture design: Revit	- Outsources BIM objects and designs - Not focus on projects funded by local owners
C_1 - Construction company (general contractor) - Local private owned enterprise	- 2,500 employees - Designs and constructs residential, office and commercial buildings	- Architecture design: Revit - Structural design: Tekla - MEP design: Revit and Navisworks - Project management: Synchro	- In-house design management - Mandatory BIM application for all Design and Build projects (since 2014) - Focuses on BIM for site: Safety, VR/AR
O_1 - Owner - Local private owned enterprise	- 1,800 employees - Invests in real estate properties for sale and rent: office, residential commercial and entertainment buildings	- Structural and MEP design management: Revit and Navisworks - Quantity take-off: In-house developing plugins	- In-house design management - Cooperates with local authorities to conduct BIM pilot projects
GA - Government Agency - Under the management of the Vietnamese Construction Ministry	- 10 government employees - 20 voluntary BIM specialists and industry senior managers - Conducts the national BIM diffusion program (since 2016) co-sponsored by the UK government - Influenced by the UK's BIM standards and policies	- Cooperates with BIM software vendors and developers to carry out research on various BIM tools matching the Vietnamese context	- Cooperates with project owners to conduct BIM pilot projects to get data to publish case studies and practical experiences - Supports project owners in the initial phase (setting BIM system, preparing BIM based contract, recommending BIM consultants, giving incentives)

Note: small size (10–100 employees), medium size (100–200 employees) and large size (>200 employees) based on the classification of the Vietnamese government[17].

4.3 Units of analysis

Table 4.2 presents the units of analysis of case studies including BIM specialists and non-BIM specialists within case organisations. To maintain confidentiality, names of companies and respondents were coded. The abbreviations TM, MM and E stand for the position of participants in the company of top management, middle management or employee, whereas D, C, O and GA refer to the type of organisation such as design company, contractor, owner or government agency. For instance, the full code TM_1D_1 means participant 1 at top management level working at design company 1. Details of the BIM specialists and non-BIM specialists are illustrated in Table 4.3 and Table 4.4 respectively.

Table 4.2 Units of analysis for the first round of case studies

Company	Participant	Position	BIM role
D_1 (Design)	- TM_1D_1, TM_2D_1 - MM_1D_1, MM_2D_1, MM_3D_1 - E_1D_1, E_3D_1 - E_2D_1	Top management Middle management Employee Employee	Non-BIM specialist BIM specialist BIM specialist Non-BIM specialist
D_2 (Design)	- TM_1D_2	Top management	Non-BIM specialist
D_3 (Design)	- MM_1D_3	Middle management	BIM specialist
D_4 (Design)	- TM_1D_4	Top management	Non-BIM specialist
C_1 (Contractor)	- TM_1C_1 - MM_1C_1 - MM_2C_1, MM_3C_1 - E_1C_1, E_2C_1, E_3C_1, E_4C_1, E_5C_1, E_6C_1, E_7C_1 - E_8C_1, E_9C_1, $E_{10}C_1$, $E_{11}C_1$	Top management Middle management Middle management Employee Employee	Non-BIM specialist BIM specialist Non-BIM specialist BIM specialist Non-BIM specialist
O_1 (Owner)	- TM_1O_1	Top management	BIM specialist
GA (Government Agency)	- GA_1, GA_2	Government agents	Non-BIM specialist

Total: 7 organisations with 15 BIM specialists and 14 non-BIM specialists

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[17] https://english.luatvietnam.vn/ecree-no-39-2018-nd-cp-dated-march-11-2018-of-the-government-on-detailing-a-number-of-articles-of-the-laws-on-small-and-medium-sized-enterprises-160820-Doc1.html

Table 4.3 Background of BIM specialists in the first round of case studies

Participants	Position	Specialty	Industrial/BIM tool experience (Years)
MM_1D_1	BIM manager	Digital design	5-10/5+
MM_2D_1	Head of architecture	Architecture	15+/5+
MM_3D_1	Head of MEP	MEP engineer	15+/3-5
E_1D_1	Modeller	Architecture	3-5/1-3
E_3D_1	Modelling leader	Architecture	5+/5+
MM_1D_3	BIM manager	Architecture	10-15/5+
MM_1C_1	BIM manager	Structural engineer	5-10/5+
E_1C_1	BIM coordinator	Structural engineer	3-5/3-5
E_2C_1	BIM coordinator	MEP engineer	3-5/3-5
E_3C_1	BIM coordinator	Structural engineer	5+/3-5
E_4C_1	BIM coordinator	Architecture	5+/5+
E_5C_1	BIM coordinator	Structural engineer	1-3/3-5
E_6C_1	BIM coordinator	Quantity Surveying	3-5/3-5
E_7C_1	BIM coordinator	Architecture	5+/5+
TM_1O_1	BIM manager	MEP engineer	15+/5+

Total: 15 BIM specialists

Table 4.4 Background of non-BIM specialists in the first round of case studies

Participants	Position	Specialty	Industrial/BIM tool experience
TM_1D_1	Director	Architecture	20+/0
TM_2D_1	Vice director	Structural engineer	20+/0
E_2D_1	Drafter	Architecture	5-10/0
TM_1D_2	Director	Structural engineer	15+/0
TM_1D_4	Director	Architecture	10-15/0-1
TM_1C_1	Site manager	Civil engineer	15+/0
MM_2C_1	MEP site supervisor	MEP engineer	10-15/1-2
MM_3C_1	QS site manager	QS engineer	10-15/0
E_8C_1	Site supervisor	MEP engineer	3-5/0-1
E_9C_1	Site supervisor	MEP engineer	3-5/0-1
$E_{10}C_1$	Site supervisor	Civil engineer	1-3/0
$E_{11}C_1$	Site supervisor	Civil engineer	5+/0
GA_1	Change agent	Structural engineer	1-3/0
GA_2	Change agent	Structural engineer	1-3/0

Total: 14 non-BIM specialists

4.4 Summary of findings

Table 4.5 summarises findings in the first round of case studies. The findings are structured in three levels: main themes, sub-themes and sub-sub-themes.

Each main theme is represented as a group of sub-themes. An individual sub-theme is expanded into a number of 'sub-sub-themes' linking directly to the codes which contain interview data for verbatim quotations. Two main themes were found from analysing the data based on the experiences of the participant interviewees including: "Perspectives of BIM specialists on BIM profession" and "Perspectives of non-BIM specialists on BIM profession". These two themes were brought together to understand the holistic view of BIM adoption in Vietnam. While the first theme highlighted the pessimistic views of BIM specialists on the stagnant status of BIM adoption affecting their career path, the second theme showed the positive attitudes of promising BIM technologies among non-BIM specialists but, on the other hand, emphasised the concern of BIM impacts on non-BIM specialists' status quo and the normal routine. In other words, non-BIM specialists were worried about what impacts BIM innovation would have on their current business. The details of themes are presented in the following sections.

Table 4.5 Summary of findings in the first round of case studies

Main themes	Sub-themes	Sub-sub-themes
Theme 1: Perspectives of BIM specialists on BIM profession	Job insecurity	- *Welfare concern* - *Not self-confident of BIM roles*
	Depleted motivation	- *Poor morale* - *Disadvantage career path* - *Feeling of isolation*
Theme 2: Perspectives of non-BIM specialists on BIM profession	BIM profession as a supporting role	- *Supporter for project deliverables* - *Simply 3D visual representation*
	BIM as emerging skills for AEC industry	- *BIM not recognised as a mainstream profession* - *BIM not of much relevance to construction business*

4.5 Reporting the findings

4.5.1 Theme 1: Perspectives of BIM specialists on BIM profession

4.5.1.1 Job insecurity

4.5.1.1.1 *Welfare concern*

BIM specialists indicated their concern arising from the **copyright liability** of BIM software and the proliferation of illegal copies of BIM software used by construction professionals in the development of BIM artefacts. *"Copyright liability can make the BIM team stop working until all related legal issues are resolved"* - MM_2D_1. This could eventually lead to contractual delay penalties despite failing to deliver the project on time. Most participants admitted illegal BIM programs had been used in their workplace, thus raising the risk of financial and reputational damage. *"Penalties for infringement could damage organisational finances and affect employees' wages"* - MM_3D_1. Further, the BIM manager noted that *"I acknowledge the dangers of using pirated software, but the company cannot completely prevent software violation due to the financial restrictions"* - MM_1D_1.

Lack of IT infrastructure was viewed as a challenge to realising the full benefits of BIM. BIM specialists have not been equipped adequately with BIM devices for practice, and therefore do not see the significant benefits of using them. The costs associated with setting up BIM are not only software licenses but also hardware purchases, internet connection upgrades and training costs. One senior manager stated that *"the software products are very expensive. Purchasing two licenses enables only two people working at the same time; so, our employees must take turns using the software"* - MM_1D_1. One BIM specialist working on the construction site said that *"there is a lot of dust and moisture, so the hardware used must be resistant enough to withstand such tough environment"* - E_3C_1. Further, BIM files such as 3D descriptions of a building are generally much larger than CAD files and require higher quality hardware: *"More* *memory and hard disk space are needed in addition to upgrading the computer processing power"* - E_3C_1. Construction sites also need to *"have good and stable internet connection to ensure the information exchange"* - E_5C_1. Moreover, unless doing in-house BIM or standalone BIM applications, higher levels of collaboration and a real-time communication platform for project team members require *"the integration of cloud-BIM technologies which intensify the pricing burden on company"* - E_7C_1.

Contractual issues also negatively impacted BIM specialists' work because, based on the official contract, relevant documents were currently limited to 2D drawings. BIM models were typically not used for the purpose of supporting the design and construction process, but usually built after the 2D drawings for the official contract documentation were almost finished. BIM thus became an add-on to the established design process operating primarily on the basis of 2D CAD drawings and the roles of BIM specialists were relatively not recognised and appreciated. *"So far, 3D models are just for internal reference as the 2D drawings are still the decisive tools for establishing binding contractual agreements among the partners"* - MM_2D_1. Clients were traditionally contracting with architectural companies to deliver designs which satisfy their intentions and meet legislative requirements but not purchasing models. BIM specialists admitted that *"it's difficult to claim an extra cost of BIM services to clients who are unlikely to understand why they need to pay more for design products to be delivered 'properly' as this should be the contractual responsibility of architectural companies - doesn't matter what tools are being used"* - MM_2D_1. Generally, large design and construction firms acknowledged the advantages of BIM and had shouldered their own cost, but their in-house applications were still around the most basic forms of 3D visualisation and clash detection to fulfil a specific need. *"Lack of contract forms to clearly mandate and align BIM practices might lead to silo-BIM as each BIM group is thinking in terms of their own cost but not the cost to the overall project"* - E_2C_1. In particular, *"silo workings might limit the more complex and integrated use of BIM (e.g. a single master project model* *developed in uniform by each project participant) and weaken the BIM community as less knowledge and experience are generated"* - E_1C_1.

Another issue that arose was the negotiation of **fair compensation** for BIM specialists who control the entry of data into the model and are responsible for any inaccuracies in it. The BIM-related tasks require more time spent inputting, reviewing and exchanging BIM data which is a new cost in the design and project administration process. While architects perceived *"being unfairly paid for additional BIM workload"* - E_1D_1, they admitted the "*requirement of continuously upskilling to undertake new BIM tasks*" otherwise *"being replaced with BIM competency personnel or outsourced BIM partners"* - MM_1D_1.

Moreover, many companies may have **overstated their actual BIM use** to lure unfamiliar clients but later fail to generate contractually required BIM deliverables. This exaggerated claim to advanced BIM adoption is likely to make clients not trust BIM, resulting in less chance of genuine BIM service providers selling BIM services. *"There are a lot of companies in the market, probably driven by the software producers, advocating incredibly high levels of what BIM can achieve. It might be able to achieve those levels, but the problem is that the industry hasn't caught up to that yet"* - MM_1D_1.

Lack of client demand was seen as a barrier to top management's commitment and support of BIM practices which negatively affects the operation of the BIM team. This is because *"the clients have high control over projects. Thus, when clients lack BIM knowledge, consequently there are no demands on BIM for projects"* - MM_3D_1, and *"the intangible benefits of BIM, such as increasing communication among parties and potential for risk prediction, are unable to be proven and it's difficult to expect clients to pay more for BIM services"* - MM_1D_1. BIM managers shared that *"we don't have any plan to expand the size of the BIM team (either recruiting or training new BIM professionals) as there is less job to do"* - MM_1C_1. Another BIM manager commented that *"BIM team members have to accept lower salaries (e.g. similar to CAD drafters) or job rotations, moving from head* *office to construction sites to serve as shop-drawing technicians"* - MM_1D_1. Additionally, some competitors using pirated software offer BIM services at lower prices than the companies employing BIM model-authoring tools. A BIM specialist expressed that *"we lost the clients by fake-software license users"* but insisted on the market potential because *"the clients' awareness of BIM has been increasing, and we just lack **knowledgeable clients** who are educated regarding the benefits of model-based deliverables and information exchange"* - MM_1D_3.

Extra workload was perceived as **harmful** to BIM specialists' welfare. For example, a BIM specialist complained that *"site people always wait for the detailed revision list assigned by BIM coordinators to begin their job although they can easily find the updated drawings and download them from the database"* - E_6C_1. If site people present a more active attitude by accomplishing possible revisions in advance, *"the amount of extra work left to us will be reduced considerably. So that we can focus on coordination and the efficiency of the whole process will be improved significantly"* - E_6C_1. Also, there was a high turnover rate in BIM teams as BIM specialists felt that *"we are often stressed by the complicated coordination and difficulties involved in balancing the company's task and the client's demand"* - E_7C_1. BIM specialists were assigned to more than one project at the time by the company while having to constantly support insufficient BIM competent people (e.g. clients or subcontractors). *"We don't have time to rest"* - E_7C_1.

Payment delays persist in the construction industry and continue to be a key concern to industry practitioners, including BIM specialists. A BIM manager stated that *"many public projects are in shortage of capital due to complex procedures of payment or ineffective utilisation of funds - resulting in late payment for design companies and contractors"* - MM_1D_1. The late or delayed payments, in turn, lead to the lack of turnover capital in R&D activities, especially funding BIM professionals. Late payment of work by clients is the norm for contractors despite their cash flow being at risk. The BIM manager of a contractor revealed that *"it is commonly accepted among contractors that larger projects pay more slowly.*

Very few contractors exercise their rights and demand to be paid on time because construction is mostly a relationship-based industry" - MM_1C_1. Many general contractors have multiple projects with the same owners and have worked with specific trade contractors numerous times over the years. If contractors complain about overdue invoices, they might lose an opportunity to secure future work from that business network.

4.5.1.1.2 *Low self-confidence associated with BIM roles*

As BIM is still new and has some shortcomings in being **compatible** with existing workflow and industry standards, BIM specialists might have low confidence in their daily practices. BIM managers of case companies complained that the object of diffusing BIM would never be achieved if the Vietnamese government does not change their old assessment of designs which still relies on the traditional 'paper-based' approach. Adequate information is not properly transmitted and is then misinterpreted when AEC firms try to transform their digital model data into official paper forms. In other words, *"people are using new technology and process just to produce old outcomes"* - T_1O_1. The problem of incompatibility could also occur *"between various software programs and file formats employed in a project by different parties or between older and recent versions of the same software product"* - E_4C_1. Moreover, BIM software itself has not yet developed to optimise a specific task such as piping, ductwork or structural detailing; thus, the preference to use familiar software matching a particular business practice is understandable. For example, the subcontractor responsible for a complex steel structure used the 3D models from designers to establish design intent and provide baseline data, but entered the information into a second model (e.g. in-house model) to generate their shop and fabrication drawings. This is because *"the subcontractors were not confident that the shared BIM model is accurate enough for construction tolerances, particularly installation space"* - E_1C_1.

BIM specialists disclosed that there is a lack of organisational and legal structure (**uncertain roles**) to determine the access to and to define responsibilities for input and analysis data and their correctness, particularly when people have to take turns using BIM software due to the limited number of licenses. *"I am often getting blamed for others' mistakes as we share one account to use the software. It's even worse when sending our model to unfamiliar project teams"* - E_1D_1. Another BIM specialist added *"I feel uncertain if there is no structure determining the stakeholders' roles, their information rights and liabilities, their model access (read, write) or their obligation to provide a special functionality or data outputs"* - MM_2D_1.

The perception of **unsatisfactory BIM products** has reduced the confidence of BIM specialists. The majority of BIM specialists acknowledged that their models are deficient and are thus perceived as inadequate to assure their BIM roles within the company, not to mention the construction industry. *"We can't guarantee our position in the company with imperfect BIM products"* - MM_3D_1. Purchasing BIM authoring packages can represent a significant overhead for construction companies, while at the same time a small number of software licenses is not adequate for a complex project's large demands.

BIM specialists did not perceive **complexity** when using a specific BIM tool for a single discipline, for example, Revit for architectural design or Navisworks for clash detection on site. However, a complex coordination process was seen as a challenge to BIM adoption. *"Due to the complexity and time involved in just gathering and maintaining so many different data libraries from various parties, we could be slow in providing updates and feature improvement to meet project deadlines"* - E_2C_1. Moreover, since BIM software programs are still under development for specific tasks such as structural detailing or the companies cannot afford to purchase full BIM packages, in-house customisations are required. *"To reconfigure BIM tools for specific tasks, we need to program add-in apps or plugins. But it's not easy because this task is mostly related to IT coding while our majors are in construction"* - E_3C_1.

The finding also explored a common situation of **returning to the CAD tradition** in BIM based projects. *"It is challenging to learn new software, but the* *temptation to revert back to old behaviour is too much for some to handle, especially with the pressures of a looming deadline"* - MM_3D_1. Almost none of the BIM specialists described themselves as highly confident in preparing BIM documents as they admitted the extensive use of CAD tools for producing quick details and simple 2D information. *"CAD has been widely used in conjunction with BIM. I cannot imagine doing detailed drawings and templates without CAD"* - MM_2D_1.

With the shared belief in technology as an enabler of good design, BIM specialists expected to be promoted to higher positions. Organisations, however, have been slow or resistant to seeing digital design roles in a leadership position. As a result, BIM specialists might feel they are not being listened to, which adds to the resentment and leads to a breakdown in trust with top management. *"Lack of top management support and commitment downgrades our roles of leading BIM in the company. People don't intend to do BIM seriously. The top management rejects our proposals of recruitment and software purchase, whereas the scope of work and position are ambiguous and overlap with 2D drafters. We are also not empowered to make a change"* - MM_1D_1.

BIM is not a standalone tool like CAD but a collaborative tool which facilitates cooperation and enables better information sharing and communication between different teams in a project. BIM specialists cannot fulfil their roles if the input data were not properly contributed by other teams. *"There is also hesitancy from specialist contractors not wanting to provide or submit information into the model to prevent their techniques from leaking out. The clients also prefer to keep their trade secrets, especially the financial resources"* - E_5C_1. Examples are **the transparency** of the development and structure of prices, the allocation criteria being used by clients and the measurement of performance.

Lack of formal education and training is another barrier to BIM specialists' confidence. *"Our practices are still proceeding by trial and error as fewer members have experienced formal courses at schools"* - E_6C_1. Some software vendors and BIM experts offer tutorial courses, but they are only based on theory or software instructions. *"Most training courses are designed to promote what the software can do but there is less practical evidence showing what the humans have to make the software do that"* - MM_1D_1.

The perception that **BIM is just for large and complex projects** is popular in the industry. It is difficult to convince project participants who feel that *"the workload is not on a complex level to warrant the use of BIM"* - E_4C_1. Some contractors believed in their experience on typical projects and did not need BIM. *"Most buildings in Vietnam are in basic shapes that can be designed and constructed quickly and efficiently based on precedents"* - MM_1C_1. As a result, BIM specialists have lost confidence in their roles because *"when our efforts are not consistent with the needs of the rest of the teams involved, it will be just extra file weight and time loss"* - E_7C_1.

4.5.1.2 Depleted motivation

4.5.1.2.1 *Poor morale*

BIM specialists, especially those with architecture backgrounds, indicated their concerns about **low creativity** when using BIM because *"BIM requires too much information from other professions too early on in the design process which few project parties appreciate. Also, managing various sources of data requires a lot of knowledge which stifles pure artistic creativity"* - E_1D_1. In other words, BIM is better suited to serial production than one-off design as every building is a prototype. As one architect stated, *"BIM will only enable you to build what the construction industry enables you to build because it's inherently linked into common products that are available in the market"* - E_4C_1. The feeling that BIM is too rigid might discourage architects who were well educated about creative design at schools. *"It's a trade-off. You have to play by its rule [BIM]. It irons out human-prone error but also irons out feeling free to be creative and do something different"* - E_3D_1. In this sense, BIM might curtail creativity and open up a gap between commercially-led practices and design-led practices.

The limited learning opportunities is another challenge. It was implied that BIM specialists do not have time allotted for sharpening BIM skills. *"We cannot highly concentrate on BIM training because other employees might feel poor morale when having to fill in to cover the work we left out [out of office for training]"* - E_3D_1. Others said that *"less distraction from usual work could increase the speed and quality of BIM learning"* - E_1D_1. Some companies organised training courses outside working hours but it was not effective as one senior manager stated that *"I'm exhausted after work and it feels like my brain just completely refuses to do or learn anything, not to mention my subordinates"* - MM_3D_1.

BIM specialists explained their poor morale as a consequence of **industry norms**. First, *"construction firms are largely project-based coming together for a limited time to produce a specific result, and employment is often on a contractual and temporary basis"* - E_6C_1. The fragmentation of the industry makes it difficult to develop the level of trust necessary for information sharing. Further, the participant groupings tend to coalesce and separate at project-based intervals which limits experiences gained from one project being used in future projects. Second, risk shifting or a reliance on manipulating contractual disputes for the benefits of some parties at the expense of others has been common practice. *"Each company tends to focus on its interest or even seeks to profit at the expense of other participants. In this environment, it fails to develop the collaborative setting for BIM"* - MM_1D_3.

In addition, several BIM specialists experienced poor morale when constantly working in a **trial or pilot environment**. This mechanism did not offer an opportunity for BIM specialists, especially younger staff, to acquire practical experience making them feel unenthusiastic and anxious about their skill erosion. *"Every day working around pilot projects and trial experiments frustrates us"* - MM_1C_1. Further, the unavailability of free trial software negatively affected the decision to use BIM. *"I would like to try out various BIM features in my works to verify its effects. However, convincing top management to purchase an unfamiliar software is a tough journey whereas the trial versions are not* *always available"* - E_1C_1. Further, the trialability also required the collaboration of all participants. One BIM specialist stated that *"even the intention to try out BIM in a limited scope of works requires the input data provided by other professionals. Their willingness to use the outputs and leave feedback is also necessary for us to improve the products"* - E_5C_1. As the result, it was suggested that *"the company may experiment with only the modelling aspect of BIM [in-house BIM] rather than to use it for the full lifecycle management of a building [BIM based project]"* - MM_2D_1. By doing that, companies would have the opportunity to examine the benefits of BIM without putting too much of their bottom line at risk. BIM specialists, on the other hand, might feel dissatisfied as their skills are of limited use and their contributions are hidden in projects.

BIM costs and benefits are not equally distributed over a project's lifecycle. The major cost of creating BIM models happens during design and engineering, while most of the benefits occur in the downstream phases of the value chain to trade contractors. As the result, stakeholders such as architecture firms working on the early phases of a project may lack incentive to set up BIM models. In addition, upstream players such as main contractors often have exclusive access to project information to cover risks via claims. As such, they may lack motivation to participate in projects where BIM models make that information more transparent. *"It's unfair that we are working more but being paid less while others take advantage from our outcomes without any contribution"* - E_3D_1.

4.5.1.2.2 *Disadvantaged career path*

BIM specialists found that their career progression was hindered in comparison with peers using AutoCAD. In particular, in the same period of time working, AutoCAD users could accumulate sufficient experience from real projects, qualified by the number and size of completed projects, to gain promotion or achieve professional certificates. Conversely, BIM adopters only carry out pilot projects which is inadequately recognised in professional profiles and the scope of work is limited in large and long duration projects which means professional profiles are being slowly updated. *"My career path is ambiguous and lags behind CAD users"* - E_1C_1.

The evolving BIM work resulted in an unclear job structure as another uncertainty for BIM specialists and their promotion prospects. *"When I entered the construction industry, there were a clear-cut career path for me. While the titles and steps may have varied across companies, the progression for someone in project management was nearly an industry standard"* - MM_1C_1. The introduction of BIM creates new roles, for example BIM coordinators and BIM managers, which changed this simple progression. All of a sudden there was a parallel path in construction companies. However, *"choosing the BIM path seems a lot more risky as the companies are reluctant to re-organise their job structure"* - MM_1C_1.

There is a **high turnover rate** in the BIM department as companies have been confused whether BIM is a new career path or just an addition to their current responsibility. If organisations choose the second view, it makes BIM a skillset that all staff members must learn, which means BIM roles do not remain specialised in the organisation. In this situation, BIM specialists might migrate from a BIM career to non-BIM career or to another organisation to seek better experience. A BIM specialist implied that *"working at construction sites could be an alternative. The title of BIM specialist is not a big deal as I possibly get higher payment on site due to my technology skills and construction experience"* - E_1C_1. Others said that *"It's time to apply for a better position, for example BIM leader in another company. Or finding a new place which offers a better chance of learning, where my voice is heard and respected, and lets me feel free to try out various BIM tools"* - E_7C_1.

4.5.1.2.3 *The feeling of isolation*

BIM professionals possessed feelings of isolation at work which potentially contributed to discouraging them from pursuing higher levels of BIM implementation. *"We feel lonely in the new BIM profession"* - MM_2D_1, and *"the connection to BIM fellows and experts is lacking"*- MM_3D_1. **The lack of a diffusion network** is one of the main themes identified that leads to feelings of isolation.

BIM specialists stated that it is impossible for them to raise questions of BIM applications or report a software crash to any official support (e.g. BIM knowledge network) because the administrators could track the software licenses back and find their violation. Moreover, younger BIM staff indicated that they received little guidance from senior managers on the implementation of BIM into daily tasks. Older professionals were experienced in traditional AEC work, however, they tended to lack BIM technical skills, whereas young people with better technology competence lack discipline specific skills.

Lack of peer support is another cause of feeling isolated when BIM specialists found less assistance from site people. To ensure the accuracy of an as-built model, BIM specialists had to constantly revise the design models to reflect changes made in the field. But often BIM specialists did not have the budget to make these changes during construction built into their services, making it cost-ineffective to re-work their design models to update actual works made by site people. Further, BIM specialists worked from distant sites so that the updates were unable to keep up with the construction progress and thus did not capture data in real-time. *"Site people should be responsible for providing the as-built BIM deliverables to the owners due to their proximity of the sites. Or at least, they should help us with checking, tracking and reporting the changes"* - E_4C_1.

BIM specialists considered **working in silos** as an implementation barrier to BIM. One BIM specialist noted that *"A low level of BIM is not sophisticated. It only requires project teams to produce information electronically and share it via the extranet or other network system. Yet, many firms are unable or unwilling to change existing working methods and be more collaborative"* - E_2C_1. There are two reasons for this phenomenon. First, a complex project was considered a multidisciplinary environment involving different parties with each adhering to their own industry standards and interests which negatively impacts the BIM's knowledge sharing among them. Second, the conservative attitude of a 'large household name' company was holding back its ability to collaborate in BIM-focused projects. Large companies attempted to be leaders taking control in the BIM process despite their insufficient BIM capability compared to other small partners.

4.5.2 Theme 2: Perspectives of non-BIM specialists on BIM profession

4.5.2.1 BIM profession as a supporting role

4.5.2.1.1 *Supporter for project deliverables*

Most non-BIM specialists at high level management described BIM as a support tool for project deliverables. For example, the director of an architecture firm stated that *"3D representation is most commonly used in visual **marketing** strategy and technical meeting with stakeholders"* - TM_1D_1. Another president commented that *"the company actively attempts to introduce BIM to clients who aren't requiring BIM and use it as a **marketing feature** to get a leg up in the bid to land a job"* - TM_2D_1. This is because decision makers (e.g. directors and owners) traditionally rely on the experience of senior managers to effectively solve problems, particularly in planning and estimating, rather than being supported by BIM technologies.

It was found that current **government support** for BIM adoption remains at the level of persuasion, with few financial incentives offered and no enforcement for the use of BIM along with a lack of BIM-oriented standards and regulations. Legal implications of BIM and related contract documents were perceived as particularly unclear. Consequently, BIM models were used as reference sources but not formal documents which involve risks around sharing agreements among participants and compliance with current regulation requirements. As one director implied, *"it's risky for project approvals when BIM practices have not been legally supported"* - TM_1D_2. Similarly, another senior manager commented that a *"3D model is only used as a supplement to the* *main 2D paper-based documents as it's complicated, unclear or overlapping standardisation"* - TM_1D_4.

Top management groups explained the reason for not further developing BIM due to **the lack of preconditions**. For example, most benefits from BIM adoption were reported in projects involving prefabrication, *"a practice that is only gradually becoming more widespread in Vietnam"* - TM_1D_1. Further, the absence of e-procurement discourages the use of digital data which in turn prevents adopters from fully taking advantage of the models: *"e-tendering naturally mandates contractors to exploit their BIM models to win a job, thus increasing their experiences and knowledge. For clients, e-procurement helps to reduce complexity, and improves competitiveness and transparency"* - TM_2D_1.

4.5.2.1.2 *Simply 3D visual representation*

Non-BIM specialists at lower level management such as site engineers perceived BIM as simply a 3D visual representation to assist them with **constructability issues**. A typical response was *"3D models help site staff with understanding complex MEP intersection settings"* - E_8C_1. However, site staff expressed their distrust in using BIM models in the entire construction process due to corrupted data transmission and downtime issues. Site supervisors noted that *"we can't rely on the inaccurate 3D models for our consecutive scheduling analysis"* - $E_{10}C_1$ and *"it's impossible to create 4D scheduling models as the speed of BIM tools were not fully able to catch up the site progress"* - $E_{11}C_1$.

In addition, site staff could not completely engage in developing BIM models as their tasks were under the control of site managers. Information updating for as-built models was likely to be interrupted or inconsistent as the new decisions of **personnel rotation and arrangement** within and across projects were practised frequently by site managers. The structure of project teams is a temporary network with people continually leaving and new employees taking their places. *"When new employees arrive on site, they have to learn the project rules and processes, including the BIM process, which may take time before they become effective, resulting in lost productivity"* - MM_2C_1.

Non-parametric data was viewed as a challenge to the adoption of BIM at the higher level. It was mentioned that site managers used the visualisation ability of BIM for decision making optimisation, but they did not use the BIM model directly as a base for generating the schedule (e.g. 4D BIM). There are some issues such as weather conditions and the availability of necessary resources for construction planning, but these data items were not included in a standard 3D BIM model. *"Not all data can be denoted as numbers or graphics. For example, the wet season lasting several months could lead to slip and fall accidents or weakened concrete products, whereas the dry season usually coincides with the harvest season when most manual workers return to their farms causing labour shortages"* - MM_3D_1.

4.5.2.2 BIM as emerging skills for AEC professionals

4.5.2.2.1 *Not recognised as a mainstream profession*

A clear theme from the analysis of data was that BIM work was not recognised as a mainstream profession such as architecture and engineering. BIM was perceived as a new skillset (i.e. computer technology enhancement) necessary for AEC professionals rather than as a standalone construction practice. This is because the BIM philosophy requires committed collaboration with all stakeholders, relying on trust and transparency, which is not the norm in a conventional project approach. The Vietnamese government agents (e.g. GA_1 and GA_2) asserted that their current intentions were to increase the awareness of BIM among industry and emphasised the need for BIM education associated with universities and companies. Their explanations were "*considering BIM as a new discipline means the government must revise most building codes and standards to support* it" - GA_1 and "*it's really an exhausting task which is beyond our current capability*" - GA_2.

Through the case studies, it was found that **social influence** significantly impacts the level of innovation adoption of an individual. In the case of Vietnam, non-BIM specialists not only observed less evidence of successful BIM based projects within their peer network of competitors or partners but also encountered unsatisfactory experiences with BIM partners. One senior manager did not believe BIM would become a mainstream practice because of its collaborative platform: *"I heard lots of rumours about 4D, 5D or even 6D BIM being individually implemented by some companies but I have seen just the limitation to 3D applications. BIM cannot further develop without all possible partners doing it and sharing information generated from the model"* - TM_1C_1. Another site engineer described the difficulty when working with partners having less experiences in BIM: *"We are able to launch 4D BIM but cannot find BIM competent subcontractors to team up with. It's always daunting to work with partners not capable or at the same level we are"* - E_8C_1. One senior manager acknowledged the negative impact of incompetent peers and suggested that *"we cannot expect the maturity of BIM while people around us are at the low level. It would be easy to work always with our strategic partners and elevate their knowledge to where we want to be and share the cost of training with them so that we can both learn together"* - MM_2C_1.

Lack of IT department support makes BIM slow to become a mainstream practice. With all players, file types and disciplines located in multiple offices with varying degrees of network connectivity and speed between them, keeping everybody on the right set of files is problematic. IT departments should be an integral part of BIM execution because server synchronisation and bandwidth optimisation are crucial. Senior managers, however, did not realise the important role of the IT department and felt surprised when the researcher made the connection between the IT team and BIM team. It did not make sense for a construction company to have a robust IT team in-house because the managers were not sure if high levels of capital investment in computer systems and communication networks could yield significant gains in productivity and economic returns. Common comments of top management were *"the IT team oversees network security, hardware maintenance or website operation whereas the BIM team is responsible for the issues of software interoperability and sync. Both don't work together"* - TM_1D_1 or *"our IT* *team is small in size and its function is related to managing the local area network and physical assets such as computers, laptops, etc."* - TM_1C_1. Another manager revealed that *"we contract with an outside IT company to provide cloud services and coding as we don't invest much in the field of IT"* - MM_2C_1. In contrast, a site engineer stated that *"even if you can solve all the coordination issues and make the software work together in theory, keeping it all in sync is a big problem that the BIM team alone cannot completely address. The IT team must be involved in BIM"* - E_9C_1.

4.5.2.2.2 *Low relevance to construction business*

BIM was viewed as of little relevance to the construction business. Interviews revealed that neither general contractors nor owners were interested in the additional cost associated with BIM services. Contractors indicated that BIM skillsets help designers increase the speed and accuracy of the designs, but these benefits are not directly relevant to their bottom line. A similar comment was that *"we still make profits with* ***traditional methods****, just rework and raise extra claims"* - TM_1C_1.

The focus of the interviewed owners was observed as making quick profits by selling buildings faster. They may have to build units at lower cost to sell quickly rather than raise the standard of construction. As a result, BIM aimed at increasing building standards and efficiencies was not considered as an important goal. In other words, BIM was perceived as a tool or skillset to help project members (e.g. contractors) achieve their goals but has been slow to change owners' **business models**. Further, owners were usually not occupiers of the buildings. Hence, higher level BIM applications for the post-construction stage such as operation and maintenance (i.e. 6D BIM) were neglected, making standalone 3D BIM impractical in their business. The highest priority of owners was described as *"we formed the buildings, sold the units quickly, made the profits, and got out"* - TM_1O_1.

Although temporary works such as scaffolding and temporary stair towers significantly impact site works through safety and movement, they often do not appear in BIM. Therefore, site engineers perceived BIM as having relatively **low advantage** for their daily tasks. *"The role of temporary structure is underestimated by BIM people as it is just temporarily erected and removed when the job's done. But it sticks to site people's daily routine by providing support or means of access during construction works"* - $E_{10}C_1$. Another added *"not only the quality of permanent products such as concrete beams but also our safety and performance are guaranteed by well designed temporary structures"* - $E_{11}C_1$. Currently, temporary structure objects manually inserted into BIM cannot automatically generate information impact on construction safety. *"It's a waste of time feeding data into architectural design models. What we need is a sufficient planning of temporary structure to avoid spatial conflicts and congestion among work crews"* - E_9C_1.

The effortless **observability** afforded by BIM to top management of an organisation is a contributing factor for BIM adoption. It was commonly accepted that BIM holds significant advantages at 3D visualisation and clash detection. Beyond that, other benefits of BIM are not fully visible such as increased safety and efficient communication, or are difficult to measure such as return on investment. Top management doubted the tangible values of BIM: *"what difference did the well paid BIM employees, sophisticated computers and expensive software provide? Was there a real benefit? Can you quantify it? and Where is the concrete evidence?"* - TM_1D_4. Other senior manager admitted that *"the system, software and hardware will disrupt the workflow, require constant update, and change the way you do business. Unless you use BIM for yourself, such as facility management, there is no directly relatable capital in virtual construction or BIM"* - TM_1D_2.

4.6 Discussion

4.6.1 Explaining the findings using Diffusion of Innovation Theory

4.6.1.1 Innovation affecting perspectives on BIM

Theme 1 and Theme 2 demonstrated perspectives of BIM specialists and non-BIM specialists on the new BIM profession. Five perceived characteristics of innovations help explain the rate at which innovations are adopted: relative advantage, observability, complexity, trialability and compatibility (Rogers 2003). Theme 1 showed that the attributes of complexity, trialability and compatibility have been marked as important to BIM specialists' jobs because these attributes are relevant directly to the manipulation of software. First, innovations need to be easy for the users to understand and the tools need to be easy to use to increase the likelihood of adoption (Wan Mohammad et al. 2018). Second, free trial versions should be available to test the key functions of a software or the software could be tested on a small portion of a project (Juan, Lai & Shih 2017). This will enhance trialability, alleviating doubts while at the same time helping users make an informed decision. Third, innovation needs to be presented to adopters as consistent with the desired outcomes that current methods produce (Gledson & Greenwood 2017).

Theme 2, on the other hand, implied that non-BIM specialists relied on the attributes of relative advantage and observability to make the decision to adopt an innovation. This is because late adopters tend to innovate when there is a clear potential for increased profits. Technologies must therefore provide potential adopters with the perception that the use of the technology is better than the current method of doing work (Saka, Chan & Siu 2020). In addition, the innovation needs to be presented in a way that the results of using the innovation are observable to others (Noor, Junaidi & Ramly 2018). In the case of Vietnam, the applications of BIM on site are limited, as temporary works are not typically covered in the BIM process, and return on investment of using BIM was not clearly defined. Site engineers and owners, consequently, perceived BIM as an emerging computer skill and less practical for efficiency.

4.6.1.2 Environment affecting perspectives on BIM

4.6.1.2.1 *Educational conditions*

Prior studies found that highly educated workers tend to adopt new technologies faster than those with less education (Rogers 2003). Currently, most Vietnamese BIM professionals are self-taught on BIM. They may only know the tools of BIM but not the process (Bui 2019; Gerges, Austin & Jaeger 2017). BIM specialists thus have a negative stance on BIM as they do not feel confident at work, particularly in integrated design where multiple disciplines work together. Non-BIM specialists, on the other hand, look at BIM as additional costs because they are not educated about BIM's value. Business-minded people rely on the return on investment to assess the project success but it is not applicable to the use of BIM (Young, Jones & Bernstein 2008). Non-BIM specialists doubt BIM because they spend money on hardware, software, training and infrastructure just to put a good system in place, and, on paper, will have no real savings to show for it.

4.6.1.2.2 *Peer network*

The adoption of a new technology involves the management of risk and uncertainty. Individuals thus require assurance from trusted peers who they personally know and trust and who can give them credible reassurances that their attempts to change will not result in embarrassment, financial loss or wasted time (Robinson 2009). The main themes confirm the findings from innovation adoption literature that socially proximal referents such as close relatives, colleagues or peers have been classified as normative referents who are viewed as providing factual information as well as establishing the norms for behaviours (Bindah & Othman 2016). In the case of Vietnam, BIM specialists felt isolated due to the lack of a peer network to exchange knowledge, whereas non-BIM specialists did not feel necessity or peer pressure to change as their surrounding peers were also not doing BIM.

4.6.1.3 Culture affecting perspectives on BIM

4.6.1.3.1 *Collectivist culture*

The main themes implied that both BIM specialists and non-BIM specialists were only concerned with legal liability while using BIM whereas ethical issues were of little concern. Past research also found that counterfeit software packages have been used in Vietnam for internal applications without any ethical concerns (Bui, Merschbrock & Munkvold 2016). This low moral sensitivity could be explained by the "collectivist" culture in Asian countries, including Vietnam. The collectivist culture leads to a weak assumption of individual responsibility. Consumers in the collectivist culture not only like to share software, they also like to share responsibilities. There is the idea that the rightness of a law decreases when more people violate it or, in other words, "the law cannot apply if everybody breaks it" (Wang, Zhang & Ouyang 2005, p. 6).

4.6.1.3.2 *Uncertainty avoidance*

Uncertainty avoidance is the degree to which members of a culture feel threatened about or uncertain in unfamiliar situations (Hofstede 2011). In the culture of greater tolerance of ambiguity and uncertainty, it is easier to convince people to make decisions on innovation adoption because they do not demand high levels of documentary evidence before making decisions (Shane 1995). On the contrary, people in a low uncertainty acceptance culture are not willing to try new things without a guarantee of success. The Vietnamese construction industry is characterised by a high uncertainty avoidance culture in which local companies, even large ones, tend to be risk averse and do not want to be BIM champions. Generally, local companies prefer to work with partners with higher or the same BIM to share the risks, which means they wait and see until the market becomes mature with more

BIM competent professionals engaged. Otherwise, they only work with strategic subcontractors and educate these subcontractors to the level qualified for BIM-related tasks, which reflects silo working and spontaneous adoption. This phenomenon explained the depleted motivation of BIM specialists when their patience and motivation are wearing thin waiting until BIM is accepted as a norm.

4.6.1.3.3 *Power distance*

Power distance is the degree to which members in a culture accept that the power is distributed unevenly in society (Hofstede 2011). Members of high power distance cultures such as Vietnam accept status differences and are expected to show proper respect to their superiors. Status differences exist within the organisational hierarchy, but they may also be based on age or social class. Senior managers are old and experienced people, but they do not find it easy to use BIM tools, whereas younger staff are good at software but have less practical experience. This leads to the lack of understanding by top management, usually non-BIM specialists, when considering BIM as being of little relevance to the construction business. Young BIM professionals, on the other hand, felt isolated as their innovative ideas and proposals are not understood by senior managers. The strong power distance culture may impede the voice of lower position people within an organisation, particularly when their creativity is opposed by their superiors' conservative views (Andrijauskien & Dumčiuvienė 2017)

4.6.1.3.4 *Social recognition*

Social recognition is argued to be of fundamental importance for employees, as it contributes to their perceptions of self-worth and identity (Bjarnason 2009). It is evident that workers care about social recognition and their relative standing within the group (Kosfeld & Neckermann 2010). In particular, an emerging and minority group like BIM professionals expects to be socially accepted and valued. In the case of BIM adoption, BIM specialists do not feel satisfied and happy with their company supplied BIM technologies as they are insufficient in meeting the expectations of other social members such as peers and senior managers, resulting in their belief of unstable positions in the workplace.

4.6.2 Cross-case analysis

Participants in different disciplines hold different views towards the BIM profession (Table 4.6).

Table 4.6 Perspectives of participants on BIM profession

Case organisations	BIM specialists	Non-BIM specialists
D_1 (architecture)	Depleted motivation	Supportive roles
D_2 (engineering)		Supportive roles
D_3 (engineering)		Supportive roles
D_4 (architecture)	Job insecurity	
C_1 (contractor)	Depleted motivation	Emerging skills
O_1 (owner)	Neutral	
GA (government agency)		Neutral

BIM specialists in design company D_4 were concerned about the compatibility of their new positions (roles) with existing social norms and hierarchies, and thus felt **job insecurity** when having to struggle for social recognition. On the other hand, BIM specialists in design company D_1 and contractor company C_1 presented a **depleted motivation** due to insufficient accessibility to knowledge sources such as a peer network and the complexity involved in the collaboration with incompetent partners.

Non-BIM specialists in design companies D_1, D_2 and D_3 considered the BIM profession as a **supporting role**, with the lack of an enabling environment for BIM adoption such as lack of government support, low IT infrastructure and insufficient education and training. Non-BIM specialists in contractor company C_1 perceived BIM as an **emerging skill**. They encouraged BIM specialists to take the lead of pilot projects (i.e. trialability). However, until the outcomes of BIM are well observed (i.e. observability), the engagement of non-BIM specialists in contractor companies has been still limited.

Participants in owner company O_1 and the government agency GA showed a **neutral attitude** towards the BIM profession, seeing the profession as having little relevance to their business. BIM's potential for long-term values of sustainable design was seen as not important as tangible values or generating quick returns. Also, owners and government agents are not direct implementers of BIM. Digital transformation with BIM adoption may not happen in the near future. However, owner company O_1 is open to exploring potential values of BIM while the government agency is actively evaluating BIM benefits.

4.7 Triangulating themes

4.7.1 Using secondary data to validate themes

Figure 4.2 shows how BIM specialists of company D_1 integrated BIM models into 2D drawing to explain the plan, section and elevation of a stair design. Although it is easier to understand the stairs in axonometric, the line representation of that BIM model in a paper print is just a pair of lines. All BIM components (e.g. stairs, beams, walls, etc.) have area, volume, materials and other attributes that can be queried or retrieved. Printing a set of drawings from a BIM model, however, makes this rich information so small that it is unreadable on the popular A3 or A2 paper size.

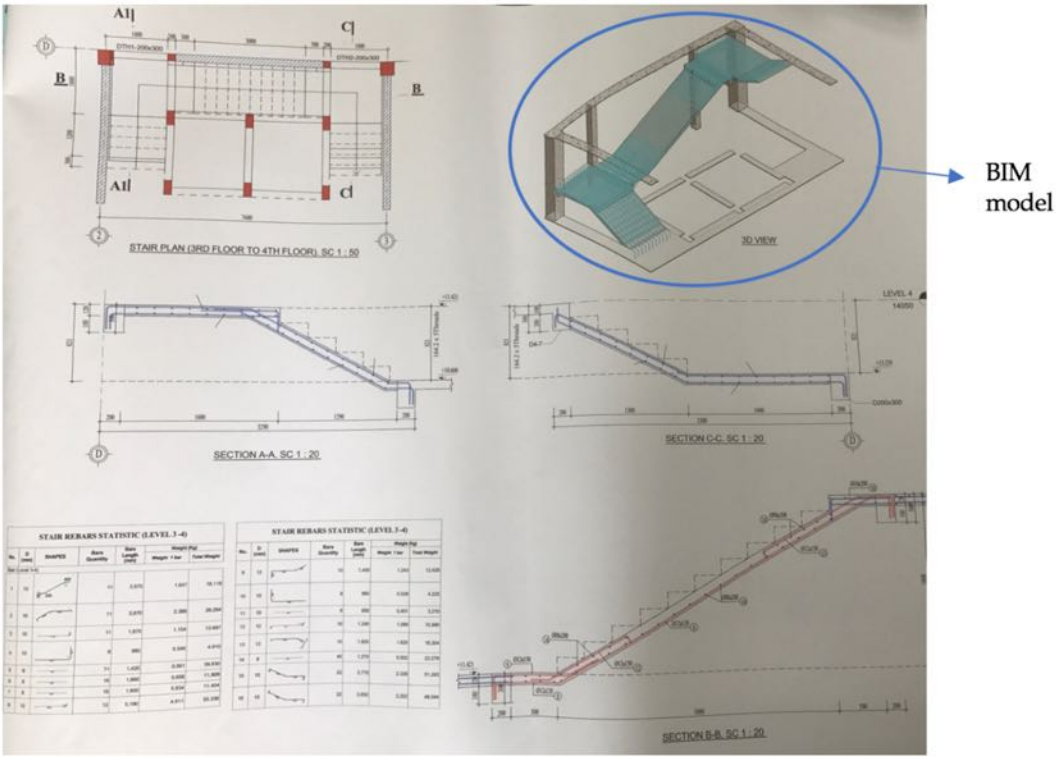

Figure 4.2 Integrating BIM model into paper-based drawing (by company D_1)

The task of the designer is two-fold: to create the design, and then to communicate the design. Although BIM models excel in improving the way designers create such as better design coordination to meet the functional, aesthetic and economic requirements of project stakeholders, designers have found that the data-rich digital models are not easily communicated. Traditional paper-based drawing sets, which include some 3D features (see Figure 4.2) cannot serve as a useful medium to explain and communicate information contained in the electronic BIM models, requiring a change in the way design teams meet with other project stakeholders (e.g. contractors) to discuss and coordinate their work.

Since a digital model has not been accepted and cannot legally replace printed copies signed and stamped as original, there is not much change in the representation of a design drawing exchanged among project stakeholders in Vietnam. BIM specialists are only allowed to use 3D models for visual support of architectural and technical drawings. This phenomenon explains why the roles of BIM specialists are not highly recognised for their practical contribution to the entire project. However, in a single design discipline such as architecture, structure or MEP, the work of BIM specialists might be praised by design teams as a reliable in-house source of information for optimal solutions and interference checking prior to issuing final designs to construction sites and clients.

For the general contractor company C_1, the design drawings (see Figure 4.3) passed to construction teams are required to represent not only the technical issues (inside the red border) but also the construction methods (inside the blue border). The 2D work wrapped in the red lines was completed by an engineering design company, whereas the 3D part within the blue lines was developed by in-house BIM specialists of company C_1. According to the response of BIM specialists from company C_1, it took them four months to accomplish the additional 3D views. The challenge lies in the interoperability between the Tekla structural tool and the Revit architectural tool. Further, an extra month was needed to communicate the new form of design presentation of the hybrid 2D-3D annotated view to all site engineers.

Figure 4.3 implies that only the 2D work of the engineering company was approved by key project stakeholders (e.g. project managers) as a reliable and legal source for subsequent construction activities. The 3D model created by the contractor's BIM specialists was seen as just a 'proposal', acting like the supplementary explanation of the construction method (e.g. assembly instructions for rebar cages).

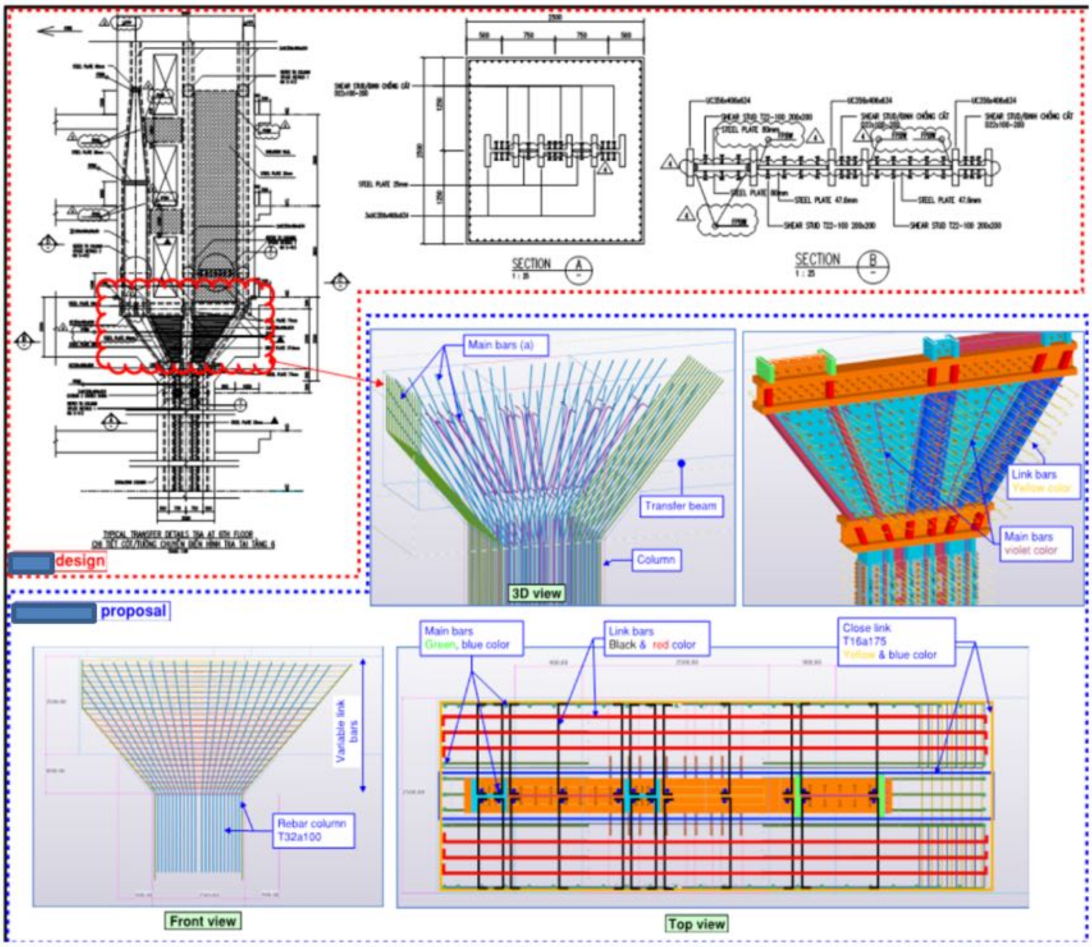

Figure 4.3 Transferring 2D designs to 3D shop drawings (by company C_1)- Refer to Appendix 14 for full page figure

Paper representations of a building that combine 2D and 3D views help construction crews to understand the whole idea of rebar assemblies but are not really effective for actual execution in the field. First, most tasks on site are carried out by manual workers with less skills and education, therefore transparencies and detailed 2D formats including dimensions, locations and specifications of components are recommended rather than 3D views, particularly in a limited print area of a portable drawing which is usually an A3 size sheet. Second, it is impossible to manually measure the true dimensions of a 3D element for quick estimating and tracking actual volume of work on site by the traditional method using ruler and scale as it is a stereoscopic display. Field personnel are therefore provided BIM handheld mobile devices with measuring tools integrated, increasing costs for contractors such as purchasing of tablets and apps and training.

Figure 4.4 illustrates the structural BIM model of a cable-stayed bridge in a local province of Vietnam. Company D_3 was in charge of structural design and their BIM specialists used Tekla software to create this model. Printing information (e.g. dimensions) attached in a BIM model is not easy because of multiple scales and viewpoints, and dense data, making the drawing unreadable.

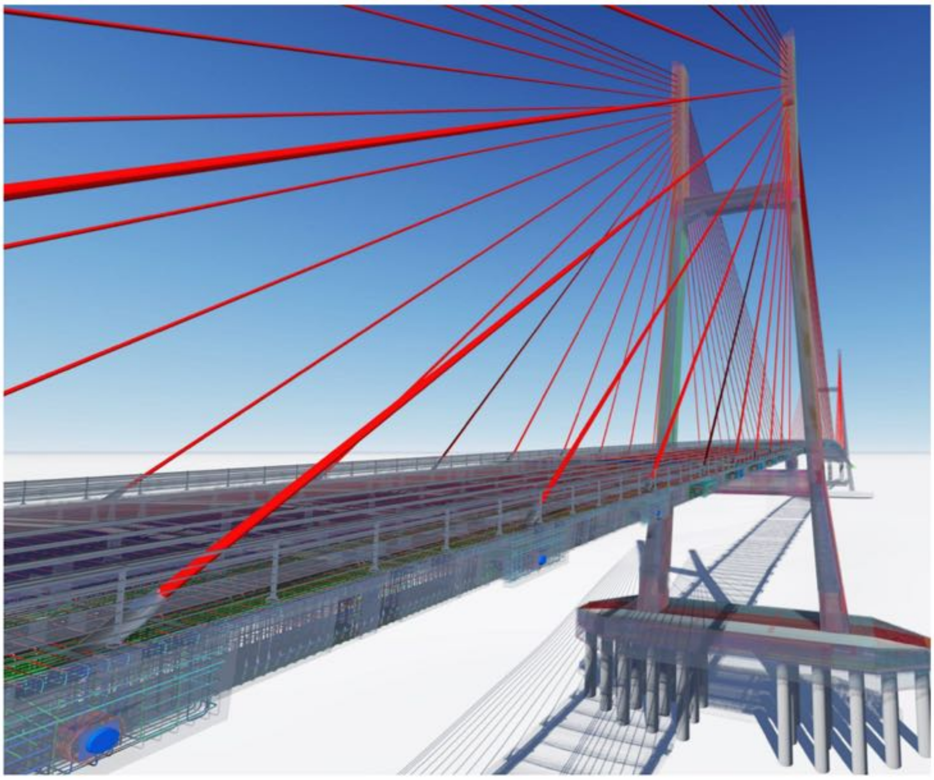

Figure 4.4 Structural design of local bridge (by company D_3)

The paper drawing size fits into an A2 or A3 standard for portability in the field, hence there is no more space to add information into complex 3D elements (see Figure 4.4). The BIM specialists of company D_3 had to represent the BIM model with only 3D views and just used it for meeting representation, making their roles unappreciated by peers such as site engineers.

Research indicates that a BIM model as the centralised database helps designers to reduce design conflicts, enable clash checking and better maintain information and design model integrity by relying on one information source (Kouch, Illikainen & Perälä 2018; Yusuf 2014). However, efficient information exchange was limited to only a group of designers (i.e., creators or makers of the model) due to the lack of regulations regarding the new way of communicating design information. As yet, valuable information integrated in the BIM model is insufficiently communicated among project parties because information is still predominantly handed over in the form of drawings, either as physical printed plots on paper or in a digital format but with limited accessibility requiring electronic devices and apps.

BIM specialists in Vietnam have to work around the issue of transferring information from computer generated models to construction crews by one of three ways:

- the majority of 2D components with annotations and additional 3D views (see Figure 4.2)
- a hybrid form of 2D and 3D views with annotations (see Figure 4.3)
- the entire 3D view without annotations (see Figure 4.4). Such representations of BIM outputs, however, fail to highlight the importance and innovation of the BIM profession compared to the conventional 2D process, and thus still impede its more widespread use at higher levels of 4D or 5D BIM.

4.7.2 Using direct observation to validate themes

Figure 4.5 shows the delivery of BIM models from company D_3 to the government agency at the operation and maintenance phase. This period involved neither the architects nor the construction professionals because all the design and technical documentation, including 4D time and 5D cost data attached in the 6D model, was handed over to the public owners. This caused an overload of information which, in turn, confused local government workers who were non-BIM specialists and hampered their decision making.

Figure 4.5 Transferring 6D BIM model to Vietnamese government workers

The diffusion network (i.e. the knowledge and experience sharing channel) plays an important role in facilitating project-based learning from BIM drivers and champions. However, due to the fragmented nature of the AEC industry, there is a lack of a BIM diffusion network at the state and national level, resulting in sluggish BIM practices of not going beyond 3D design in the adopting companies, particularly the public sector.

4.7.3 Using member checking to validate themes

Table 4.7 shows the results of follow-up interviews including participants' comments and further interpretations. The findings from previous interviews were sent via email to key participants for review one week before the face-to-face conversation.

Table 4.7 Follow-up interviews

Themes/Sub-themes	Follow- up Questions	Participants	Comments
1. Welfare concern *2. Not self-confident in BIM roles* *3. Poor morale* *4. Disadvantage career path* *5. Feeling of isolation* *6. Supporter for project deliverables* *7. Simply 3D visual representation* *8. BIM not recognised as a mainstream profession* *9. BIM not of much relevance to construction business*	- To what extent do you agree with the findings? - Any additional comments or alternative interpretations of the findings?	MM_1D_1 (BIM manager)	- Completely agreed - Added a comment on 'sustaining motivation' toward adoption
		TM_2D_1 (Vice-director)	- Completely agreed - Added a comment on 'autonomy clash' between BIM team and current governance structure
		MM_1C_1 (BIM manager)	- Completely agreed - Added comment on the 'redirection' of BIM adoption
		MM_2C_1 (Site MEP manager)	- Mostly agreed (7 out of 9 points) - Had no idea of point 1 and point 3 - Added a comment on 'imitation' rather innovation
		E_1C_1 (BIM specialist)	- Completely agreed - Added a comment on the 'optional' adoption of innovation
		E_2C_1 (BIM specialist)	- Completely agreed - Added a comment on the stronger engagement of owners
		GA_1 (Government agency)	- Mostly agreed (6 out of 9 points) - Had no idea of point 1, point 2 and point 3 - Added a comment on BIM education training for owners

Seven out of 29 participants agreed to participate in the follow-up interviews. The majority of them showed high consensus with findings (over 65%). Some comments were also made by participants. MM_1D_1 emphasised the importance of 'sustaining motivation' of BIM staff who were frustrated with the slow pace of change and sluggish recognition of new BIM roles.

TM_2D_1 was more concerned about 'autonomy clash' between the [new] BIM competence group and the current organisation's governing structures that require the system's readiness and capacity for change coming into play.

From the contractor's perspective, MM_1C_1 found early on that design models passed from design parties are not detailed enough and of little use to them, thus requiring them to create their own construction models. However, reliance on a small number of in-house BIM specialists such as BIM modellers, BIM coordinators and BIM managers to manipulate both 3D and 4D models during works, means that the use of BIM for site safety and logistics management is not as widespread and fully complete as possible. This results in the low quality of models for construction sites where 2D drawings and models had different and even conflicting information, particularly in the situation of tighter schedules. Therefore, the BIM team of the main contractors decided to redirect their BIM adoption strategy from 'adding support BIM staff to site' to 'training site staff and subcontractors' on the basic BIM skills to self-manipulate the models. The responsibilities of the BIM team were reduced to only focus on managing models and transferring models to sites and doing research and development tasks.

As a site engineering worker, MM_2C_1 was interested in the application of BIM quickly and effectively into his daily operating environment. To catch-up the innovation, site staff initially focused on the 'imitation of innovation' by repeating BIM practices guided by BIM specialists with no or small adjustments and building technological capabilities and absorptive capacity; then, as the technological gap decreases, they will allocate more R&D resources to innovation and attempt technological leapfrogging with the full adoption of innovation.

Due to the limited BIM practices on site, the degree of autonomy on BIM trials was seen as a critical factor to sustain motivation of BIM competent personnel, noted by E_1C_1. For example, the BIM team is allowed to conduct 'optional adoption', an opportunity for adopters to try, test and learn their BIM interest areas. E_1C_1 stated that "g*iven the facts of lacking a clear career path and lacking career advancement opportunities, our job satisfaction lies in the accessibility to new technologies and opportunity to be pioneers of change*".

Strengthening the owners' engagement in the initial phase of the project was found to be another concern. A BIM specialist noted that *"there are an increasing number of clients who are willing to let BIM be used on their projects but no clear targets, for example, the requirements of BIM maturity; and less knowledge of available BIM capabilities in Vietnam"* - E_2C_1. This results in the situation where BIM staff cannot prepare BIM solutions well in advance, thereby finding it difficult to explain the trade-off between the level of BIM maturity and BIM costs to clients. In particular, 5D BIM (and above) is not widespread in Vietnam, and this increased the fees for technology purchases, training for BIM staff as well as clients' staff, and outsourcing BIM work to third parties.

Regarding the government agency's perspectives, GA_1 insisted that *"there is a need to train clients, particularly public owners, with basic BIM principles, so they are capable of demanding and releasing the correct information, at the right time and with the appropriate level of quality"*. However, developing a general BIM education framework for later adopters such as owners, under the management of the Vietnamese government alone, appeared to be ineffective because many owners have a background that may not even be related to construction disciplines, whereas others do not understand what their role is and the elements they need to demand and control in a BIM process. The recommendation of the government agency GA_1 is to look for assessors and be instructed by the team they have employed. For this purpose, roles such as BIM consultant or adviser have already emerged. This BIM consultant or adviser is designated in the first stages of a project to help the client assess their long-term objectives for their business, delimit the scope of BIM in their projects; and assist the client in the use of the information during the lifecycle of a project (Silverio et al. 2017).

4.8 Evolution of the Diffusion of Innovation Theory in organisational context

The Diffusion of Innovation Theory, which originated in communication theories, traditionally focuses on how marketers' communication strategies influence consumers' adoption of a new product or a service (Rogers 2003). The consumers (or adopters) are assumed to freely make their adoption decision (Zhang, Siebers & Aickelin 2012). In other words, the hierarchical position of the decision makers responsible for adoption decisions is supposedly equivalent in the community. Cited examples are farmers who adopt a new seed or patients who adopt a new drug (Rogers 2003). These technologies are widely used in personal settings where users adopt a technology voluntarily or willingly (Tscherning & Damsgaard 2008).

However, findings from the first round of case studies imply that the technology adoption of BIM is the product of the social interactions within the organisation. In reality, the decision on adopting BIM is made by a few authoritative individuals in management while the actual users, the staff members, are forced to use the innovation with little knowledge or influence on the choice. The process of innovation decision making is no longer a linear five-stage mental process which an individual goes through, beginning from the first recognition of innovation to the formation of an attitude towards it, then to the decision to adopt or reject, then later to the implementation and use of the idea or the new practice, and finally to decision confirmation (see Figure 4.1). Instead, the adoption process is dynamic and interactive as shown in Figure 4.6.

Figure 4.6 indicates that at the organisational level, the adoption of an innovation is more related to compulsory use in which decision makers and implementers are separate units. These two groups also have different perspectives on BIM jobs because of their different interests. Decision makers (at a higher status) measure the innovation based on their knowledge of the innovation such as previous experience in BIM and the perceived benefits of BIM to the entire organisation (see Theme 2). On the other hand, implementers (at a lower status) are persuaded to use BIM due to BIM's benefits to individual values such as job security, incentives and career advantage (see Theme 1).

During the adoption process in the organisational context, communication channels such as dialogues, agendas, media and change agents play an important role in mediating the misunderstandings between decision makers and implementers. The confirmation of whether the organisation will keep using or abandon the use of a technology is a matter of negotiation or a collective innovation decision between stakeholders. Similarly, Houghton and Kerr (2011, p. 247) argued that "technology is a by-product and facilitator of human accomplishment and a part of the social order, our norms and ideas".

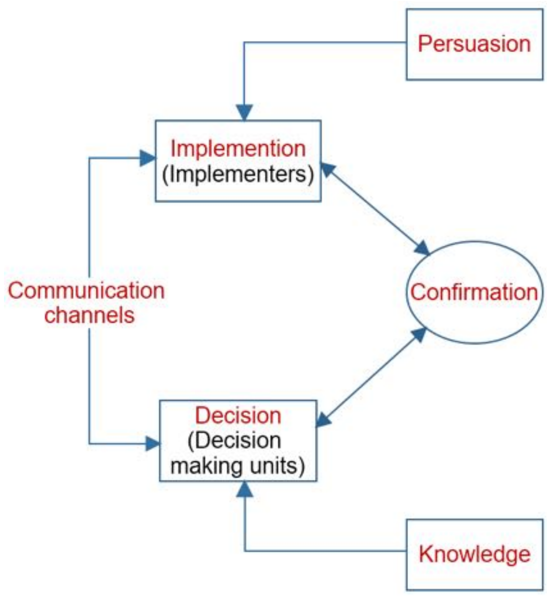

Figure 4.6 The adoption process in an organisational context

4.9 The need to supplement Diffusion of Innovation Theory

During the follow-up interviews (see Section 4.7.3), the majority of participants confirmed the consistency of the findings with their perceptions. Diffusion of Innovation Theory also proved its strength of interpreting attitudes of participants towards BIM jobs. However, findings from the first round of case studies show that the theory is suitable to examine human decisions of adopting a technology but may be not sufficient to explain human actions of implementing this technology. Some sub-themes emerged in relation to the actions that need to be taken for the successful implementation of BIM, for example, sustaining the motivation of BIM staff, engaging project owners, aligning BIM with current system structures and conducting interactive BIM education. Hence, another theory, Activity Theory, is selected and used together with Diffusion of Innovation Theory in the following case studies in Chapter 7 and Chapter 8 to analyse these emerging required actions in a holistic manner. This required the researcher to review existing literature prior to commencing new empirical work of the second round of case studies.

As a result of the updated literature review, Chapter 5 describes the limitations of the Diffusion of Innovation Theory in explaining the findings from Chapter 4. A review of Activity Theory is undertaken in Chapter 6 including a justification as a holistic lens of interpretation in this BIM research and potential supplement to the shortcomings of the Diffusion of Innovation Theory presented in Chapter 5.

4.10 Summary

This chapter described perspectives on the BIM profession by participants in organisations involved in BIM based projects. The key findings from the first round of case studies are as follows:

- BIM specialists felt they operated in a negative work environment with concerns about job security because non-BIM specialists, particularly senior managers, paid little attention to the welfare of BIM specialists. Issues that the BIM specialists faced included a heavy workload with few incentives, potential for liability based on copyright claims from illegal software use, poor infrastructure, unclear rights and responsibilities in BIM contracts.
- The concerns of job security of BIM specialists also arose from an environment which does not encourage the adoption of BIM. For example, the BIM process is not compatible with current organisational workflow and industry standards. Along with low support from senior management, there is also a lack of BIM training and education and little client demand.
- BIM specialists did not consider technical complexity as a main barrier to BIM adoption. Instead, the disinterest and poor cooperation of non-BIM specialists was perceived as a more important blockage. BIM specialists could not fulfil their role unless there was input from other teams.
- BIM specialists felt depleted of motivation because their BIM roles or titles were not socially recognised by non-BIM specialists in current organisational hierarchies.
- BIM specialists lost their motivation because they had to work in a trial or pilot environment for a long time. This mechanism did not offer an opportunity for BIM specialists, especially younger staff, to acquire

practical experience, making them feel unenthusiastic and anxious about their skill erosion.

- The feeling of isolation from a peer network, a lack of a knowledge sharing network, made BIM specialists less motivated to pursue a high level of BIM implementation.
- Non-BIM specialists perceived BIM jobs as supporting roles because 3D visualisation still dominates use.

The next chapter examines the limitations of Diffusion of Innovation Theory for BIM research which rationalises the need for theoretical amendment and in turn prompts the combined use of Diffusion of Innovation Theory and Activity Theory.

CHAPTER 5 Limitations of Diffusion of Innovation Theory in BIM research

5.1 Chapter objectives

Despite being one of the most popular theories used in BIM research, Diffusion of Innovation Theory is not without limitations. Following the framework developed in Chapter 4 (see Figure 4.6) and taking into consideration the first round of case studies, this chapter highlights the limitations of Diffusion of Innovation Theory in explaining BIM adoption in the organisational context as below:

- Favouring technology: Diffusion of Innovation Theory assumes that technological innovation is positive and will be adopted by a target population over time. Innovation tends to be regarded as a 'good thing' despite evidence of negative and unanticipated consequences while using the innovation, such as immature BIM practices in the Vietnamese construction industry.
- Promoting a top-down diffusion approach: Diffusion of Innovation Theory also assumes that the mandatory use of BIM guarantees the success of BIM projects. However, the central control of decisions about which innovations should be diffused or a top-down diffusion of the innovation from experts to users may fail if the sharing of power and control among members of the diffusion system is poorly considered.
- Paying less attention in the post-adoption stage: Diffusion of Innovation Theory mainly focuses on making an impression on end-

users and influencing end-users' initial adoption decisions via communication channels. However, post-adoptive behaviours cannot become habitualised if end-users' problems in their daily operation or the real context of work are ignored.

- Using the terms adoption and implementation interchangeably: In reality, the organisational structure of a decision making hierarchy establishes the division of labour which distinguishes people who make adoption decisions, called mandators, from others who comply with and carry out these decisions, called implementers.
- Changing technologies during the adoption process: Diffusion of Innovation Theory also assumes that technologies are fixed, and unchanging innovations are diffused from producers to adopters.

5.2 Favouring technology

Jayasena et al. (2019) argued that most BIM researchers using Diffusion of Innovation Theory alone have taken a technological deterministic stance in their studies that "BIM technology is a given" or "BIM can make things happen", and these show a pro-innovation bias that "BIM must be adopted". It is, therefore, necessary to have a flexible approach, such as combining Diffusion of Innovation Theory with another theory, to reduce this technocentric perspective on BIM (Çidik, Boyd & Thurairajah 2017). As well as technology, social and learning conditions also have a significant effect on adoption behaviours (MacVaugh & Schiavone 2010).

5.3 Promoting a top-down diffusion approach

Diffusion of Innovation Theory has been criticised as having been simplified to focus solely on a new product or innovation, disregarding the complex societal, cultural, economic and other factors that determine how a product is adopted into society (Al-Mamary et al. 2016). In particular, Diffusion of Innovation scholars are often found to collaborate with manufacturers, government agents or senior managers to enable the innovation diffusion within a community (e.g. construction industry) by business strategies or policies (Chile 2017). By focusing on top-down diffusion of innovations, Diffusion of Innovation Theory's approach may not guarantee long-term success due to neglecting the actual innovation practices required to be implemented at lower levels such as by site engineers (Ayodele 2012).

Diffusion of Innovation Theory assumes that properly using communication channels including the media, peer networks and change agents (e.g. innovation champions) along with superior attributes of innovation enable potential adopters to make rational adoption decisions (MacVaugh & Schiavone 2010). However, this is not achieved easily because not only technological conditions but also social and learning conditions need to be taken into account (Schiavone & Macvaugh 2009). First, a complex innovation such as a BIM ecosystem does not fit into a single entity. This makes it harder for users of an existing technology to adopt a newer and completely different product as the use of the innovation requires complementary technologies which are not widespread in the market (MacVaugh & Schiavone 2010). Second, innovation adoption requires some level of new learning to enable use. Thus, the user, user community or technology provider must negotiate the barrier of knowledge required for adoption. Older technologies are difficult to disrupt when existing learning capabilities and accessibility to learning do not significantly assist in use of the new technology (MacVaugh & Schiavone 2010).

5.4 Paying less attention to post-adoption stage

Wisdom et al. (2014) summarised the main areas of innovation adoption and diffusion research using Diffusion of Innovation Theory including the external system (i.e. conditions for innovation adoption such as an innovative environment, government policies and regulations), organisations adopting the innovation (e.g. organisational training readiness and efforts), innovation (e.g. the level of complexity, relative advantage) and individuals (e.g. adopters' attitudes and peer network), as in Figure 5.1. Figure 5.1 shows that the outcomes of studies on innovation adoption using Diffusion of Innovation Theory mainly address the issues of pre-adoption (e.g. being aware of an innovation) and ongoing adoption of innovation (e.g. making a decision on trying an innovation), but are not concerned with post-adoption (e.g. making a commitment to adoption). As such, Diffusion of Innovation Theory is unable to explain the full innovation adoption process (Hameed & Arachchilage 2017).

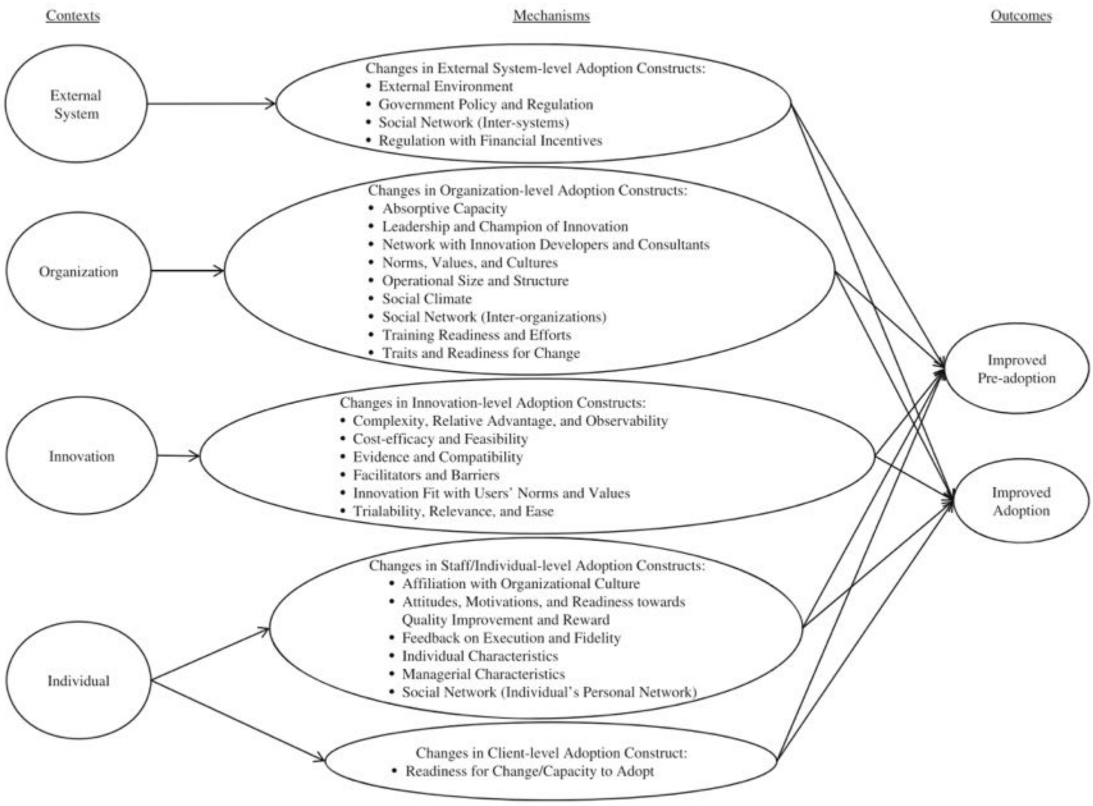

Figure 5.1 Summary of research on innovation adoption using DOIT (Wisdom et al. 2014)- Refer to Appendix 15 for full page figure

Due to this theoretical gap of Diffusion of Innovation Theory, it is necessary to find support from other theories to help properly interpret post-adoption behaviours. In this thesis, Activity Theory is chosen as a supplementary theory to Diffusion of Innovation Theory because of its appropriateness for investigating social interactions of collective decision making, negotiation and boundary crossing which mostly occur after adoption decisions (Engeström 1987).

5.5 Distinguishing the terms adoption and implementation

Research on BIM, in general, has used the terms adoption and implementation interchangeably. Rogers (2003, p. 21) provided a general definition of adoption as "a decision to make full use of an innovation as the best course of action available". On the other hand, Klein and Sorra (1996, p. 1055) stated that adoption is "a decision, typically made by senior organisational managers, that employees within the organisation will use the innovation in their work". The adoption of an innovation often changes the way people do their routine tasks but might not require decision makers to acquire new skills. For example, top managers could check the quality of designs through BIM models instead of traditional CAD papers, but they do not need to learn Revit, Autodesk's BIM software for creating 3D models.

Implementation is defined as the process of putting a decision or plan into effect. Klein and Knight (2005, p. 243) noted that "innovation implementation is the transition period during which [individuals] ideally become increasingly skillful, consistent, and committed in their use of an innovation". In this sense, the implementers, or direct practitioners of a new technology, have to develop new skills and knowledge to manipulate such new technology and be prepared for behavioural change of sharing BIM knowledge with other partners.

At an organisational level, BIM is adopted in mandatory settings where potential users do not have much choice but to embrace the new technology (Al-Jabri & Roztocki 2010). Makkonen (2007) presented the holistic conception of the "organisational innovation adoption and implementation process". Makkonen's model (see Figure 5.2) differentiates the adoption and implementation processes by analysing the actors (e.g. senior managers and employees) separately associated with their different activities, objectives and expected outcomes. According to Makkonen (2007), the top managers make an initial adoption choice of BIM and implement strategies or plans to increase and sustain the use of BIM among organisational members in a top-down approach. BIM adoption strategies aim to create conditions for wide use across employees, for example, the commitment and support from senior managers to provide the required resources such as BIM tools and BIM experts for the implementation as well as the allocation of sufficient time to get the BIM related job done. The employees, on the contrary, have to accept the initial adoption of BIM and, through the accumulation of knowledge from actual implementation, have to adjust their post-adoption behaviours to better adapt to changes in the use of new tools, processes and working conditions in a bottom-up approach.

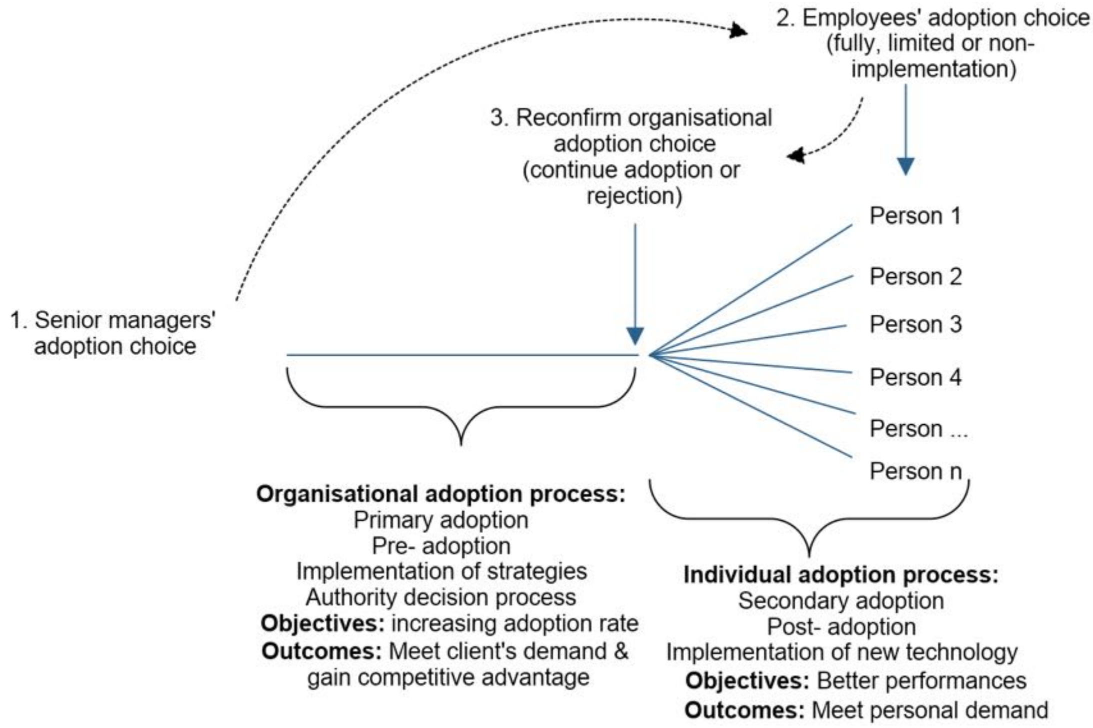

Figure 5.2 The interrelationship between innovation adoption and implementation process in an organisation, adapted from Makkonen (2007)

The post-adoption behaviours of employees as the actual implementers of BIM tools may positively or negatively affect the adoption intentions of top management as the decision makers. For example, case studies in Vietnam showed that employees still preferred to apply a hybrid BIM-CAD system to take advantage of each technology's most advanced functions rather than making the transition to full BIM as mandated (Bui 2019). Other study showed that construction professionals conformed to the Government BIM mandate but limited their adoption to only 3D modelling and clash detection, so-called "low-hanging fruit applications", while showing reluctance to pursue a higher level of BIM implementation beyond 4D scheduling BIM (Ayinla & Adamu 2018). The passive attitudes like "we wait until someone tells us to use it"

(Bosch-Sijtsema et al. 2017, p. 1) or "wait-and-see" (Juan, Lai & Shih 2017, p.363) observed in BIM implementation teams reflect passive post-adoption behaviours of employees which a mandate from top management alone may not be sufficient to address.

Hochscheid and Halin (2019, p. 276) stated that the difference between adoption and implementation is not explicitly made in BIM adoption literature. However, the studies of Klein and Knight (2005), Klein and Sorra (1996) and Makkonen (2007) above have shed light on BIM research with the focus on the interaction between senior managers, usually non-BIM users, and employees such as site engineers, usually BIM users, including pre adoption, during adoption and post adoption to provide a comprehensive understanding of BIM adoption and implementation.

5.6 Changing technologies during the adoption process

Technology may not remain stable during its adoption but its functions may be modified, its uses may be negotiated and its knowledge may be collectively constructed. Similarly, Lyytinen and Damsgaard (2001, p. 1) suggested that "complex IT solutions should be understood as socially constructed and learning intensive artefacts". In addition, a case study in the Vietnamese construction context conducted by Bui (2019) showed that the project teams not only adopted BIM but also customised modelling programs to make these programs fit the local regulations.

While Diffusion of Innovation Theory is one of the most popular theories in investigating the adoption of innovation, it has a limitation due to its nature inherent in communication theory. That is, Diffusion of Innovation Theory assumes that a new idea or new technology will be diffused entirely into the target community with little or no customisation of technology itself and relevant manipulation. Change agents influence decisions of potential adopters by a persuasive communication strategy which is a "process of customizing the design and delivery of a communication program based on the characteristics of an intended audience" (Seeger & Wilson 2019, p. 3).

Further, Diffusion of Innovation Theory interprets the non-adoption as a result of personal limitations of the potential users, such as inexperience or less skill, and ineffective communication channels, while in practice, the resistance to adoption may occur due to the lack of complementary technologies in network externalities, such as immature IT infrastructure (MacVaugh & Schiavone 2010). Limited access to learning is another challenge to BIM adoption. Thus, the users, user community, academia and technology providers must work together to negotiate the barrier to knowledge adoption to facilitate boundary crossing (MacVaugh & Schiavone 2010).

5.7 Summary

This chapter summarised the limitations of Diffusion of Innovation Theory for studies on BIM adoption in an organisational context. In particular, Diffusion of Innovation Theory does not offer adequate guidance to deal with collective adoption behaviours such as the long-term vision of relevant stakeholders but focuses on individuals' decision making which is subjective, compulsory or spontaneous. To cover the theoretical gaps of Diffusion of Innovation Theory, it is necessary to consider a supplement from another theory, especially one popularly used in analysis and understanding of social interactions.

The next chapter justifies the selection of Activity Theory as a suitable supplement to Diffusion of Innovation Theory and provides a brief review of Activity Theory and its applications in BIM research.

CHAPTER 6 Activity Theory: Literature review and discussion of potential combination with Diffusion of Innovation Theory

6.1 Chapter objectives

This chapter introduces Activity Theory as a qualitative theoretical framework appropriate to investigate social relationships and collective activities. Basic concepts of Activity Theory are reviewed and the uses of Activity Theory to guide BIM research are demonstrated. The literature review implies that the limitations of Diffusion of Innovation Theory such as insufficient study of post-adoption behaviours and collective adoption (see Chapter 5) could be compensated for by supplementing the investigation of innovation using Activity Theory. Activity Theory presents a holistic and ecological perspective on joint human activities, providing the means of studying human actions and interactions with tools (e.g. technologies) from a cultural historic and environmental view.

Activity Theory has been used as a powerful tool to interpret the work (activity) of a group as opposed to Diffusion of Innovation Theory which considers individual motivation for adoption. Potentially these theories can be combined to supplement each other and to form a framework for holistic analysis of BIM adoption and implementation activities.

6.2 Justifying the selection of Activity Theory for literature review revision

A search for another theory properly addressing the limitations of the currently used theory of Diffusion of Innovation Theory and coherent with the research design needs to meet some criteria as follows:

- The chosen theory should fill the theoretical gaps of Diffusion of Innovation Theory.
- The chosen theory should fit the philosophical perspective adopted as well as the methods of investigation, analysis and evaluation (i.e. case study) undertaken in the research.
- The combination between the two theories should bring insights to the chosen topic of BIM research and the wider subject area of construction innovations.

Based on these three criteria, Activity Theory was found to be an approach well suited to complement the weakness of Diffusion of Innovation Theory in this research. First, Activity Theory is a conceptual framework developed on the basis of Vygotsky's social constructivism (Verenikina 2010), which matches the theoretical perspective of this thesis. Also, using Activity Theory is seen as a perfect fit for qualitative research in general (Frambach, Driessen & van der Vleuten 2014) and, in particular, is appropriate for [multiple] case study design because this widens an understanding of the complex and dynamic reflective actions of two or more groups of units of analysis (Lampert-Shepel 2008). Second, Activity Theory is capable of unravelling the intricacies of a trajectory of innovation, from its early introduction through the various diffusive practices (Wiegel 2011). Activity Theory has developed a conceptual framework and systemic analytical tool specifically for studying contradiction, instability and uncertainty inherent in the implementation (or post-adoption) phase of innovation (Ferreira, Zdunczyk & Simpson 2010). Third, innovation activity, including BIM adoption, is motivated by the objects to be changed (Verenikina 2010), and any change in existing activity system is naturally contradictory and challenging (Grigoryan & Babayan 2017). Activity Theory helps to identify the sources of contradictions and enables collective learning to deal with them (Engeström 2001), for example, co-constructing knowledge of BIM to better negotiate confusing roles and responsibilities of stakeholders in BIM based projects. Last but not least, both Diffusion of Innovation Theory and Activity Theory are increasingly used as a lens to guide data analysis in BIM adoption and diffusion studies (Jayasena et al. 2019; Miettinen et al. 2018). Literature regarding both Diffusion of Innovation Theory and Activity Theory is often cited together in BIM studies including Miettinen and Paavola (2014), Mäki and Kerosuo (2015), Lu et al. (2018) and Akintola, Venkatachalam and Root (2019) but there are very few studies in which research models use a combination of characteristics from both Diffusion of Innovation Theory and Activity Theory.

Other theories, which have been used to explain the behaviour of information technology adoption or acceptance, were also compared to Activity Theory such as Institutional Theory[18], Technology Acceptance Model[19] and Theory of Reasoned Action[20]. However, these theories have some disadvantages which make them inappropriate for the study of interactions between BIM specialists and non-BIM specialists as follows.

[18] **Institutional Theory** is a theory on the deeper and more resilient aspects of social structure. It considers the processes by which structures, including schemes, rules, norms and routines, become established as authoritative guidelines for social behaviour (Scott 2004)
[19] **Technology Acceptance Model** is the theory developed by Davis (1989) assuming that when users perceive that a type of technology is useful and also easy to use, they will be willing to use it.
[20] **Theory of Reasoned Action** is a theory developed by Ajzen and Fishbein (1980) which aims to explain the relationship between attitudes and behaviours within human action. It is mainly used to predict how individuals will behave based on their pre-existing attitudes and behavioural intentions.

The key insight of Institutional Theory is imitation. Rather than necessarily optimising their decisions, practices and structures, organisations look to their peers for cues to appropriate behaviours (Marquis & Tilcsik 2016). This theory, hence, is criticised by its overwhelming focus on isomorphism (or similarity) which in turn has fallen short on adequately theorising differences across organisations (Meyer & Höllerer 2014). Also, findings in the first round of case studies in Chapter 4 showed that each stakeholder such as BIM specialist or non-BIM specialist possesses individual aims and objectives that could be in conflict with the goal of the project. In this study, Activity Theory with its potential to identify contradictions within and across activity systems, such as problems due to distinctive expectations, values and goals among project practitioners, could be a more suitable theory.

The Technology Acceptance Model has argued that people's attitudes toward behaviours and subjective criteria determine their behavioural perceptions toward technology applications, which consequently affect their own behaviour (Davis 1989). Perceived usefulness and perceived ease of use are two major factors influencing a user's technology acceptance (e.g. intention, attitude or use), and the two factors are influenced by many external variables such as peer influence or the availability of technology information (Hsiao & Chen 2016). However, this model is argued to be more appropriate for individual use and acceptance of technology rather than in a corporate or institutional application that requires integration of information technology (Ajibade 2019). This is because the Technology Acceptance Model posits that a person is highly influenced to buy and use the new technology by their peers and colleagues or by an expert recommendation through advertisement (Pantano & Di Pietro 2012). Consequently, the more employees recognise that the new technology will make their tasks easier to perform, the higher the probability they will use it and accept the new technology as being useful (Jones, Mccarthy & Halawi 2010). In contrast, the technology used in the working environment cannot be completely influenced by an employee's friends or employee's self-interest, but the company's rules guide the behaviour of the employees (Ajibade 2019). Hence, there is rule-governed behaviour for using a new technology within an organisation. Similarly, findings in the first round of case studies in Chapter 4 implied that employees are obligated to use BIM and follow their companies' rules and guidelines on how it is deployed and used to ensure uniformity in application across various internal departments. Further, given employees' desire for promotion and incentives, career advancement remains a driving force taking precedence over perceived ease of use or perceived usefulness. Due to these weaknesses, the Technology Acceptance Model is unable to accurately explain the actual usage behaviour of employees as BIM specialists under a BIM mandate by senior managers as non-BIM specialists.

The central construct of Theory of Reasoned Action is the behavioural intention of what an individual intends to do or not to do (Trafimow 2009). Behavioural intention, in turn, is determined by attitude (i.e. individual's evaluation of the behaviour) and subjective norm (i.e. individual's beliefs of what it is important other community members think they should do) (Nor, Shanab & Pearson 2008). This theory, despite being widely used for predicting individual behaviours, fails to explain collective behaviours. This is because the Theory of Reasoned Action is based on the assumption that when someone forms an intention to act, they will be free to act without limitation (Gunasinghe et al. 2019). This theory does not take into account that specific conditions which enable the performance of a behaviour may be unavailable to individuals, for example, the limited choices of tools provided by the company or organisational rules that constrain and regulate individual behaviours (Eagly & Chaiken 1993). Findings in the first round of case studies in Chapter 4 also indicate that some emergent themes such as moral issues of the unauthorised use of BIM software and the effect of habits that site people prefer to take notes directly on printed drawings rather than on virtual models have been ignored in Theory of Reasoned Action, making it inappropriate for this study.

After reviewing the published research on theoretical frameworks used most frequently in the field of innovation adoption for investigating collective behaviours, particularly post-adoption behaviours in organisational contexts, Activity Theory appears to be an appropriate lens through which to examine the interactions between BIM specialists and non-BIM specialists within and across AEC companies. Allen, Karanasios and Slavova (2011) claimed that Activity Theory allows researchers to analyse information behaviour as both an individual process of a single activity system and a collective process of two or more interactive activity systems. Further, while Diffusion of Innovation Theory has addressed the issues of informing adopters about innovation via communication channels (e.g. training, change agents, media) and conducting top-down interventions through policies or mandates, this theory may not provide a comprehensive explanation of the unsustainable commitment of end-users (e.g. staff) as this requires motivating and enabling conditions such as rules, a community of users, division of labour, long-term vision and goals, available tools and abilities to identify conflicts which possibly result in change resistance. In this case, Activity Theory is well suited to describe how human activity and the settings in which the activity is situated co-evolve over time and change the nature of future activities while participants deal with new barriers and possibilities (Akintola, Venkatachalam & Root 2019). The next few sections provide an overview of Activity Theory covering these motivating and enabling conditions for the consistency of post-adoption behaviours.

6.3 Introduction to Activity Theory

6.3.1 Key elements of Activity Theory

The third generation Activity Theory by Engeström (1987) is chosen as a theoretical lens supplementing Diffusion of Innovation Theory to interpret the activities of adopting and implementing BIM in construction companies (see

Figure 6.1). The first and second generations of Activity Theory originated within the cultural historical tradition of Russian psychologists Lev Vygotsky (Vygotsky 1978) and Alexei Leont'ev (Leont'ev 1978). The traditional Activity Theory framework only involved three principal elements: subjects, the actors engaged in the activity; tools, the instruments used in the activity; and objects, the targets of the activity. The theory proposed that any work activity is mediated by previous perceptions and behaviours (the historical cultural background of actors) and motivated by objects that take the form of tools as a medium of action in order to obtain expected outcomes (Engeström 2001).

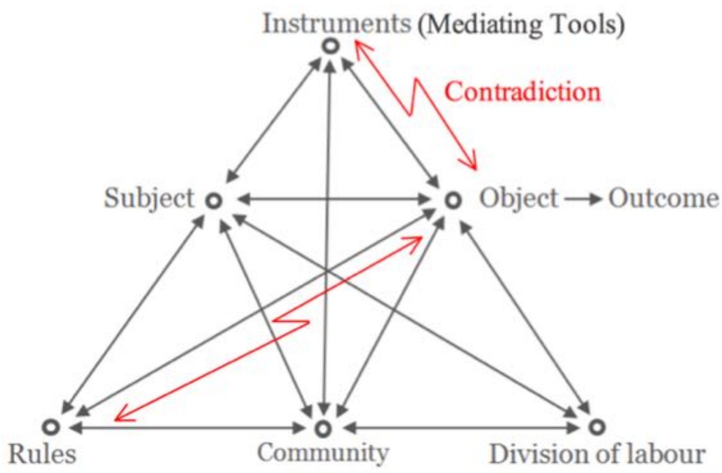

Figure 6.1 Activity Theory framework (Engeström 1987)

In the third version of Activity Theory, Engeström (1987) added three more elements that relate to social factors: rules, the cultural norms and regulation governing the performance of an activity; community, the environment or social context in which the activity is being carried out; and division of labour, the hierarchical structure of activity – the roles and responsibilities of actors in the activity system. When an activity system operates, its outcomes are not always expected results but could include unexpected results that were transformed from the contradictions emerging when the activity system's elements interact with each other (Plakitsi 2013), for example, a contradiction such as a breakdown in the activity where a tool is used inappropriately or in an unanticipated manner by the subjects (Bødker 1996). Such contradictions, however, should be seen as a source of change and development rather than problems or conflicts (Engeström 2001). The identification of contradictions in an activity system could help actors to focus their efforts on the root causes of tensions, to make proper decisions and take actions to adopt change.

6.3.2 Shared objects and outcomes

Gomes, Tzortzopoulos and Kagioglou (2017) considered the BIM environment as a collaborative platform that involves multiple parties. Assuming each group's actions are embedded in a collective activity system, the third generation Activity Theory was developed to understand the interactions to form new meanings that go beyond two or more activity systems (Engeström 2001). Gomes, Tzortzopoulos and Kagioglou (2017) used Activity Theory to understand how multidisciplinary design teams conduct collective decision making. These researchers suggest that in this situation (see Figure 6.2), two activity systems expand from object 1 to object 2 by means of a 'dialogue'. This expansion approaches both objects and outcome in a partial overlap. In cross-border activities, object exchanges and a new object 3 appears. This third object gives rise to a "seed of transformation" (Yamazumi 2006, p. 81). In other words, the newly generated third object gives rise to a driving force for the transformation of the original activity system.

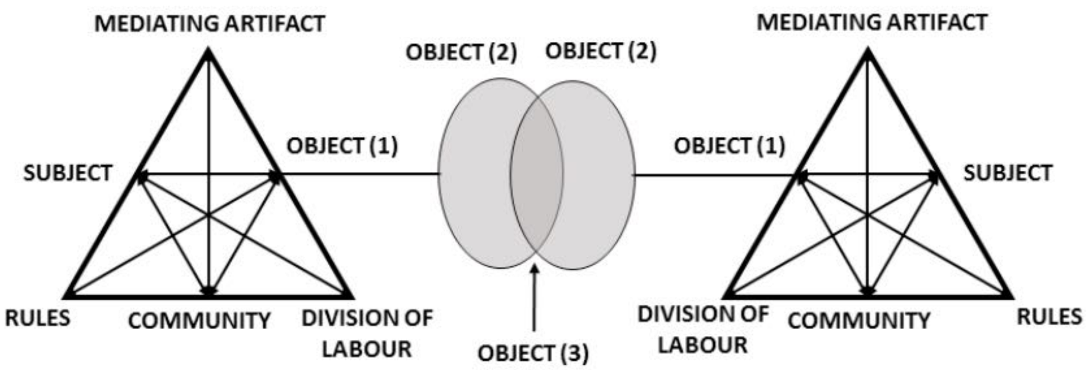

Figure 6.2 Shared or collective object between multi activity systems (Gomes, Tzortzopoulos & Kagioglou 2017)

When two or more activity systems interact, the object is only partly shared because each of the participants focuses on a different subset of its attributes and sees the object of design differently according to their special interest and their technical specialisation (Miettinen et al. 2012). Through their activities, people constantly change and create new objects. The new objects are often not intentional products of a single activity but unintended consequences of multiple activities. Engeström (2009, p. 3) called it a "run-away object". Run-away objects are contested objects that generate opposition and controversy but they can also be powerfully emancipatory objects that open up radically new possibilities of development and wellbeing (Engeström 2009).

6.3.3 Contradictions

As mentioned previously, while the term contradiction may be considered by some as a disadvantage or a flaw, Activity Theory takes the view that contradictions are a sign of richness, mobility and the capacity of an activity to develop rather than a problem to be avoided (Foot 2001). Engestrom (2001) argued that they are not simply conflicts or problems, but are "historically accumulating structural tensions within and between activity systems"(p. 137) and they generate "disturbances and conflicts, but also innovative attempts to change the activity" (p. 134). Karanasios, Riisla and Simeonova (2017) summarised four types of contradictions as below:

- primary contradictions: arising within the elements or nodes of the activity system such as subject, object, tools, community, rules and division of labour
- secondary contradictions: occurring between the nodes of an activity system
- tertiary contradictions: arising when a more culturally advanced activity within the central activity of interest introduces a more advanced object or motive
- quaternary contradictions: existing between the central activity system and the outside activity systems.

6.3.4 Boundary crossing

A boundary can be seen as a "hidden" contradiction or socio-cultural difference leading to discontinuity in action or interaction (Akkerman & Bakker 2011). As contradictions emerged between multiple interacting activity systems are unavoidable, participating subjects must move across boundaries of collaboration activities to seek and give help, to find information and tools wherever they happen to be available (Engeström & Sannino 2010). The boundary can be difficult to identify because within a community, the boundary serves to maintain socio-cultural values and facilitates the exchange of such values among community members but at the same time, the boundary prevents the easy passage of knowledge between the communities (Garraway 2010). Engestrom (2001) defined the boundary zone as a space where boundaries of different community of practices intersect. While such space is generally a place of challenge, contestation and the playing out of power relations, it can also be a potential site for new learning opportunities and new knowledge creation (McMillan 2009). In this boundary zone, participating subjects constantly negotiate and combine ingredients from different contexts to achieve hybrid situations (Engeström, Engeström & Kärkkäinen 1995).

6.3.5 Expansive learning

Engestrom (2001) linked notions of boundary crossing to the potential for a collective effort of expansive learning. He questioned the efficiency of traditional teaching or training (i.e. teacher-centred approach) in dealing with innovative issues. Traditional teaching presupposes that the knowledge or skill to be acquired is itself stable and reasonably well defined and there is a competent 'teacher' who knows what is to be learned (Engeström 2001). However, the problem is that in today's rapidly changing and competitive world, traditional teaching cannot catch up with the continuously evolving technological initiatives unless they support continuous learning and improvement (Muketha & Micheni 2020). People and organisations are all the time learning something that is not stable, not even defined or understood ahead of time (Engeström 2001). Rather than relying on a reliable source of knowledge such as formal curriculum, instructions, standards or regulations or waiting until new knowledge is updated or becomes readily available, learners can construct new knowledge together. Through identifying, understanding, resolving and negotiating contradictions at boundary zones (see Figure 6.3), learners jointly construct a new shared object and concept for their collective activity, and implement this new object and concept in practice (Engeström & Sannino 2010).

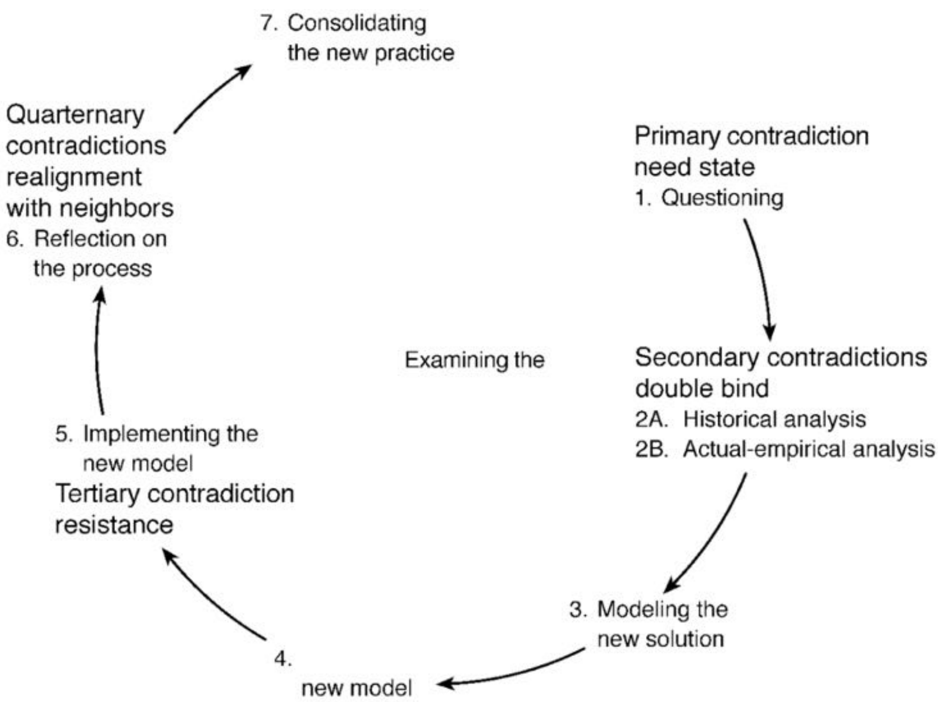

Figure 6.3 Sequence of learning actions in an expansive learning cycle (Engeström 1987)

Traditional expansive learning refers to processes in which an activity system, for example a work organisation, resolves its pressing internal contradictions by constructing and implementing a qualitatively new way of functioning for itself (Engeström 1987). Successful expansive learning eventually leads to a qualitative transformation of all components of the activity system (Engeström & Sannino 2010). However, the AEC industry with its unique nature of project-based and temporary grouping may not require that complete transformation of participating parties. The original version of expansive learning is thus simplified to adapt to temporary learning conditions, namely knot-working. The key aspect of knot-working is that it is not necessarily linked to large organisational change; instead, knot-working is a way of creating temporary teams that can work on particular aspects of an activity (Vicars et al. 2015).

6.3.6 Knot-working as a new collaborative working method

Engeström (2000) introduced the concept of knot-working as a new collaborative working practice across organisational boundaries and hierarchies. Differing from the conventional team working in which different stakeholders gather, in a planned or spontaneous manner, to work together in the same space, knot-working implies intensive collaboration for a few days at a time and after this each stakeholder is free to resume working on their respective projects in their own offices (Kerosuo, Mäki & Korpela 2013). Recently, knot-working has been restated as a new idea and an emerging practice for enhancing collaboration across organisational and team boundaries in BIM based building projects (Kerosuo, Mäki & Korpela 2015; Klitgaard et al. 2017; Townsend 2019).

The choice of knot-working as a collaborative form becomes appropriate for situations where innovation is the aim. This means people have to “learn something that is not yet there” (Engeström & Sannino 2010, p. 2) in order to address unknown issues which only occur during the cross-disciplinary interactions. For example, designers often define a model as tightly connected components to secure the consistency of change so when one component changes, other components with an interrelationship with this component change accordingly. However, this strict inter-connectedness may prevent quantity surveyors from flexibly retrieving data of specific components which cannot be priced separately. Designers may also require understanding of mathematical formula used to calculate area and volume to better communicate with quantity surveyors on cost saving alternative designs where the complex shape of components may increase the costs of execution.

Knot-working is related to activities performed by temporary groups which are the norm in construction projects. Temporary groups are understood as one-time formations created for the purpose of completing a task's objects with a clear deadline (Engeström 2000). Knot-working is a boundary crossing, collective way of organising work. Knot-working is a means for participants to construct the shared objects (Engeström et al. 2012). Each shared object is negotiated at boundary zones of different activities and is seen as a 'knot'. In knot-working, people intensively tie, un-tie and re-tie a knot within a short period of time to solve a problem or accomplish a task (Kerosuo, Mäki & Korpela 2013). When the problem or a task is solved by achieving the shared object, the knot dissolves and a new knot may be formed.

Knot-working differs from teamwork in the sense that it is connected to shared objects of activities instead of team members, and does not involve trust building or leadership among team members (Engeström et al. 2012). The practitioners and the initiators of the knot can change as the knot works towards its object (Klitgaard et al. 2017). For example, architects may withdraw from a knot if their contribution to untying this knot is far less significant than engineers or contractors. In short, knot-working suggests that partners from different activity systems interact at boundaries in ways which are not limited by the rules, regulations or normalised practices of each individual intersecting activity system (Townsend 2019).

Knot-working gives subjects the freedom to work with their tools because it is through the use and development of the tools that learning and innovation happen (Klitgaard et al. 2017). For example, one party may have a chance to try and learn from others' BIM software, allowing hands-on experiences as well as self-reflection of software compatibility and advantage (Kerosuo, Mäki & Korpela 2013). Some challenges of knot-working are identified as follows:

- Innovative activity must pursue a long-term object (e.g. 6D BIM facility management) because expansive learning (i.e. co-construction of new knowledge) may never happen in activities oriented to short-lived objects or fixed goals such as 3D BIM applications (Klitgaard et al. 2017).
- The phases of a project that require knot-working must be properly identified. In this instance, a facilitator of knot-working is needed. Normally, this facilitator must have a sound knowledge of the construction industry and be respected by others, as a senior project manager; or the contract gives this facilitator the function to set up rules and authority, such as BIM consultants hired by project owners (Klitgaard et al. 2017).
- Good preparation of all members is required beforehand (Kerosuo 2015). For example, everyone is aware of how to work as a group, how programs used by others work, and what kind of data each member needs. In their action research study of knot-working, Kerosuo, Mäki and Korpela (2013, p. 3) described that "before engaging in actual knot-working, the participants met five times in total to plan the formation of knot-working groups, the requirements for the initial data, timetables, working methods, the necessary tools, objectives to be set for the design work, assessment tools for the design solutions and the collaboration with the client and the end users".
- Another challenge is that knot-working requires solid expertise in one's own job and ability to translate jargon into understandable language to mediate the communication. However, finding suitable experts may be a challenge in future knots because their 'correctness' depends on the task of the knot, and the 'right' experts may not be assigned to the project group (Kerosuo 2015).

In short, knot-working is more appropriate for innovative activity such as BIM pilot projects where innovation is the ultimate aim and more risk tolerance is accepted, where project team members are purposefully selective such as design–build projects where the main contractor can nominate or select BIM competent partners as subcontractors, and where an experienced facilitator gets involved such as a BIM champion who is an expert on BIM and the construction industry. The project's tasks themselves are not necessarily complex, i.e. technology-based, but they are intertwined in a complex way during the project process, i.e. social-based (Kerosuo 2015). Knot-working, if applied correctly in favourable conditions, can speed up decision making and enable the different parties to commit themselves to the achievement of a common goal. This is because knot-working gives participants an opportunity to receive immediate feedback from others to ask questions, mediating an expansive learning process to understand the goals, information needs and working methods of other disciplines (Buhl, Andersen & Kerosuo 2017; Klitgaard et al. 2017).

6.4 BIM research using Activity Theory

Several researchers have applied Engestrom's activity-theoretical framework to study the conditions of implementing and using BIM in the AEC industry, for example, the study of BIM use in Finland (Miettinen et al. 2012), the use of BIM in the project lifecycle (Hannele et al. 2012), the perspectives of BIM users in the UK construction industry (Ganah & John 2016), collaboration in multidiscipline design teams (Gomes, Tzortzopoulos & Kagioglou 2017), and the implementation of BIM in the operation and maintenance phase (Lu et al. 2018). Most of these researchers agreed that Activity Theory is a theoretical foundation for the comprehensive analysis of human activity-related contextual issues of BIM uses. Miettinen et al. (2012, p. 2) argued that:

"There is a mismatch between technological and social-institutional dimensions of socio-technical development. Technological changes driven by the competitive pressures proceed while institutional changes have a stronger inertia and lag behind. New technologies are brought to organisational structures that were developed during the previous technological paradigm; thus, creating tensions between users and existing organisational structure".

Unsatisfactory consequences could result, for example almost no gains in productivity and effectiveness despite well equipped technology for employees (Miettinen et al. 2012). Miettinen et al. (2012) proposed Activity Theory as a theoretical lens to uncover such problems in order to develop further the tools and the ways of human utilisation in different phases of the design and construction process.

Ganah and John (2016) focused on the implementation stage of construction projects and argued that "BIM offers an environment in which an Activity Theory framework can be developed and used to understand not only the BIM environment but also the socio-technological nature of the project being developed" (p. 5).

Hannele et al. (2012) noted that new tools are always brought into existing [old] organisational structures and used simultaneously and interactively with traditional tools as new elements that transform the established practices and skills. However, their study showed that BIM has provided new means and demands for collaboration but expansive uses of BIM for providing new interactive processes across professional fields have not come true. For example, BIM has been adopted quite generally for design use but the old ways of collaboration seem to prevail, especially between designers and between designers and building sites. Hannele et al. (2012) applied Activity Theory to understand contradictions between old and new practices regarding BIM adoption, and what BIM means to practitioners.

Lu et al. (2018) adopted Activity Theory to investigate BIM use in building operation and maintenance due to its strength in comprehensively analysing human activity-related contextual issues. Lu et al. (2018, p. 318) noted that "in the construction industry the activity theory has also been used as a theoretical basis for analyzing the complexity and interactions of actions in projects, and interpreting the development of tools in activities".

6.5 Limitations of Activity Theory in investigating BIM research

6.5.1 Focus on contradictions

Under Activity Theory's perspective, contradictions can result in tensions but also transformation in activity systems (Murphy & Rodriguez-Manzanares 2008). Contradictions are not simply conflicts or problems, but are "historically accumulating structural tensions within and between activity systems", that is, they generate "disturbances and conflicts, but also innovative attempts to change the activity" (Engeström 2001, p. 137). As well as a possible strength, however, the focus on contradictions might be a possible limitation of Activity Theory, as there is a danger that it overshadows processes that result from congruence, while these are equally important for understanding socio-cultural dynamics (Frambach, Driessen & van der Vleuten 2014).

In addition, despite it being one of the most commonly employed concepts of Activity Theory (Turner & Turner 2001), the definition of contradiction is vague and ambiguous. Often the interpretations of contradictions are left for the readers or adopting researchers to resolve (Karanasios, Riisla & Simeonova 2017). Activity Theory provides a guideline for identifying possible contradictions occurring in interacting activity systems (Murphy & Rodriguez-Manzanares 2008) but there is no broader understanding on the types of change enabled through contradictions as well as possible solutions to addressing contradictions. Because of this, the application of this concept may be limited, and researchers may only uncover surface level contradictions or tensions, or simply identify problems but be unable to deal with them accordingly.

6.5.2 Underestimating individual motives

6.5.2.1 Activity is assumed to be more collective than individual

Activity Theory pays attention to social interactions when people use particular tools in the pursuit of a shared object (Bloomfield & Nguyen 2015). This theory assumes that studies of people's activities cannot be reduced to assessing individual or internal processes only and allows for the close examination of the interactions between human subjects and the world around them (Nørkjaer Gade et al. 2019). For example, Activity Theory provides a perspective which views contradictions as not so much rooted in the personalities of individuals but as rooted in the systems in which individuals are a part (Murphy & Rodriguez-Manzanares 2008).

However, Batarseh (2018) found that both extrinsic and intrinsic motivation drivers significantly influence individual willingness to adopt and increase BIM use. The extrinsic motivation driver is the perception that a user will use technology because it is perceived to be instrumental to achieve valued outcomes of a collective activity (e.g. teamwork) while the intrinsic motivation driver refers to an individual's intention to perform a task for its own sake (e.g. interesting and satisfying) as opposed to completing it for some other external reason (Chiu 2018). For example, top managers may employ BIM to exert control over cost and quality of projects (Jacobsson & Linderoth 2012) and expect employees to comply with a BIM mandate for collective interest (Kong et al. 2020). It is, however, challenging to align employees' motivation with such managerial attitudes because employees prefer to work in conditions with adequate autonomy and task flexibility (Papadonikolaki 2017).

As BIM has a tendency to be used more for control than as a means of innovating and developing organisational processes, users or employees may lose their motivation and commitment to adopt BIM. Similar results were found by Jacobsson and Linderoth (2012) who claimed that users' satisfaction (e.g. decision making power and job satisfaction) has a positive influence on the fulfilment of shared objects (e.g. organisational targets). They also found that sometimes even though employees initially adopted BIM [under the mandate] and agreed it could improve the company's competitiveness, they did not personally want to expand BIM uses at work. The reason for this post-adoption reluctance may be due to not meeting individuals' beliefs and expectations about consequences of BIM use (Batarseh 2018). A case study in Vietnam (Bui 2019) also showed that employees acknowledged the increased competitiveness of the company through the use of BIM but simultaneously did not think that current BIM use was well adapted to the industry's conditions mediating personal interests such as information accessibility and income.

6.5.2.2 Social interactions are not easily observed in the virtual world

The introduction of BIM as a virtual tool into the AEC industry presents a problem to Activity Theory as the boundary between tool and reality becomes blurred (Allen, Karanasios & Slavova 2011). Activities are more explicitly grounded in the real world, where architects may initially draft on computers but then communicate their design intents through physical drawings with clients and contractors. However, as simulation of functions of BIM gets better in supporting 'immersion' and the virtual aspects appear and behave more and more realistically, the boundary between virtual and real is likely to be less blurry (Pan & Hamilton 2018). Designers are dealing more with virtual objects in digital models and their social interactions are performed in a virtual environment. Sometimes designers (e.g. BIM coordinators) are even embedded in a fully virtual world in which much of their mental capacity is used to adapt to the virtual world (Fjeld et al. 2002).

Subjects traditionally transform internality (mental process) into externality (physically observable reality) via mediating tools and vice versa. For example, architects use a computer and a printer to transform their design ideas (internal thinking) into drawings (external products) while as more drawings (external products) are (re-)produced, their design styles (internal practice norms) are consistently established. Tools shape the way people interact with reality (Uden, Valderas & Pastor 2008). The use of digital tools has changed the design activity tradition, moving it towards internalisation as Bannon and Kaptelinin (2001, p. 196) argued that "information technology can provide users a sort of reality which does not obviously represent anything else [physical materiality] and is intended to be just one more [virtual] environment the individual can interact with". In other words, virtual realities could cause a problem of ill-defined activity for Activity Theory in the sense that human behaviours of social interactions may not be easily observed in the virtual environment.

In this study, perspectives of AEC professionals on BIM adoption at both the individual level and organisational level including their personal attitudes and collective reactions are examined to reflect the new form of social interactions in the virtual world (see Chapters 4, 7 and 8). This study also suggests knot-working (see Chapter 9) as a new collaborative working tool which allows decision makers or less experienced BIM users to cross boundaries between real and virtual reality. Knot-working is described as involving "encountering difference, entering into territory in which actors are unfamiliar and, to some significant extent, therefore, unqualified" (Bloomfield & Nguyen 2015, p. 35).

6.5.2.3 Lacking attributes of tools

Human activity is purposeful and carried out by sets of actions through the mediation of tools, which can be physical or psychological (Hasan & Kazlauskas 2014). According to Engeström (1987), the uses of tools are both enabled and constrained by other elements of the activity system such as rules (e.g. social norms), division of labour (e.g. system hierarchy), community (e.g. peer effect), objects (e.g. purposes) and subjects (e.g. users' competency). Tools act as a means of mediating the interactions between subjects and objects (Plakitsi 2013). The materialisation of a tool is only observed through the interactions among elements of the activity system. In Activity Theory, a tool does not have attributes, such as complexity, trialability, compatibility, observability and relative advantage, which are clearly described in Diffusion of Innovation Theory (Rogers 2003). Activity Theory avoids a techno-centric angle but this might "limit vision to the inherent properties of the tool and fail to understand its relationship with the surrounding context" (Murphy & Rodriguez-Manzanares 2014, p. 28).

6.6 Discussion: Diffusion of Innovation Theory and Activity Theory supplement each other

The advantages and limitations of BIM research using Diffusion of Innovation Theory or Activity Theory separately have been critically reviewed in Chapter 2, Chapter 5 and Chapter 6 which supports a need to combine the two theories. The combination of Diffusion of Innovation Theory and Activity Theory is proposed to take advantage of the strengths of both theories while compensating for the disadvantage of each theory when used on its own to examine innovation adoption (see Table 6.1).

Table 6.1 Diffusion of Innovation Theory and Activity Theory can supplement each other

Theory	Advantage in BIM research	Disadvantage in BIM research
Diffusion of Innovation Theory	- Describes the attributes of tools in detail - Focuses on individual decisions of adopting an innovation	- Favours technology - Promotes top-down approach (e.g. BIM mandate)
Activity Theory	- Considers tools as instruments mediating human activity to achieve objects - Considers activity as a collective of interacting individuals and communities, instead of an individual's decision	- Lacks the attributes of tools - Underestimates the role of individuals in innovation decision process
Diffusion of Innovation Theory & Activity Theory	The two theories are compatible and supplement each other.	

Source: developed from Chapter 2, Chapter 5 and Chapter 6

According to Table 6.1, the lack of tool attributes in Activity Theory is supplemented by Diffusion of Innovation Theory's technology characteristics. Factors affecting decision makers' choice of adoption, which have been neglected in Activity Theory, are also addressed by adding Diffusion of Innovation Theory's features such as personal characteristics, prior knowledge and environmental characteristics. This combination provides a better balance when taking into account the attitudes of both individuals and organisations. The strength of the technology focus of Diffusion of Innovation Theory is supplemented by the ability of Activity Theory in examining social interactions (e.g. learning and doing).

Further, while BIM research has been previously examined using Diffusion of Innovation Theory or Activity Theory separately, the combination of the two theories used in this area is still rare. Therefore, this combination provides insights for investigating BIM activities that encompass the individual, organisational and project level.

6.7 Summary

This chapter justified the selection of Activity Theory as a theoretical supplement to Diffusion of Innovation Theory for the study of interactions among BIM adopters. As the literature review evolves, it implies that the theoretical supplement is a reciprocal relation because Diffusion of Innovation Theory can also bridge the knowledge gaps of Activity Theory. The compatibility between Diffusion of Innovation Theory and Activity Theory leads to the proposal to combine the two theories to establish a more holistic analysis framework for this study.

The next chapter demonstrates the evolution of the combined framework and applies it to the analysis of the second round of case studies. Findings are validated by comparison with findings in the first round of case studies, with current studies and with products made by participants such as models.

CHAPTER 7 Findings from the second round of case studies

7.1 Chapter objectives

This chapter investigates BIM collaboration activities of BIM specialists and non-BIM specialists in the Vietnamese construction industry. As previously discussed in Chapter 3 Methodology and Chapter 4 Findings from the First Round of Case Studies, the combination of Diffusion of Innovation Theory and Activity Theory is applied to guide the analysis of the second round of case studies. Figure 7.1 shows how the evolved framework of Diffusion of Innovation Theory (see Figure 4.6) and the original framework of Activity Theory (see Figure 6.1) come together to establish the first version of the combined framework (see Figure 7.2).

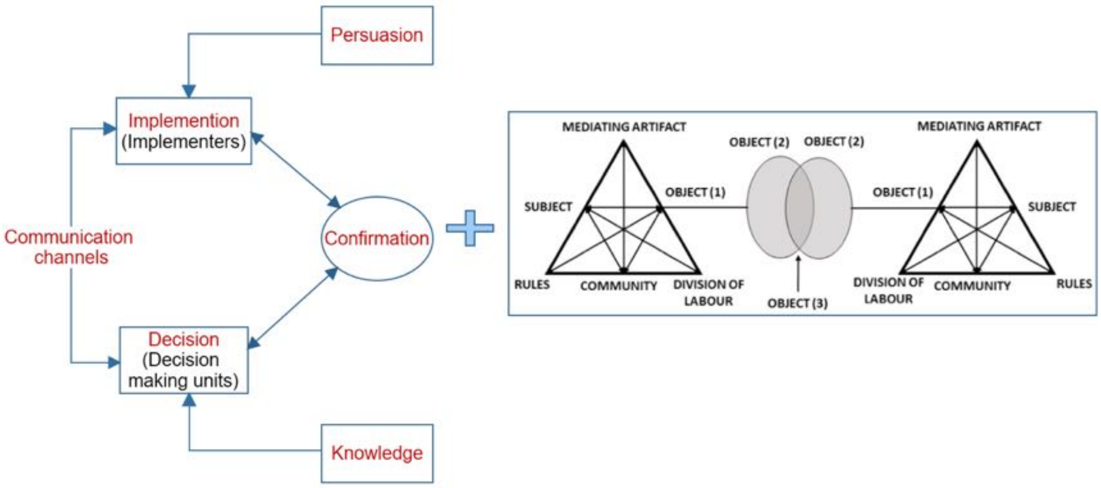

Figure 7.1 Combining Diffusion of Innovation Theory and Activity Theory- Refer to Appendix 16 for full page figure

The first version of the combined framework distinguishes the activity of innovation decision (by subjects at higher levels in the organisation) and the activity of innovation implementation (by subjects at lower levels in the organisation). Each activity system has different objects and expected outcomes which require the mediation of multiple tools (e.g. technologies and communication channels) to confirm the practice of an innovation by most stakeholders (subjects) within the organisation. In reality, a mandatory use of innovation in an organisation is likely to be accepted for a time, long enough to measure an innovation, but probably reluctantly accepted or worked around over an extended period of time (Houghton & Kerr 2011). Mandated systems (organisations) may produce a culture of conflict and opposing attitudes among system members which is considered in the following case studies.

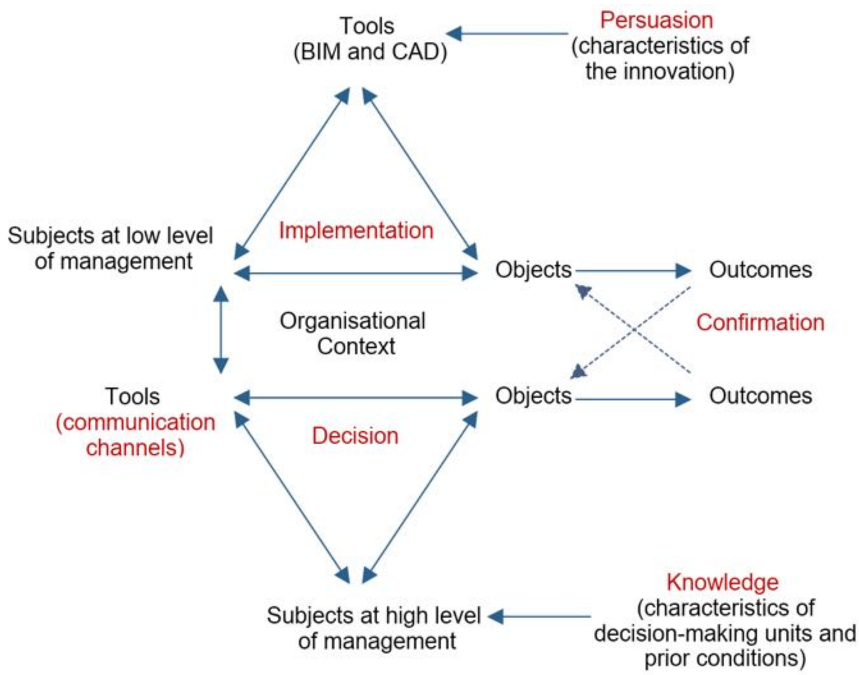

Figure 7.2 The first version of the combined framework of Diffusion of Innovation Theory and Activity Theory

Under the lens of the first version of the combined framework, this chapter aims to achieve the research objectives which accordingly generates the main themes of the study:

- To identify common **tools**, both BIM tools and non-BIM tools, used to mediate the interaction between BIM specialists and non-BIM specialists

- To identify **objects** which motivate the adoption of BIM by BIM specialists and non-BIM specialists
- To describe who (**subjects**) are responsible for which BIM adoption aspects, their abilities and shortcomings
- To examine the objects versus actual outcomes achieved through BIM interactions
- To describe the **mandatory BIM conditions** at firm level, project level and national level and their impact on project performance
- To identify the **contradictions** that emerge during BIM interactions.

7.2 Context of organisations adopting BIM in the second round of case studies

Table 7.1 provides the context of organisations adopting BIM in the second round of case studies including their name, size and scope of business, BIM tools being used, and current BIM uses.

Table 7.1 Context of case organisations in the second round of case studies

Company	Size and scope of business	BIM tools	BIM implementation
GA - Government Agency - Under the management of the Vietnamese Construction Ministry	- 10 government employees - 20 voluntary BIM specialists and industry senior managers - Conducts the national BIM diffusion program (since 2016) co-sponsored by the UK government - Influenced by the UK's BIM standards and policies	- Cooperates with BIM software vendors and developers to carry out research on various BIM tools matching the Vietnamese context	- Cooperates with project owners to conduct BIM pilot projects to get data for publishing case studies and practical experience - Supports project owners in the initial phase (setting BIM system, preparing BIM based contract, recommending BIM consultants, giving incentives)
D5 - Architecture and engineering	- 200 employees - Designs and consults on the architecture, structure, and MEP	- Architecture design: Revit - Structural and MEP	- In-house design management - Not mandatory to use BIM

design company - Local private owned enterprise	engineering of high-rise projects - Offers project management service	coordination: Navisworks	- Does not include BIM in business scope - No plan to develop BIM team
D₆ - Engineering design and advisory company - Global enterprise (100% foreign capital)	- 7,500 employees - Designs and consults on projects of MEP engineering, energy, underground and geotechnical engineering - Environment and planning advisor - Infrastructure advisor	- Architecture design: Revit and Navisworks - Structural and MEP design: Tekla - Design management: BIM 360 Team - Programming: Dynamo	- In-house design management - Mandatory BIM application for MEP engineering design - Provides CAD/BIM services from 2D to 6D - Has R&D department to develop BIM tools
C₂ - Construction company (general contractor) - Local private owned enterprise	- 500 employees - Designs and constructs residential, office and commercial buildings	- Architecture design: Revit - Structural design: Tekla - MEP design: Revit and Navisworks - Project management: Synchro - Site management: BIM 360 field	- In-house design management - Established BIM centre in 2013 - Mandatory BIM application for all Design and Build projects (since 2016) - Focuses on BIM for coordination: clash detection and site arrangement - Experiments with BIM for site safety
O₂ - Owner - Local private owned enterprise	- 700 employees - Invests in real estate properties for sale and rent: office, residential and commercial buildings - Develops industrial parks, transport infrastructure and social facilities - Invests in tourism and accommodation services	- None	- Hires BIM specialists to report BIM progress - Adopts BIM to respond to the mandate of government

Note: small size (10–100 employees), medium size (100–200 employees) and large size (>200 employees) based on the classification of the Vietnamese government[21].

21 https://english.luatvietnam.vn/ecree-no-39-2018-nd-cp-dated-march-11-2018-of-the-government-on-detailing-a-number-of-articles-of-the-laws-on-small-and-medium-sized-enterprises-160820-Doc1.html

7.3 Units of analysis

Table 7.2 presents the units of analysis of case studies including BIM specialists and non-BIM specialists within case organisations. To maintain confidentiality, names of companies and respondents were coded. The abbreviations TM, MM and E represent the position of participants in the company of top management, middle management or employee, whereas D, C, O and GA refer to the type of organisation such as design company, contractor, owner or government agency. For instance, the full code MM_1D_5 means participant 1 at middle management level at design company 5. The background of BIM specialists and non-BIM specialists is illustrated in Table 7.3 and Table 7.4 respectively.

Table 7.2 Units of analysis for the second round of case studies

Company	Participant	Position	BIM role
GA (Government Agency)	- GA_1, GA_2	Government agents	Non-BIM specialist
D_5 (Design)	- MM_1D_5, MM_2D_5, MM_3D_5 - E_1D_5	Middle management Employee	BIM specialist BIM specialist
D_6 (Design)	- TM_1D_6 - MM_1D_6 - E_1D_6	Top management Middle management Employee	Non-BIM specialist BIM specialist BIM specialist
C_2 (Contractor)	- TM_1C_2, TM_2C_2 - MM_1C_2, MM_2C_2 - MM_3C_2, MM_4C_2 - E_1C_2	Top management Middle management Middle management Employee	Non-BIM specialist BIM specialist Non-BIM specialist BIM specialist
O_2 (Owner)	TM_1O_2 MM_1O_2	Top management Middle management	BIM specialist BIM specialist

Total: 5 organisations with 11 BIM specialists and 7 non-BIM specialists

Table 7.3 Background of BIM specialists in the second round of case studies

Participants	Position	Specialty	Industrial/BIM tool experience (Years)
MM_1D_5	MEP leader	MEP engineering	5-10/3-5
MM_2D_5	Head of structure	Structural engineering	20+/3-5
MM_3D_5	BIM leader	Architecture	3-5/1-3
E_1D_5	BIM modeller	Structural engineering	1-3/1-3
MM_1D_6	Head of MEP	MEP engineering	10+/10+
E_1D_6	BIM coordinator	MEP engineering	10+/10+
MM_1C_2	BIM manager	Architecture	10+/5+
MM_2C_2	BIM leader of project	Structural engineering	10+/5+
E_1C_2	Site engineer	Civil engineering	10+/5+
TM_1O_2	Project director	Architecture	10+/5+
MM_1O_2	Owner's representative	Architecture	5+/3-5

Total: 11 BIM specialists

Table 7.4 Background of non-BIM specialists in the second round of case studies

Participants	Position	Specialty	Industrial/BIM tool experience
GA_1	Change agent	Structural engineering	1-3/0
GA_2	Change agent	Structural engineering	1-3/0
TM_1C_2	Site manager	Civil engineering	15+/0
TM_2C_2	Deputy site manager	Civil engineering	10-15/0
MM_3C_2	Site supervisor	Civil engineering	10+/0-1
MM_4C_2	Site supervisor	Civil engineering	10+/0-1
TM_1D_6	Project manager	MEP engineering	15+/0

Total: 7 non-BIM specialists

7.4 Summary of findings

Table 7.5 summarises the findings in the second round of case studies.

Table 7.5 Summary of findings in the second round of case studies

Main themes	Sub-themes	Sub-sub-themes
Theme 3: Mediating tools of BIM activities	Tools used in BIM implementation activity	- *Traditional communication tools are dominant* - *Digital tools do not actively enhance communication on site* - *Site engineers are key medium for communicating BIM data*
	Tools used in BIM adoption activity	- *Lack of experience in creating BIM Execution Plan* - *Revision of BIM Execution Plan is not considered important*
Theme 4: Objects of BIM activities	Multiple objects in BIM implementation activity	- *Inefficient communication of technical intentions* - *Only sharing objects with specific partners*
	Unclear objects in BIM adoption activity	- *Over-specify goals* - *Lack of competencies to comply with specific objects*
Theme 5: Subjects of BIM activities	Organisational characteristics affecting subjects of implementation activity	- *Division of labour (social hierarchy)* - *Rules (cultures or norms)* - *Community (places where actors play their roles)*
	Personal re-evaluation affecting BIM implementation activity	- *Meaningfulness* - *Feeling useful* - *Open opportunities*
	Environmental characteristics affecting BIM adoption activity	- *Social influences* - *Market demand* - *Culture*
	Personal characteristics affecting BIM adoption activity	- *Innovativeness* - *Socioeconomic status* - *Communication behaviour* - *Formal education*
	Prior knowledge affecting BIM adoption activity	- *Previous practice* - *Felt needs/problems to change* - *Organisational norms*
Theme 6: Outcomes of BIM activities	Outcomes of BIM adoption activity	- *Perceived benefits of BIM vary for different types of clients* - *Balanced framework of monetary and managerial outcomes* - *Diffusion of policies in favour of BIM adoption*
	Outcomes of BIM implementation activity	- *Automation* - *Collaboration* - *Work efficiency* - *Redundant files* - *As-built inconsistency* - *Not having formal role description to determine the outcomes*
Theme 7:	BIM mandate is not properly enforced	- *Still using old communication methods* - *BIM mandate is not rooted in practice*

Mandatory settings of BIM activities	BIM mandate affecting BIM implementation activity	*- Limitations of internal capacity to comply with BIM mandate* *- BIM mandate does not consider human-related factors*
Theme 8: Contradictions occur during BIM interactions	Contradictions of scope of work	*- Who is the leader of BIM adoption?* *- Responsibilities of BIM deliverables*
	Contradictions of time	*- BIM modelling requires more time* *- Modelling may not save time in custom design* *- Single discipline finds it easier to adapt to BIM* *- Cross-disciplinary collaboration is more challenging*
	Contradictions of costs	*- Costs of BIM implementation* *- Cost saving in BIM based project*
	Contradictions of quality	*- Quality of virtual models* *- Quality of physical works*

There are five theoretical themes identified through the lens of the combined framework of Diffusion of Innovation Theory and Activity Theory including tools, objects, subjects, outcomes and mandatory setting. Each main theme contains sub-themes and sub-sub-themes which reflect the behaviours, perspectives and interplay between participants regarding their actual BIM implementation in projects. Subsequently, the emerging theme of contradiction occurs as a result of dynamic interaction between the five elements of tools, objects, subjects, outcomes and mandatory setting.

7.5 Reporting the findings

7.5.1 Theme 3: Mediating tools of BIM activities

Adopting the combined framework (Figure 7.2), this study divides BIM activity into BIM adoption activity and BIM implementation activity. While BIM implementation activity (e.g. 3D modelling and BIM coordination) was undertaken by BIM specialists and non-BIM specialists at employee level, BIM adoption activity (e.g. making a decision on mandating the use of BIM in a company or a project) was carried out by non-BIM specialists at top management level such as senior managers, project owners and policy makers.

7.5.1.1 Tools used in BIM implementation activity by BIM specialists and non-BIM specialists at employee level

7.5.1.1.1 *Traditional communication tools are still dominant*

This section describes the traditional means of construction communication which are mainly adopted in case study companies including face-to-face communication, oral presentation, phone, email, text message, paper-based drawings and mobile apps using WIFI/3G.

Construction management and the collaboration between the site team and the BIM team included a lot of **face-to-face communication**. One site supervisor explained that *"as site workers are often seasonal, temporary, low skilled and low paid, it is less likely that they will participate in further training of BIM. Face-to-face talks are preferred to make sure that site workers don't miss our instructions"* - MM_3C_2. Face-to-face interactions were especially useful for building the confidence of early BIM adopters such as site engineers on site. The presence of BIM team members on site encouraged site engineers to test and try various BIM applications with less concern of making mistakes. *"BIM specialists were assigned to work side by side in the construction site. Information and hands-on experience can be asked face-to-face instead of using remote communication tools or waiting for proper meetings"* - MM_4C_2. Another site engineer confirmed that *"the challenge of adopting new technology is reduced due to the instant backup of the BIM team with competent specialists for all disciplines"* - E_1C_2.

The culture of 'being afraid of losing face' makes communication frustrating because it is difficult to acknowledge individual or organisational shortcomings in front of other parties, whereas making that admission via **email** might be easier. Further, site managers were found to be reluctant to use the model. They were found to take a glance at the computer screen and say *"okay, you look at the model, but… then come closer to the traditional drawings on the wall and continue their discussion"* - MM_2C_2. The conclusions at the end of the meeting, of problem-solving or a plan, were **orally announced** by site managers.

The site manager spent a lot of time on the **phone**, which could be considered as verbal communication, while not face-to-face. If a person could not be reached by telephone, the site manager sent them an **email** or **text message**. *"Regular meetings and telephone calls are the most preferable method of communication and data exchange on site. Other methods such as emails and text messages are also conducted with a high frequency"* - MM_2C_2.

Paper-based drawings are still the dominant means of construction documentation and visualisation because it is difficult to directly take a measurement on 3D models unless carrying a tablet with built-in BIM apps all the time. *"Builders identify and calculate actual measurements of length, perimeter and area from scale diagrams. Site engineers can also sketch a few items as well as write comments on drawings as annotations for builders"* - MM_3C_2. With 2D, the project information is in the drawings. The drawings are the data, and these drawings are primarily a collection of lines, circles and text. Symbols and abbreviations are added to scale diagrams to ease the reading of data and avoid too much information written on the detailed plans. A common misunderstanding is to assume that when information models are created, 2D drawings are not needed. *"It is certainly possible to extract much information from an information model, to provide guidance for the construction worker, but that requires software (e.g. BIM 360 field), hardware (e.g. tablets) and skills"* - MM_1D_5.

The Vietnamese AEC professionals also use **Zalo**, which is similar to the WhatsApp application on smart mobile devices, to communicate in their daily work. Zalo is 'freeware' which allows users to send text messages and voice messages, make voice and video calls, and share images, documents, user locations and other media. However, it is not considered a formal or secure communication method as it operates on a social media platform. Data retrieval is also not its main function. More importantly, *"users are easily distracted at work by others' online activities"* - MM_2C_2. Zalo is convenient for instant contact to ask for more details about the work or report urgent situations. Site people can send the pictures or clips of the part of work they are unsure of to the BIM team to get help. The BIM team can then notify the solutions or changes to site people to make preparation beforehand but *"the approved change orders (in the form of authorised and signed papers) and site meetings are still required to avoid disputes"* - MM_1C_2.

7.5.1.1.2 *Digital tools do not actively enhance communication on site*

This section explores the causes of ineffectively communicating through digital tools such as the inability to convey non-verbal cues or return to previous communication behaviour during a tight schedule, not including construction knowledge, lack of skilled workers, not flexibly supporting brainstorming, and imbalance between data mining skill and modelling skill.

Despite the support of 3D BIM representation, resolving errors or creating new design solutions still requires face-to-face meetings to facilitate inquiry, interpretation and in-depth discussion of the issues. Digital tools cannot convey **non-verbal cues** of senders in the message which may lead to the misunderstanding of receivers. In other words, *"technology cannot adequately convey emotion"* - MM_3D_5. For example, when BIM specialists found design clashes, they sent an email attached with an error-listing file extracted from BIM models to the relevant designers. Designers may feel upset because they think the email was written in a rude tone and respond with an email in the same tone of voice, causing a back and forth of unhelpful emails. BIM specialists simply notified the facts they observed in the models and expressed them in a 'straightforward' or 'frank' way. *"People may choose the wrong words to communicate their opinions via electronic devices, especially a dispute about who is at fault. When this is the case, people definitely need a direct conversation to see the posture and facial expression of each other"* - MM_1D_5.

Collaboration between the BIM team and the site team was typically incomplete if the site team was **busy or had a tight schedule**. *"Don't assume site people read reports or standards, especially when time overruns"* - MM_1D_5. A BIM manager suggested that *"it's easier to ignore an email than a meeting. Having a face-to-face meeting makes it easier to have clarity, even if everyone isn't physically in the same room (using digital conferencing platforms)"* - MM_2D_5.

During the design stage, the contractor's method of working was not considered. For example, the erection sequences or installation spaces were not described in BIM models. A site supervisor declared that *"no matter a good model is delivered to site, it is less useful if it does **not integrate the construction knowledge** in the design process. That's why we still rely on traditional dialogues to address constructability issues on site"* - MM_4C_2. On the contrary, a BIM leader of a design company explained that *"we just show site people how the final product would be and left the decision of how to make it to them. We are not experts in construction and it is also not our scope"* - MM_2D_5. Another BIM leader stated that *"while builders blame that our designs are less practical and not detailed for performance, they rarely conform to our instruction but spontaneously make changes to meet the deadline"* - MM_1D_5. As the result, it was observed that the effort of the BIM team was not valued by the site team, and BIM models were not directly used on site but only seen as a reference source for construction plans. Further, the *"site team often organises internal face-to-face meetings to interpret our design's intentions against their construction plans but rarely invites us (designers) to join"* - MM_2D_5.

Conventional communication was preferable because *"site engineers did not perceive it necessary to extensively diffuse BIM models to people with **low IT skills"*** - E_1C_2. BIM was mostly used within the group of site engineers. Subcontractors work effectively with a 2D representation of the project but not many of them are able to work with BIM. Site engineers transferred 3D models into 2D shop drawings again which were later disseminated at the construction site using oral and face-to-face conversations to allow all people, especially manual workers, to easily understand the construction works.

Project stakeholders can observe and understand the conflicting situations better through 3D visualisation. However, 3D BIM models did **not effectively support brainstorming** to resolve conflicts among multiple disciplines in BIM coordination meetings. Whiteboards, sticky notes, markers and flip charts are still considered as popular tools for collaborative brainstorming. For example, a senior manager of a main contractor company stated that *"project teams used flexible and malleable mediums such as whiteboards and paper-based drawings to manifest ideas quickly. They also used abstracted visualisations to support discussion"* - MM_1C_2.

Creating a data-rich information model is as important as having **data mining skills**. A 3D design model becomes less useful if the end-users such as site teams cannot extract data from this model for their construction uses. In order to facilitate data mining by end-users, data has to be standardised, organised and unified by the creators of the 3D model (e.g. architects) and there is a need to upskill end-users with the knowledge to collect, process, analyse and retrieve information from the model. A site engineer argued that *"architects often give priority to 3D visualisation rather than to consistency in information handover protocols which makes it difficult to promote the use of BIM on site"* - E_1C_2. On the contrary, a BIM specialist claimed that *"on site engineers are busy on the field work and they don't have sufficient time to improve their data mining skills to exploit the model passed from architects"* - MM_1C_2.

7.5.1.1.3 *Site engineers are key medium for communicating BIM data*

Site engineers are among the first target adopters on site but site engineers did not reach their potential of diffusing BIM because of a steep learning curve, unproductivity due to redundant information, wasting time waiting for 'error-free models' from designers, and resistance to changing their communication habits.

The second round of cases studies showed that site engineers are the main BIM users on site. Instead of having only one design at the site, site engineers had to use multiple models and software programs to accomplish their tasks. While being given less support from site managers, site engineers were struggling to communicate with the 'BIM laggards' such as manual workers and subcontractors. It became their responsibility to deliver the information from the models designed by the BIM team to the different assemblers and site workers. This was a complex task due to several reasons. First, it takes time for a **learning curve** in both theory and practice, hence site engineers inevitably made mistakes such as models with errors or incomplete models and lost 'trust' from their managers and workers. BIM specialists, such as E_1C_2 and MM_2C_2, admitted that the site engineers of each project were the first adopting group to be targeted. *"The proximity to site and the position between site managers and workers make site engineers easier to communicate with most people working on site. If well trained, site engineers would be a medium of communicating BIM data over the site"* - E_1C_2. However, site engineers were only provided with short courses and on-the-job training due to the tight schedule and budget. They need more time to mature their BIM skills. Another BIM specialist commented that *"site engineers have potential to become change agents of BIM. As they are not formally educated in BIM, additional time is required for them to prove their ability"* - MM_2C_2.

Second, there were many instances of **redundant information** in the BIM models for the site team, making them difficult to use. The same BIM model that was developed by the BIM team was passed to the site team, however the information used by the BIM team encapsulated a high level of detail which was beyond the needs of the site team. A site engineer found that the long lists of clashes printed out from the integrated model to be problematic. *"It is not possible to identify the real design errors on the lists because the real design errors were in danger of being lost among small and non-significant errors"* - MM_3C_2. Another site engineer agreed that *"the models we deal with contain so much information. People often talk about coordination as if it was only* *clash detection, but quality assurance is so much more. BIM specialists have to assure that the required information is in the right place in a model"* - MM_4C_2.

Thirdly, on site practices accept some geometric clashes, such as pipes recessed in walls, and site engineers could flexibly allow work to continue while updating the solution on the site in the model through comments on an indentation or small hollow to notify people concerned. However, the BIM contract required the generation of **error-free models** which is a very time consuming process due to revision or redesign. As the result, the BIM models were late in being handed over from the designers to the construction site and, accordingly, BIM models could not keep track of as-built updates and failed to build confidence for site people to adopt. *"Creating error-free models is impossible and also not necessary. Firstly, data can be lost during the export and import processes. Secondly, most construction works are operated by manual labourers which possibly have more errors than computer simulation"* - MM_2C_2.

Site engineers were considered as target adopters on site when BIM specialists initially attempted to diffuse BIM over construction sites. This is because a site engineer plays an intermediary role in *"looking for and sending information from BIM models to non-BIM specialists such as site managers, workers and subcontractors"* - MM_3C_2. However, the steep learning curve associated with BIM impedes site engineers from fulfilling their communication roles. Site engineers were unable to manipulate BIM models independently without the support of BIM specialists. In some cases, the site engineers simply notified that *"there is something missing or something wrong with the model, but they were unable to solve the problem"* - MM_4C_2. The **communication habits** of site engineers also impacts their behaviours of data exchange. A BIM specialist said that *"they [site engineers] firstly discussed with their colleagues (even those in different project teams or companies); then asked for advice from site managers, and later submitted the RFI (request for information) to the BIM team and waited for the responses"* - MM_1C_2.

7.5.1.2 Tools used in BIM adoption activity by non-BIM specialists at management level

7.5.1.2.1 *Lack of experience in creating BIM Execution Plan*

A BIM Execution Plan (BEP) is a tool to provide a standardised workflow and general guidance for strategic BIM implementation in a holistic approach for a particular project. It outlines the overall project vision, defines BIM uses, and serves as a record of agreement among stakeholders about their roles, and responsibilities, and the specific information transferring between them (see Section 2.2.1.7 for more details). This section provides two reasons for a poor BEP in the case study companies: the lack of experts qualified to develop an effective BEP; and concerns about contractual liability and duties associated with a BEP.

The use of a BIM Execution Plan (BEP[22]) is not standard on most medium to large scale construction projects. In particular, top management groups in the case companies showed their lack of experience in preparing a BEP which leads to time consumed searching BEP templates for advanced BIM users or expensive consulting with BIM experts. A BEP is important because the confusion of BIM roles among project stakeholders may lead to inconsistent project performance such as conflicting priorities or duplication of effort. There is the issue of who authors a BEP. Having a single qualified BEP requires someone with a **lot of expertise** with knowledge about every software package used on the project and contract law. However, *"those responsible for enforcing a BEP (e.g. BIM team) rarely have even a small part of that expertise"* - TM_1C_2.

Moreover, top managers of AEC firms were reluctant to prepare a BEP due to **contractual liability and duties**. The client often demanded contractors compile a formal BEP, usually based on someone else's BEP, which includes

[22] A BIM Execution Plan (BEP) is a comprehensive document that helps project teams identify and execute the role BIM plays in the various phases of construction management.

many elements unknowable at concept design. *"The client doesn't understand the BEP they demand we mimic because it is so complex and technical. Either we leave it out and not get the BEP approved to commence site works or make something up that may or may not happen and end up being held responsible when it doesn't"* - TM_2C_2. Similarly, another senior manager disclosed that *"we end up with a situation where the BEP is left in the drawer, either too hard to do, or done by an underling with no authority. Or even worse, a BEP done by an outside BIM consultant with no responsibility for its effects on the project (you know, the thing we are actually building), and ends up being a millstone around everyone's neck"* - TM_1C_2.

7.5.1.2.2 *The revision of BIM Execution Plan is of less concern*

Currently, the creation of a BEP[23] is assigned to the BIM team of main contractors or the BIM consultants hired by the project owners. The BEP provides for the establishment of protocols for the development, use, transmission and exchange of digital data, and defines expectations of Level of Development for model elements at various milestones of the project (McArthur & Sun 2015). Theoretically, the BEP stands as a guiding tool to outline the overall vision along with implementation details for the team to follow throughout the project. The BEP should be developed in the early stages of a project, continuously developed as additional participants are added to the project, and monitored, updated and revised as needed due to the increasing complexity during the implementation phase of the project (Messner et al. 2010). But rather than the BEP being a 'living document' requiring constant reviews and updates by all parties throughout the project lifecycle, there is only one BEP version specified in the entire project. The reasons were identified as below.

[23] The BEP is often prepared by the BIM consultants hired by the project owner in Design–Bid–Build projects or by the BIM team of the main contractor company in Design–Build projects. See Chapter 2, Section 2.2.1.7 for more details.

First, because the current BEP includes everything, right up to facility management, nobody takes them seriously at the start of a project. *"When people actually commence their work following the initial 'agreed' BEP, they would like to renegotiate some terms in the BEP but it's too late for major change"* - MM_2C_2.

Second, **legal problems** could affect the revision of the BEP. *"Remember we are talking about a single plan covering everyone in the project. Any change requires the participation and agreement of everyone – even if the change doesn't materially affect them"* - MM_1C_2.

Third, the BEP is issued as **a specification of compliance** rather than as a collaborative plan. Ideally, a BEP is written by a project stakeholder who has high power to make decisions or impacts on the projects such as a main contractor or a project owner but other project teams (e.g. design firms and subcontractors) have authority to collectively develop a BEP as the BEP also impacts their BIM collaborative working. However, it was found that the main problem still occurs in the development of a 'collaborative' plan. Often, less powerful project teams experienced this problem when told *"just do what I said because I'm in charge or I know more than you do or I'm bigger than you"* - MM_2C_2.

7.5.2 Theme 4: Objects of BIM activities

7.5.2.1 Multiple objects in BIM implementation activity

7.5.2.1.1 *Inefficient communication of technical intentions*

Poorly conceived communication breakdown meant the unintentional failure of one party to convey their intentions to another led to misunderstanding among creators and receivers. For example, BIM specialists (e.g. architects) created the models in their own way, added information (e.g. parameters) in the models and expected downstream customers who used them (e.g. site engineers) could understand their technical intentions and possibly retrieve and use these data-rich models for subsequent work. However, a site manager argued that *"yes, architects might feel professional pride when much more* *information was added and available here [BIM models, but this information stays hidden for construction workers on site"* - TM_2C_2. Other site manager claimed that *"most models don't seem to provide enough information, or are too generic and are not specific enough for specialised tasks"* - TM_1C_2.

7.5.2.1.2 *Only sharing objects with specific partners*

Objects were not equally shared among BIM specialists. The architects shared BIM objects such as better coordinated documents primarily with structural engineers and to a lesser extent with the owners of the projects and the contractors. The site engineers stated that they only shared BIM objects with the architects. The structural engineers mainly shared BIM objects with architects and seldom with MEP engineers and subcontractors. The MEP engineers only shared BIM information with architects and the owners. The contractors indicated they generally shared BIM objects with all the other disciplines, mostly with architects, engineers and owners. As expected, structural engineers and contractors were the only disciplines that shared BIM objects with subcontractors. Overall, the case studies indicated poor collaboration among the various stakeholders driven by their asymmetric exchange of objects and scopes of work. *"Sharing data is the core activity of BIM adoption but this activity is not performed in a proper and equal manner. Close partners and sponsors likely received the data first, and with higher quality and quantity"* - MM_1D_6. This is because BIM participants not only share the data but also have responsibility for explaining the uses of data to receivers, which is very time consuming and less beneficial if receivers are strangers in a one-off project.

7.5.2.2 Unclear objects in BIM adoption activity

7.5.2.2.1 *Over-specifying goals*

In considering the objectives of BIM adoption, it is observed that decision makers mandating the use of BIM overlooked two factors: first, setting unrealistic requirements; and second, being unwilling to pay extra fees to cover the additional work to meet their high requirements.

Still decision makers such as owners, senior managers and government agents were blamed for the poor performance of BIM. The main reason is from the lack of clear BIM objectives made by decision makers (usually non-BIM specialists) in declaring their information requirements at the outset, or at any point later in the project setup. For example, clients who **over-specified goals**, without an understanding of how the data will be generated, managed and used likely made the preceding BIM efforts of BIM specialists useless. Some clients tried to play it safe by asking for 'full BIM' or 'fully integrated BIM' without the slightest idea how such elusive deliverables may benefit them. *"Clients include BIM requirements in their project brief without exactly knowing what they want"* - E_1D_5. Another BIM specialist similarly noted that *"descriptions such as 'full BIM' are misleading and need to be taken out of any document that's contractually binding. Instead, we offer them an open dialogue to uncover what they expect out of BIM"* - E_1C_2.

One BIM specialist perceived that *"a client requiring a high level of detailed models and BIM uses can be responsible for compensating for additional design work"* - E_1D_5. However, clients as non-BIM specialists are reluctant to pay extra fees for BIM requirements as they assume that BIM users have experienced both short and long term economic benefits by using BIM such as saving time due to the automatic generation of drawings and reports, design analysis and schedule. Responding to BIM requirements (objects) should be an ongoing negotiation between BIM specialists and non-BIM specialists through the project lifecycle (see Figure 7.2). *"Only through conversation, we can establish the appropriate level of BIM (outcomes) that matches the aspirations of the clients within a certain budget"* - MM_2D_5. Given that 'true' BIM specialists avoid overselling what BIM can do for clients, they cannot always disappoint clients by refusing their demand. *"Clients have the right to demand a highly customised product, but a surcharge may be applied for extra BIM work"* - MM_1D_6. A BIM specialist, however, conceded the **difficulty of declaring the extra bill**. *"We often accept non-profitable tasks to satisfy some clients' over-demand to keep the relationship and get the contract if our team can do it (despite challenges)"* - MM_2D_5. But when that demand is outside the capacity of BIM specialists, an extra payment for hiring third parties (outsourcing or consulting companies) to support BIM specialists is required. It was a sensitive issue that might upset clients who perceived that BIM specialists aimed to seek profit from them.

7.5.2.2.2 *Lack of competencies to comply with specific objects*

This section demonstrates the limitation of both non-BIM specialists and BIM specialists regarding BIM competencies required at a high level of BIM maturity. In particular, non-BIM specialists are not equipped with sufficient BIM knowledge to realise the full benefits of BIM deliverables according to their requirements while BIM specialists struggle with balancing BIM efforts and reasonable prices as immature BIM managerial and technical skills result in high service fees.

The demand of non-BIM specialists (e.g. clients and public sector officers) was currently recognised as a motivation and drive for digital transformation of the construction industry. However, most BIM specialists, such as MM_1D_5, MM_2D_5, MM_1D_6, TM_1O_2 and MM_1O_2, argued that it is also important for non-BIM specialists to develop their required competencies to support the BIM implementation process and help achieve the desired objects of BIM. This is not easy to achieve as, for example, client organisations need to have improvement plans that allow them to gradually build capacity within their practices before being able to effectively work with their supply chain to meet their BIM requirements. *"BIM champions such as BIM consultants were emphasised as a critical factor helping non-BIM users to take the lead of the BIM training and set up the BIM vision"* - MM_1D_5. Through the interviews, it was highly recommended non-BIM users should have some competencies: necessary 'BIM skills'; understanding what the 'BIM technology' can deliver; what possible 'data sharing' methods can be used; and how 'BIM standards' can be used for specific purposes. A BIM manager stated that *"BIM allows us to do many things, but that doesn't mean that it always makes good business sense to do all these things. Clients need to be trained to understand this reality and better manage their objects against outcomes"* - MM_1D_6.

On the contrary, another BIM manager admitted their limited competence in meeting the high requirement of clients. *"A balance needs to be found between the potential value-add of BIM to the clients and the in-house capacity we have to deliver such value"* - MM_3D_5. Many AEC companies only offered BIM for internal reference because they had not reached a level of BIM maturity where applying BIM costs them less than applying a traditional CAD method of delivery. *"BIM requires substantial upfront investment that you can't pass to the clients. I don't think you can charge a premium for BIM, and this is what regulates the competitive market"* - MM_2D_5. Also, it is not reasonable to explain to clients the incompetence of implementing BIM due to high cost. *"Clients don't care what tools you are using actually. Delivering documentation based on BIM has now become less of a distinguishing factor than a means to secure repeat business"* - MM_3D_5.

7.5.3 Theme 5: Subjects of BIM activities

7.5.3.1 Organisational characteristics affecting subjects of BIM implementation activity

7.5.3.1.1 *Division of labour (organisational hierarchy and roles)*

This section elucidates that the fragmented communication between site and office-based staff as a result of a traditional division of labour could hinder the joint involvement of non-BIM specialists in the site team during the BIM process driven by BIM specialists in the office team. The root causes of fragmentation are the loose control between sites and head offices, the centralised decisional power of site managers, resistance to change by site teams, and the ambiguous position of the BIM team on site.

Site teams often work in remote areas which have infrequent connection with and support from the head office. *"There is **loose control** over communication and management between the site and the head office. Due to long travel time, office staff don't make frequent visits to site for necessary inspections. The BIM mandate, thus, has less impact on site works"* - TM_1C_2. This fragmentation enables a high degree of local autonomy of site teams which may frustrate the effort of head office to promote BIM on construction sites.

A site manager has a hierarchical position between the top management (e.g. company directors) and the employees (e.g. site engineers). Site managers traditionally **have absolute power** on the whole building process, making decisions on whether to adopt BIM design models. Unexpected situations were perceived as usual in the construction phase and the problem-solving relied on site managers' experience. While the work practices may vary, the site managers shared a common goal to *"keep the production going, no matter what the circumstances are and what tools (either CAD or BIM) are being employed"* - TM_1C_2. Site managers retained the centralised decision making to assure a single direction over multiple subcontractors and suppliers. Changes frequently occur on site, for example, if material does not arrive on time, if personnel resources are not available or if other circumstances force the site team to leave the intended path. *"We have to manage all these changes and stay on a steady pace. Trusting and sharing the authority to the BIM team who is seen as an outsider is risky"* - TM_2C_2. Also, there will often be new insights, 'last minute changes' or freshly developed issues which force the site managers to look for ad hoc solutions. Clients tended to believe that changes are still possible as long as the concrete is not poured. But the complex chain of supply and specialised crafts make it difficult to see what type of changes can still be put in effect, and what type of changes will definitely disrupt the schedule in the model for the following weeks. *"The centralised management helps us to react quickly in the situation when no extra time is given to solve the last-minute change on the spot"* - TM_1C_2.

Also, the direct subordinates of site managers (e.g. site engineers) tended to be less educated than office staff, including lack of proper training in BIM, because they spend most of their time on sites and, hence, offering a higher degree of **resistance to change**. It was found that BIM implementation was around basic applications such as clash detection, rough cost estimation, and shop drawing release that were mostly executed by the BIM team with less support from site engineers. A BIM specialist explained *"the site team is only interested in their level of work share and does not get involved in updating the model"* - E_1C_2. In contrast, a site engineer admitted that *"our experience, skill and special knowledge are implicit knowledge, not written down, or not yet documented in such a way that could be transferred to BIM specialists or anchored within the common BIM model"* - MM_4C_2. Another site engineer stated that *"the BIM team has already provided us the training course but it's all about software manipulation and modelling technique. It's too complex for us and unnecessary as we are not BIM modellers like them"* - MM_3C_2. The site team preferred to be trained in the use of BIM tools for construction processes. This is a different application from generating a 3D model. It is more concerned with adding specific information (non-geometric data) into the model and mining data from the model.

The position of the BIM team in the organisational structure is ambiguous. Not many AEC companies have a R&D department which is responsible for maintaining and developing current technologies as well as introducing new ones. *"Currently, the BIM team is embedded in the design department and in charge of software, whereas the IT department works separately and takes control of hardware and the IT system. That's why the BIM team alone has been slow to test BIM in real business"* - MM_1C_2. A senior manager explained why the BIM team was not set up as an individual department like the design department or construction department: the *"BIM team is a support function, equal in importance to but not greater than marketing, human resources and accounting. But like other support functions, BIM is a 'cost centre' not a 'profit centre'. It's an optional choice, but not a strategic business function"* - TM_1O_2.

7.5.3.1.2 *Rules (cultures or norms)*

This section shows that the construction norm holds the work experience of site managers in high regard for their ad hoc problem-solving skills and their habit of seeking instant help from personal contacts to make decisions rather than relying on technologies. In addition, the culture of 'saving face' impacts the acknowledgement of the actual level of BIM maturity within the company by top management.

Construction site managers were responsible for both the foreseen and unforeseen situations occurring throughout the building process. Unexpected situations were culturally accepted as part of normal project work, and the managers, such as TM_1C_2, TM_2C_2 and TM_1O_2, did not think unexpected problems could be completely avoided by anticipating them. They considered work as skilled, improvisational problem-solving ('muddling through') whereas the unforeseen events require immediate attention and quick decision making. Site managers perceived documentation, designs and plans to be important yet an imperfect source of information for solving problems and carrying out the work. Instead, personal work **experience** was highly valued. Long work experience helps managers act proactively. When they needed help, they relied on their **personal contacts** such as experienced colleagues, even colleagues in a different company, for advice rather than using a decision making optimisation tool such as BIM. *"Being the top-level manager, it's a normal behaviour when I discuss problems with my employees but it's so weird asking them for help. As a social norm, people always see me as the first place to seek immediate advice. I can't tell them to wait until the BIM team or head office get back to me"* - TM_1C_2. As a result, the peer network of experienced and skilled professionals in the same position helps senior managers with case studies or alternative solutions that might be applicable.

In addition, the interrogation of data exposed that **'saving face'** is one of the cultural forces which mediates BIM execution. The BIM capabilities of Vietnamese construction organisations were sometimes misrepresented to avoid embarrassment. The commitment to the introduction of BIM systems into the case study organisations is questionable as large AEC firms have overstated their actual BIM use to confirm their leadership in the market; also, some incompetent BIM companies have been awarded a project due to their lobbying. *"More people practise 'pseudo BIM' (3D CAD solution presented as a BIM solution) than you would imagine. And unsuspecting clients who can't spot the difference are being sold a pup"* - MM_1D_5.

7.5.3.1.3 *Community (places where actors play their roles)*

This section confirms the finding from the first round of case studies that non-BIM specialists do not perceive BIM as a mainstream profession but as a sub-subject of the architecture discipline. Thus, BIM specialists need to change their diffusion approach by using the same language as other community members and use normal vocabulary rather than a BIM expertise lexicon to better communicate new ideas. Further, the non-BIM specialists prefer to pursue BIM in a decentralised manner rather than mandate it because projects are executed in an uncertain and fast changing environment.

Given that BIM was not recognised as a mainstream profession in case companies in Chapter 4 Findings of the first round of case studies, BIM specialists currently served as a reference and decision support role for non-BIM specialists (e.g. owners and site managers). BIM specialists neither get involved in early concept design by design teams nor supervise the physical building by site teams. Senior staff members might see BIM specialists as *"BIM monkeys who simply model what they have already designed"* - MM_1O_2, whereas their colleagues (e.g. designers or site engineers) felt disturbed as BIM specialists sent them several requests for information. Both parties perceived that BIM is less useful, which adds to the resentment and marginalises the digital design technology profession of BIM into **'a child of architectural design'.**

Case studies found the effort of BIM specialists in promoting BIM as a positive direction for the construction industry. However, Vietnamese AEC organisations have been slow or resistant to seeing these digital design roles in a position of leadership. BIM specialists recognised that they need to communicate in '**the same language**' as end-users to convince them of BIM values. For example, a BIM specialist admitted that *"we have to speak the right language to customers. A fully parametric and fabrication level Revit family might satisfy design teams while a visualised site arrangement for safety and logistics could attract site people rather than a fully detailed LOD 500 BIM model"* - MM_1C_2. When an environment creates uncertainty, for example, BIM technologies are poorly understood or the goals of organisational response to BIM are ambiguous, the AEC professionals tend to copy the behaviour of peers to appear legitimate and progressive. *"As target adopters are different in competences and interests, we should redirect our approach to them so BIM knowledge transfer is in non-technical language"* - MM_1C_2. That is, rather than leading the implementation of non-BIM specialists, BIM specialists let non-BIM specialists host more workshops on BIM and provide a simplified explanation of BIM and its benefits. BIM specialists supported and guided non-BIM specialists on where to start and let non-BIM specialists learn and practise by 'copying' others' behaviours.

The remoteness of construction sites is also an obstacle to BIM implementation. Construction site management required **flexibility in decision making** rather than working through a third-party intermediary such as a BIM team or BIM consultant company. Sites lack logistic support due to being remote and suffer a continuous shortage of materials and specialised labour. *"The more centralised decision making and lack of delegated authority to field personnel often hindered progress and communications at critical emergency response and recovery stages"* - TM_1C_2.

7.5.3.2 Personal re-evaluation affecting BIM implementation activity

In addition to the concern about social belonging and the role of BIM specialists in the existing organisation, self-interest of BIM specialists was also seen as important for motivating their post-adoption behaviours including the

meaningfulness when BIM specialists felt *"professional pride in being pioneers of a digital change movement"* - E_1D_5, **feeling useful** when BIM specialists received positive feedback from contractors such as *"spatial coordination as the specific task that shows the most value in change avoidance during the execution"* - E_1D_6 or *"better team communication and understanding from 3D visualisation"* - TM_1O_2; **open opportunities** when BIM specialists believed that the digital design trend should gain momentum as *"more users master it and software providers develop additional tools"* - MM_1O_2, and **work–family conflict** as another factor affecting BIM specialists' evaluation of BIM jobs. BIM specialists who were sent to sites were likely vulnerable to work–family conflict. *"Challenges associated with remote work are the lack of time adequacy with family, home sickness and sacrifice of leisure activities"* - MM_2C_2. *"We haven't prepared our physical and mental attributes to adapt to long-time working on site. Our stamina is less durable than that of site people"* - MM_1C_2.

7.5.3.3 Environmental characteristics affecting subjects of BIM adoption activity

7.5.3.3.1 *Social influences*

This section explains why the government BIM mandate is seen as less important than peer effects and an unqualified labour force.

Senior managers or owners considered **the impact of government activities** to be less significant to their adoption activities. Although some national diffusion programs have raised awareness within the AEC community, such government support for BIM implementation was not strong enough. For example, *"the legal framework governing the responsibilities and liabilities of all parties involved in BIM based projects has yet to be fully defined"* - TM_1O_2. Therefore, market forces could dominate in BIM implementation. However, this scenario could result in uncertain BIM practice directions; in particular, there would be non-uniformity in the nationwide implementation of BIM as *"each market stakeholder would implement its own BIM system"* - MM_2D_5.

Also, sustaining the top-down centralised approach is expensive as *"not enough money is then available to send change agents to regularly meet with all potential adopters in the field to ensure their understandings of why and how a diffusion program works"* - GA_1.

The peer effect was seen as a determinant of the BIM adoption decision. For example, the architecture community is not increasing its BIM use. Given that architects introduced BIM tools early into the AEC industry, a high level of BIM practices (e.g. environmental simulation for greater comfort and healthy living) requires the shift to using algorithms which is perceived as harmful to design creation. *"A sophisticated model represents architectural elements by parameters and rules which are more concerned with mathematical logic and programming. That is my weakness as the design sense is quite different from the technology sense of engineers"* - MM_2D_5. Currently, contractors or owners rely heavily on experienced architects to develop the initial ideas or concepts. A top-level manager of a contractor argued that *"how can we push BIM further if its upstream users, the architects, only sustain the enthusiasm in one-off design"* - TM_2C_2. This means, the architects considered the modelling job as *"the BIM monkeys repeating what they have already designed"* - MM_3D_5 and *"frequent update and revision cycles freeze our passion as this iterative process should be a draftsperson's job with college training"* - E_1D_5. Further, senior managers of design firms admitted that *"our architectural staff are reluctant to fulfil extensive BIM data requirements while draft people (with less general design education) may not be the reliable providers of information for intended recipients such as owners or contractors"* - MM_1D_5.

The dominance of low skilled labour negatively affects the decision to adopt BIM. The site workforce is unstable because manual workers, usually farmers with short-term verbal contracts, move back and forth between sites and farms. *"It's tough to train BIM workflow for the migrant workers due to their poor discipline, temporary work and narrow skillsets"* - MM_2C_2. Consequently, large BIM based projects have unintentionally been broken down into smaller specific BIM tasks, prompting *"a growth in the use of subcontracting with increased complexity of the communication network structure"* - MM_1C_2.

7.5.3.3.2 *Market demand*

Top-level managers of large AEC firms admitted that small and medium sized enterprises (SMEs) might have more advantage in transforming from the old CAD system to the new BIM system due to their agility and neat and compact organisational structure. *"When it comes to technological innovation, SMEs hold the advantage over bigger firms due to the lack of institutional bureaucracy, which otherwise hinders, prolongs and even inhibits adoption"* - TM_1D_6. However, the rise of BIM based SMEs does not change the market share because of *"the clients' need for security from large household names"* - E_1D_6. The BIM competent SMEs have to *"accept being subcontractors of large companies for survival"* - MM_2D_5. This explains why large AEC organisations were implementing BIM at a slow pace despite current activities of BIM applications.

Similar to the first round of case studies in Chapter 4, the second round of case studies found that 'sustainable living space' has not yet become a highly demanded criteria when end-users of project (e.g. occupiers or tenants) evaluate building products. In fact, price and location of a building are the top concerns. *"The tenants have no or less sense of demanding minimum environmental standards in the building they leased, for example, establishing resource (water, energy and waste) efficiency and disposal standards"* - E_1D_6. Therefore, an incumbent business with existing high-end technologies such as CAD can still survive by concentrating on *"how to satisfy its most demanding but least price-sensitive customers"* - TM_1O_2.

7.5.3.3.3 *Culture*

This section illustrates that corruption in the bidding process and the habit of using pirated software are cultural barriers to a sustainable innovation adoption.

It was discovered that local AEC professionals perceived **corruption** as a natural part of business. Corruption was considered a social norm attached to daily business relationships. This phenomenon derives not only from discretion of officials but rather rule-violating behaviour of the related parties (i.e. business sectors). The indication from AEC firms' managers was that in order to win or be awarded a project, the organisations had to *"pay a third party to lobby the government or developer"* - MM_3D_5. As the result, the motivation for innovation was inhibited because whether the design was in a 3D [BIM] format or 2D CAD, it was less significant than the capital spent on the lobbying to be awarded the contract.

Further, Vietnamese AEC companies were used to *"working around intellectual property issues by using fake IT licenses"* - MM_1D_6. The national legal framework of copyright has not been stringent enough to inhibit infringers. This phenomenon might mediate the initial access to new technology of poorer economies in the short term, however it threatens the sustainable development of Information Communication Technology (ICT) in the long term, which affects the intensive implementation of BIM beyond basic uses. AEC firms *"simply used unlicensed BIM tools and copied the standards laid out by American software providers (Autodesk) regardless of the conformity with Vietnamese standards"* - TM_1D_6. As long as the social norm of a **'free rider'** is not addressed, the local IT capability will be underdeveloped and unable to fill the gap between western innovation and local context. Senior managers still have to struggle to reconfigure their BIM implementation in order to comply with Vietnamese codes.

7.5.3.4 Personal characteristics affecting BIM adoption activity

The second round of case studies showed that personality traits of decision makers have an influence on their adoption activities. There are four types of personal characteristics suggested by Diffusion of Innovation Theory (see

Figure 2.8): formal education, socioeconomic status, communication behaviour and innovativeness.

The first type is **formal education,** but it is not properly aligned with decision makers' professional background. Most developers or policy makers were trained in conventional business programs to manage organisations that served established markets with well defined product lines. Hence, an additional team, the BIM team, at the corporate level is required to be particularly responsible for collecting innovation ideas and putting them into implementation. A senior manager stated that *"we don't have a formal BIM adoption, it's currently ad hoc because BIM education is lacking in a formal setting"* - TM_1O_2.

The second type, **socioeconomic status**, sometimes held innovation back as top management members tried to sustain their current status of power, mastery or respect by hiring third parties (e.g. BIM consultant companies) to test small-scale and low-risk projects rather than developing in-house BIM competent teams. Senior managers were reluctant to share areas of weakness and refused to admit to self-development needs of BIM knowledge, especially disruptive innovation like BIM. *"Senior managers, particularly in the public sector, may feel that by implementing BIM, they would simply be aligning their weakness with the threats in their external operating environment"* - GA_2. Thus, senior managers tried to limit employees' doubt about upper management ability to secure trust within the company. *"If an outside BIM consulting firm took the lead of BIM practice, any failure could be accepted as the risk of experiment. But when we (senior staff) did it, people only blamed us for our incompetence"* - MM_1O_2. Further, a BIM manager conceded that *"even though the top-level management is advocating innovation, BIM cannot be successfully diffused without the collaboration of middle-level management. The more status and power the BIM team gains, the higher the threat to personal power middle managers perceive"* - MM_1D_5.

The third type, **communication behaviours** or information seeking activities, also matter. Senior managers acknowledged that *"it is acceptable to admit to a need for change (self-development) in those areas where our peers (equivalent high management level) share the same needs, in this case: commercial awareness of BIM"* - TM_1O_2. But as an exception to this interpersonal network, there is less evidence of active information seeking by senior managers. For example, senior managers might be *"willing to support training programs tailored to their staff but less willing to participate in this learning activity alongside their subordinates"* - E_1D_5. Further, senior managers were not all ready to share experiences on BIM practices in open events like non-profit conferences except those relevant to marketing such as introducing new BIM services to clients. *"While young BIM specialists feel free to exchange their knowledge with peers, senior managers are conservative and aggressively competitive. The lack of R&D makes the uses of BIM predictable and vulnerable to direct copying by rivals. That's why the BIM team is restricted from publishing any BIM activities on behalf of the company"* - MM_2C_2.

The fourth type, **innovativeness,** might reflect the tendency to innovate of the middle management team per se, but not top management. The second round of case studies found that middle managers who are BIM specialists are the most influential group in the organisation when it comes to innovation. Central to the success of middle managers is their proximity to both employees and the main technologies they use. On the contrary, the decision on BIM adoption from upper management, who are non-BIM specialists, likely arises from the fear of *"losing current market share rather than the ambition of taking over the emerging BIM market"* - MM_3D_5. Senior managers admitted that *"BIM usage is just an additional value to projects such as advertising, tax incentives, awarded contracts"* - TM_1O_2 and the company vision is *"our experiences drive us forward, not relevant to innovation"* - MM_1O_2.

7.5.3.5 Prior knowledge affecting BIM adoption activity

7.5.3.5.1 *Previous or existing business practices*

It is an implicit acknowledgement that BIM is more appropriate for complex and large-scale projects. With large capital investment for such projects, owners insist on using 'large household name' consultancies and contractors who did not use BIM software whereas there were many SMEs who did. The fear of failed projects discourages innovation laggards so that ongoing demand for large firms' services is more dependent on their reputation and ability to deliver projects irrespective of the use of BIM systems and disregard of BEPs. An owner stated that *"our current business (without BIM) is sound and is secure as we work with leading AEC companies"* - MM_1O_2. Unless there is a specific requirement imposing the change to previous practices, such as mandatory Green Buildings, owners supposed that the *"usual tools fit the usual projects and our familiar experience on existing tools [CAD] is still good so far"* - TM_1O_2. Also, top-level managers might not have the time or technical abilities to take on operational roles with the new system; hence, key staff members (lower-level employees) were *"hired or selected to lead the BIM effort"* - TM_1C_2.

7.5.3.5.2 *Felt needs or problems to change*

Decision makers did not feel it is urgent to change as there is little pressure from competitors. For example, owners who do not use BIM believed that *"other owners similar to us are either not using BIM very much or not using it at all"* - TM_1O_2. Also, while there has been much interest in the form of initiatives to implement BIM within AEC firms, *"many are still at pilot stage"* - TM_1C_1. Therefore, top management teams have not experienced sufficient cases of BIM success from their rivals or peers to consider increasing their use.

Additionally, the senior manager of a design company admitted that *"BIM tools [Revit] might allow project documents to be completed much faster than using CAD drafting tools"* - MM_1D_5, but greater effort was required to commit to a start-to-end BIM based project likely taking a few years to complete. For example, a BIM team (people) and high-end tools (resource) were dedicated to the continuous exchange of information (time and energy) with other project participants. In other words, rather than managing multiple one-off design projects at once with obvious benefit to companies, the design companies have been *"stuck doing modelling, updating and revising follow-up stages such as construction or operation within one BIM based project"* - MM_2D_5. The senior managers, therefore, were reluctant to make a choice between *"completing more projects for more clients to grow the firm steadily"* - MM_3D_5 or *"pursuing high-quality work to make the firm stand out"* - MM_1C_2. Through the interviews, most of the non-BIM specialists (e.g. chief designers and owners) were not among client groups to favour BIM. However, they kept a neutral attitude towards BIM adoption of not preventing their employees from implementing some BIM trials but also not deeply engaging in BIM implementation.

7.5.3.5.3 *Organisational norms*

Another factor is the organisation's existing norm which is built on the solid ground of specialty such as a designer, builder or supplier, not a modeller. When introducing BIM into AEC companies, BIM specialists developed the toolkit of standards and guidance and created a special language for users, to enable precision and to make a distinction from CAD. This language named new features but also renamed familiar ones, making the whole subject arcane and opaque to industry outsiders, which most clients are. According to one interviewed owner, *"BIM specialists should keep the complexities of the BIM glossary for themselves, and not burden clients with it"* – MM_1O_2. In particular, the BIM specification contains a voluminous lexicon of attributes that define complex sets of data. This might initially attract non-BIM specialists with the feeling of *"something professional and innovative"* - TM_2C_2 but using jargon-laden language more akin to academia than the built environment later creates a barrier to BIM becoming the norm in construction.

7.5.4 Theme 6: Outcomes of BIM activities

7.5.4.1 Outcomes of BIM adoption activity

This section describes the variety of realised benefits of BIM by non-BIM specialists at management level. In particular, companies' managers consider both monetary and managerial outcomes when making decisions on BIM adoption whereas the Vietnamese government agents aim to develop the policy framework to facilitate BIM activities in a standardised manner.

The second round of case studies showed that the **realised benefits of BIM vary for different client types**. If the owners are in a sector where construction projects are frequent or even the core activity, and where assets are retained, used or managed, they will *"see benefits from almost all the possibilities and likely equip themselves with the necessary skills to adhere to BIM requirements"* - MM_1O_2. If the owners are occasional developers, but will live with the asset, the lifecycle advantages may *"still justify deep involvement with digital working"* - TM_1O_2. If the owners' business model is to develop and then sell on completion, the benefits over a lifecycle will depend on the aftermarket: do buyers want asset data to assist in their management of the space? *"Project-related benefits will otherwise dominate the level of BIM adoption"* - TM_1O_2. Not only owners but also different disciplines have specific measures to assess the outcomes. For example, the metrics related to project outcomes (financial, schedule, safety and process) were rated more highly by contractors than architect or engineering users because of the contractors' responsibility for project execution. Therefore, *"BIM specialists should aim to automate the development of construction documents, like fabrication details and shop drawings that are quickly generated and easily accessed by site teams"* - TM_1C_2.

'The balanced framework' which considers both managerial and monetary outcomes has affected the business decisions of the top management of AEC firms on BIM adoption. In fact, the monetary outcome is a prerequisite for the managerial outcome, as senior managers would not adopt BIM as a management tool until it has been proven financially productive. Afterwards, BIM might be integrated into the process and business model. However, senior managers reported that the outcomes of BIM based projects are difficult to quantify. *"BIM is unable to present its intangible outcomes such as improved safety or fewer RFIs or increased project teams' understanding and communication"* - MM_1C_2. Also, the level of BIM implementation relies on the client types. *"For property developers, it's all about getting the building built sooner. The sooner the units are selling, the sooner the revenue starts"* - TM_2C_2. The common project delivery comes with a 'bid–build' approach and 'lump-sum' contract that lead to the environment where each member of the project team *"gives priority to its individual interests not to common project goals"* - MM_2C_2. This could create huge barriers to BIM implementation in full scale, and in this case only partial BIM technology elements can be used by separate participants needed to fulfil their work package.

For the Vietnamese government agents, the expected outcomes were the diffusion of **'policies in favour of BIM adoption'**. The government agents explored that *"we are working towards the development of regulations, standards and guidelines"* - GA_1 but acknowledged two challenges affecting the BIM mandate for the construction industry. First, most government-funded projects such as large transport infrastructure megaprojects were usually *"awarded to some state-owned companies for national security reasons"* - GA_2. However, less competition leads to less innovation as the public sector lags behind the private sector in terms of BIM adoption. As a result, the government was failing to make BIM mandatory as their partners in the public sector also cannot comply with the mandate. Second, *"the government BIM mandate is not rooted in practice"* - GA_2. The government agents admitted that *"there is not a prescribed structure for a common set of government practices"* - GA_1. Currently, the government agents were asking some leading private companies to join a BIM steering committee as industry knowledge contributors. However, lessons learnt from these top-ranked companies were limited because senior managers felt that *"we are already busy with day-to-day* *responsibilities and do not want the extra work of guiding the whole industry"* - MM_1C_2. Further, the issues of in-house BIM implementation tailored to each specific company and commercial sensitivity were barriers to diffusing experiences with BIM practices. *"They do not want to be transparent. BIM needs clarity in both signing contracts and flowing cash in and out. It is possible that the owners will create their own BIM, but that type will not connect to others"* - TM_1O_2.

7.5.4.2 Outcomes of BIM implementation activity

This section presents the attitudes of end-users regarding BIM outcomes in their daily work. Surprisingly, the monetary outcome, or incentives, is not perceived as an important factor driving BIM adoption compared to automation, collaboration and work efficiency. Further, BIM outcomes are recognised as being imperfect, evidenced by redundant files and as-built inconsistency, which likely discredits the potential of BIM. In addition to technical outcomes, social outcomes are also a concern during BIM practices such as the recognition of BIM roles and the harmony between BIM actors.

Through the interviews, monetary outcomes were not highly appreciated by BIM specialists but ***automation*** to automatically sync work updates, ***collaboration*** on shared data-rich models, and ***work efficiency*** with better predictability of risks were appreciated. First, BIM specialists, mostly in architecture or engineering, revealed that *"the community of architecture or engineering is discussing how to streamline design processes, how to simplify and carry out repetitive tasks quickly and efficiently"* - MM_3D_5. That explains the popularity of BIM tools like Revit among design companies as most professionals expected *"less time for drafting, more time for designing and communicating the concepts"* - MM_1D_6. Second, BIM interprets and communicates the attributes of each building system simultaneously through a shared data-rich model that aids all parties involved in the project. This automated model provides *"easier transfer of data, interference checking, documentation, and exchange of ideas between different disciplines"* - E_1D_6. Third, most BIM specialists agreed that BIM was beneficial for lowering project risk because it helped discover errors, omissions and conflicts before construction started by using the clash-detection function. For example, *"BIM provides the benefit of faster reviews for approval and permits by using the 3D visualisation function"* - MM_1D_5.

The move from documents to data means that data can be digitally re-worked for many purposes such as extraction, analysis or verification and these processes can be automated. However, BIM specialists conceded that constant auto-updates create **unmanageable files**. *"Many people blame large file sizes, after all Revit project files of 400 Mb are not uncommon"* - MM_3D_5. Those who still think the CAD way believe that splitting a project into several linked files will solve the problem. *"But if Revit is to do all the things BIM is useful for, everything needs to be instantly accessible"* - E_5C_1. Therefore, *"everything has to be in one file, or if in several linked files all those files need to be loaded into your computer at once"* - E_1D_6.

Although the information in a BIM model was shared through a mutually accessible online space known as a common data environment (CDE), it is not yet a reliable data source for formal reference because of the **as-built inconsistency**. *"Often what occurred on site (due to space, resources or technical) did not match the initial design"* - MM_1C_2. As-builts were mostly missing when BIM creation and coordination occurred in a similar timeline as construction of the building. These design issues frequently stopped the flow of design coordination until a request for information was returned from the site or the entire system and area were updated with what had been built.

Further, very few BIM specialists said that they had a **formal role description** that incorporated their BIM activities. This means BIM specialists were only seen as technical supporters which is similar to findings in the first round of case studies in Chapter 4. *"We predict and identify the list of problems but senior managers [non-BIM specialists] determine the importance of selected events"* - E_1C_2. In particular, a BIM specialist stated that *"many proposals of the BIM team are rejected, making our effort useless. It's not always a matter of technique (right or* *wrong) but* ***the harmony among BIM actors****"* - MM_1C_2. It was observed that senior managers usually gave priority to the uses of BIM which give the greatest return on effort, are the least disruptive to existing workflows and generate fewer disputes among project participants.

7.5.5 Theme 7: Mandatory setting of BIM activities

7.5.5.1 BIM mandate is not enforced

7.5.5.1.1 *Still using old communication methods*

The second round of case studies found that even in projects engaging experienced BIM personnel, the common communication method was traditional meetings where the culture of the 'blame game' of risk transfer and fee protection still occurs among parties. This situation may lead to the *"negative experience of BIM practices among all stakeholders who have expected to avoid disputes by using BIM"* - MM_3C_2.

Further, it was observed that the setting of a meeting room remains conventional: a compact room with basic equipment such as pens, paper documents, projector and whiteboard. The only thing that changed was an additional screen that displays the coordinated model for all parties to discuss. A designer argued that *"this low-tech setup prevents us from connecting directly to the master model to interpret the situations and propose the solutions. There is not even enough room and sockets for laptops"* - MM_1D_5. Another contractor commented that *"only decision makers (e.g. project management team) have access to the model in the meeting while other parties just use their eyes looking at the screen. How can the 'live' coordination perform when using such a 'dead' model?"* - MM_3C_2. In brief, the decision makers mandated the use of innovation but had not prepared well to facilitate the performance of adopters.

7.5.5.1.2 *BIM mandate is not rooted in practice*

Although mandating BIM implementation, the government agencies in Vietnam have shown **inconsistency in their practical guidance**. First, there is *"no data or evidence showing the success of BIM practices in public projects"* - TM_1C_1. Without case studies to back up the policy, most AEC professionals claimed that the BIM mandate stays as theory and has less practical value - MM_1D_5, MM_1C_2, TM_1O_2 etc. Second, given that government bodies and the public sector have been falling behind the private sector in BIM practices, a BIM manager suggested that *"there should be an alternative approach to the national BIM program, especially constructing a strategy of knowledge sharing with the help of AEC companies. For example, sending government staff to learn BIM practice in the field or inviting BIM champions to join the national BIM committee to revise the mandate"* - MM_1C_2. Third, some countries who are leaders in using BIM such as the United Kingdom and Finland and software vendors such as Autodesk have offered great support of finance, consultants and equipment to the Vietnamese government but it is accompanied by requirements for specific uses of tools or methods. A senior manager stated that *"adopting multiple guidelines and tools at once leads to a messy combination that is difficult to work out"* - TM_2C_2.

7.5.5.2 BIM mandate affecting BIM implementation activity

7.5.5.2.1 *Limitations of internal capacity to comply with BIM mandate*

Generally, workflows employing BIM were perceived by most professionals as slow and inefficient, with the exception of contractors where *"clash detection is seen as a main benefit"* - MM_3C_2. For architectural and engineering disciplines, there are some key barriers to compliance with the BIM mandate including *"limited libraries of standard objects"* - MM_2D_5, *"high demands on computing software and hardware"* - MM_3D_5, *"the emergence of new professional roles and relationships in the context of BIM"* - MM_1D_5, *"lack of interest in the part of professionals working with well established non-BIM procedures"* - MM_1D_6, and *"time and cost required for training"* - E_1D_6.

For project managers, challenges included *"limited confidence in data security"* - TM_1O_2, and agreeing on *"model ownership"* - MM_1C_2, *"project responsibilities"* - MM_2C_2, *"access rights"* - TM_2C_2, *"intellectual property rights"* - TM_1C_2, *"contractual responsibilities for inaccuracies"* - GA_1 and *"payment arrangements"* - MM_1C_2. Also, while the clients' mandate remains confused about its meaning in defining BIM deliverables, it is difficult to develop BIM models for unintended purposes. Most limitations of BIM users' competencies were found to be similar to the first round of case study findings in Chapter 4, increasing the validation of the results.

7.5.5.2.2 *BIM mandate considers human-related factors less*

Mandating BIM without considering the human element will, however, lead to widespread resistance. If individuals are not convinced on how BIM adds value to their jobs or careers, they could be reluctant to adopt new skills and instead maintain their existing work habits. Currently, much of the focus of BIM specialists has been on *"refining the software tools and technical structures required to deliver the enhanced outcomes promised by the technology"* - MM_2D_5. Also, their efforts to develop in-house training programs and cooperate with academia for BIM curricula have been evident, with a considerable *"emphasis on software and technical elements"* - E_1D_5. Less attention has been paid to the development of the non-technical capabilities for BIM specialists such as communication, negotiation and leadership skills. Also, some personal traits should be learnt or shaped to overcome the resistance of non-BIM users, for example, an openness to listening, and guiding people with a patient and friendly attitude in non-formal teaching. Through interviews, some respondents were not aware of these soft skills, and simply *"represented what they have experienced and trained to new learners"* - E_1C_2. Others were quick to acknowledge their shortcomings in the area but had *"not had the opportunity to develop or were unsure of how to do so"* - MM_2C_2. Very few BIM specialists with educational certificates and experience made a conscious effort to improve their own management and associated soft skills with training courses and education programs.

7.5.6 Theme 8: Contradictions occur during BIM interactions

Theme 8 was established by comparing 7 themes from the previous two rounds (see Table 7.6) and the literature review.

Table 7.6 Summary of themes from two rounds of case studies

Case studies	Theme
The first round of cases	**Theme 1:** Perspectives of BIM specialists on BIM profession
	Theme 2: Perspectives of non-BIM specialists on BIM profession
The second round of cases	**Theme 3:** Mediating tools of BIM activities
	Theme 4: Objects of BIM activities
	Theme 5: Subjects of BIM activities
	Theme 6: Outcomes of BIM activities
	Theme 7: Mandatory setting of BIM activities

Each sub-theme of theme 8 is developed in relation to themes 1, 2, 3, 4, 5, 6 and/or 7 as below.

7.5.6.1 Contradictions of scope of work

7.5.6.1.1 *Who is the leader of BIM adoption?*

The government is not a proper BIM leader.

It was perceived that the government does not need to take BIM leadership in the pilot BIM stage. Most senior managers were aware of the government BIM mandate but they believed that the government should take a mediating role rather than a leading or guiding role (see Theme 7). There are three reasons for this perception.

First, the subjects' capacity is not sufficient to affirm their leading role in the community. The Vietnamese public sector was found to lag behind in BIM adoption compared to the private sector (see Theme 5). According to Diffusion of Innovation Theory, an opinion leader (i.e. BIM champion) is an individual who is able to influence the attitudes or overt behaviour of other individuals in a desirable way, with relative frequency (Rogers 2003). However, to date the role of the Vietnamese government as a BIM champion is questionable because their BIM leadership has been 'encouragement' with 'attractive prospects' drawing from successful cases in developed countries. There is little evidence demonstrating the success of BIM in Vietnamese government-funded projects.

Second, a highly hierarchical structure impedes innovation in the public sector as senior officers may hold the opinion that innovation can result in threats to existing hierarchies (see Theme 5). BIM faces hurdles due to bureaucracy by top management when novel ideas have to pass through many steps of approval processes. Similarly, Engeström, Lompscher and Rückriem (2005) stated that static and hierarchical structure may not provide the necessary flexibility to promote an environment favouring innovation.

Third, Vietnam does not have a single agency responsible for all construction as in the BIM-leading countries of Singapore or the United Kingdom. Building construction and infrastructure are separately managed by Vietnam's ministry of construction and the ministry of transportation[24]. The public sector has a tendency to operate in silos where each department has different duties and the authority to execute that duty. As the result, the Vietnamese AEC industry has experienced widespread spontaneous deployment of BIM adopters regarding practice, training and education (Bui 2019; Nguyen Bao et al. 2018).

The client is not a proper BIM leader

The role of the client as a BIM leader is also confusing because in a typical office and residential building, the owner (developers) and client (occupants) are not necessarily the same entity and, thus, clients might be excluded from the design and construction process. Further, not every owner is subject to the

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[24] Source: http://chinhphu.vn/portal/page/portal/English/ministries

competitive pressure to innovate (see Theme 6). Unlike in the private sector, where innovation is basically driven by profit maximisation, public sector innovation focuses on maximising social welfare created through public investments (Wipulanusat et al. 2019). Private owners are using BIM mostly to manage the scope and the quantity of works undertaken by contractors as described in the project bill of quantities, while BIM use for design, construction and remodelling or renovation of existing buildings has been limited (Moreno, Olbina & Issa 2019). Some owners demand BIM but at a low level, and use of BIM during the whole lifecycle including operation and facility management seems far away (Davies et al. 2015). Engeström, Miettinen and Leena (1999) argued that the motive of an activity like BIM adoption can be collective but that goals are individual. It is because the social context, conditions and means influence how the goals may be compromised and prioritised, and how they may impact the subject's action on the object (Tsai et al. 2010). Similarly, it is noted that "different subjects, due to their different histories and positions in the division of labour, construct the object and the other components of the activity in different, partially overlapping and partially conflicting ways" (Khiok-Seng 2003, p. 465).

The designer is not a proper BIM leader

The designer is also not a proper BIM leader. BIM is an opportunity for designers to gain status and power which is supported by the notion in the industry that designers are increasingly contracted to act as BIM coordinators in projects (Davies et al. 2015). However, designing firms are generally far smaller than building firms as most of them have less than 50 employees (Davies et al. 2015; Tran Tien, Le Xuan & Nguyen Kim 2008). With the advantage of organisational agility, SMEs may quickly adopt BIM compared to larger firms but they lack slack resources required to remain innovative (Aibinu & Papadonikolaki 2017). The rise of BIM based SMEs or startups does not change the market share due to clients' need for security. The BIM competent SMEs have to accept being subcontractors of 'large household name' companies for survival.

A small and medium contractor is not a proper BIM leader

A small and medium sized contractor is not a potential BIM leader. The AEC industry is generally lagging in innovation when compared to the manufacturing industry because the AEC industry by nature has low R&D intensity with few people employed directly in R&D activities (Hampson, Kraatz & Sanchez 2014). Not many construction companies which are SMEs have their own R&D departments with full time staff. Some main causes are summarised as follows.

First, in order to win or be awarded a project, organisations have to pay a third party to lobby the government or developer. As a result, the motivation to innovation is inhibited because whether the design is in a BIM format or 2D CAD, it is less significant than the investment spent on the lobbying to be awarded the contract. Second, there are also structural reasons for the low interest in R&D. The AEC industry is comprised of large supply networks, which means that one company's development efforts do not make much difference if other players do not comply. Third, client behaviour is not encouraging R&D investments either. Most contractors claimed that when it comes to choosing vendors, price, not value, is the defining factor (see Theme 6). Lastly, besides prestige, price is actually the only differentiating factor between vendors. The introduction of BIM has not significantly changed the on site execution process which is characterised by labour-intensive activities and in-situ concrete methods (Er 2017; Nguyen Phuong, Birkeland & Demirbilek 2010). Still, contractors may compete more on price than on technology. Contractors are less likely to strive to get an advantage by doing construction that other companies are not technically competent to do.

Main contractor and manufacturer are potential BIM leaders

As SMEs[25] tend to have lower survival rates and more volatile revenues than larger firms, small businesses are less likely to engage in innovative activity than larger businesses (Connolly, Norman & West 2012). It is noted that large construction companies prefer to set up internal BIM departments, or BIM centres, rather than relying on external specialised BIM service providers (Herr & Fischer 2019). Similarly, the main contractors in the case studies have either separately established their new BIM department from existing departments or integrated the BIM team into the current design department.

However, R&D in construction is not organised as formally as in manufacturing companies, including construction manufacturing such as suppliers of building materials, equipment or machines (Hampson, Kraatz & Sanchez 2014). Only large contracting companies can support a dedicated R&D department whose R&D mostly occurs at the building site. That is, few firms generate radical new ideas in the laboratory but incrementally at a project level in solving day-to-day problems. This finding coincides with the argument of Loosemore (2014) that, in contrast to manufacturing which is technology intensive, construction is a service-based industry which is inherently labour intensive, thus construction innovation is fundamentally more ad hoc than manufacturing, based on ideas from employees and managers developed 'along the way' in response to challenges during the service delivery process.

It was surprising that construction manufacturers, such as companies supplying prefabricated parts, were not mentioned as potential BIM leaders by interviewees. Even in the literature, the role of construction manufacturers in BIM innovation has been neglected. There is evidence showing that construction manufacturers invest nearly three times as much in R&D than contractors and twice as much as designers (Loosemore 2014a). Further, the

[25] SMEs: Small and Medium Enterprises

AEC industry tends to imitate innovation from other industries (Seed 2015). For example, some of the digital modelling advances like BIM made in the construction industry in the past decade flow on from those made in the aerospace and manufacturing industries in the latter part of the last century (Hampson, Kraatz & Sanchez 2014). In other words, BIM may be perceived as new to the industry but is not new to the world. Digital models have been applied in the manufacturing industry since the 1980s whereas they have only been used for a decade in the AEC industry (Smith 2014).

Obviously, manufacturers are developing new equipment or product and large contractors are the main beneficiaries (Hampson, Kraatz & Sanchez 2014). It is recommended that main contractors should further develop modular construction systems, working jointly with manufacturers or suppliers to improve the applicability of innovation (Almeida et al. 2016). Case study findings (Theme 3 and Theme 6) revealed that the large construction companies started to implement BIM on internal housing projects and for Design–Build contracts, where they own the whole process. All participating main contractors have increased the proportion of prefabrication and modular systems in BIM based projects by further developing their manufacturing services. It is very common that large construction firms are owners or co-owners of factories that provide manufacturing and assembly of façade structures in Vietnam. To date, Vietnamese main contractors have the great advantage of being BIM champions as they realised that the use of BIM made it more effective to incorporate prefabrication and collaboration early on in the design and construction process (Abanda 2017). Although BIM works best with standardised components and processes (Almeida et al. 2016), the role of manufacturers or suppliers as BIM leaders has not yet been recognised.

7.5.6.1.2 *BIM deliverables: who's responsibility is it?*

Currently BIM is mainly used for the design and pre-construction phase (see Theme 3). Changes and deviations occurring in construction are rarely reflected in the integrated BIM model causing the models to contain inaccurate information for lifecycle use (Liu, Matineh & Akinci 2012). It raises the question of who is responsible for providing the as-built BIM deliverable to the owner. One option has been for the architects and engineers to make changes to their design models to reflect changes made in the field. This option was also agreed by the major research participants who perceived that the creators of the model would be more appropriate for any directly technical intervention. But the designers often do not have the budget to make these changes during construction built using their designs, making it cost-ineffective to rework their design model to reflect changes made by the contractors.

Thus, the second option is that contractors (e.g. site engineers) should do the updates because of their proximity to site and higher profit margin. However, as-built models are usually developed based on the data captured at the end of the construction process rather than constantly updating (see Theme 3). This will affect accuracy and completeness of the developed models since several components get covered or blocked at the end of construction, and hence cannot be captured (Liu, Matineh & Akinci 2012). Even in Bid–Build projects, where main contractors have greater control over the design, the task of providing an as-built model is not easy because the as-built model is manually created and not automated like BIM based design. The manual process of as-built BIM creation is tedious, intensive, subjective and time consuming and requires skilled workers (Hichri et al. 2013). The differences in characteristics of the design team and the site team make on site BIM updates difficult. The designers focus very much on the soundness (error-free presentation) of their design documentation and they tend to be more patient and work individually in a conservative way with disciplinary compliance whereas site engineers appreciate improvisation and quick decision making, team working and flexibility with the greater acceptable tolerances (Tan 2012). Further, the traditional construction method which is characterised by highly cluttered sites, unexpected occlusions, and complex and unstandardised component shapes may mean the BIM updates have a number of assumptions or missing parts (Liu, Matineh & Akinci 2012).

7.5.6.2 Contradiction of time

7.5.6.2.1 *A model requires much more information*

As a parametric-based design, BIM modelling deals with a higher level of operations than CAD does. The designers place and modify entire objects rather than drawing and modifying a set of lines and points. Not only must geometries be specified but also the meanings and the relationships inherent in the geometries. For users who are experienced architects but not skilled modellers, modelling can feel like a loss of control. Designers need to learn IT skills to encode their design intent and at the same time improve their practical knowledge of building products and services in order to describe the objects' relationships and behaviours closely tied to reality. Some AEC companies' managers in China and Australia concerned that the learning curve required with BIM could affect their business before the use of BIM is mastered and yields a better return (Liu et al. 2015a). Holzer (2011) argued that the time consumed in BIM adoption forces designers to take on more risk from a business perspective.

7.5.6.2.2 *Modelling may not save time in custom changes*

There is a misunderstanding by the research participants about the time saving aspect of BIM (see Theme 6). People commonly assumed that BIM reduces time required in documentation by creating a consistent informative virtual model which allows project stakeholders to access the model easily, thus resulting in fewer revisions or early revisions in design. This perception, however, is only partially true due to the automated function of BIM (e.g. conflict checking) which can help optimise architecture and engineering design and reduce errors and the likelihood of lost and repeated work (Li et al. 2014). Automation in design performs well for 'batch' changes, such as massive changes but in pattern. For example, a designer draws a door in plan and adds that same door in multiple sections and elevations. If the designer decides to move that door, the designer does not need to find every other representation of that door and change its location like a CAD user has to. But for minor changes which are scattered and custom and subjective changes which usually occur due to clients' last-minute decisions, editing the model was found to be frustrating and exhausting. This is because the geometry is generated from the model and is therefore not open to direct manipulation (Aubin 2012). The model operates as a unified system in which every object keeps all relationships and behaviours relative as the design evolves. While CAD drawing is brittle to change (e.g. separately modifying without affecting other drawings), any 'marginal' change in a BIM model may cause several indirect changes. That interdependency between all components of the BIM model requires the change to be approved by relevant authorities or the BIM program may treat that unsolved change as a buggy file and stop working (Moayeri 2017).

7.5.6.2.3 *Single firm or discipline finds it easier to adapt to BIM*

At the firm level (e.g. design, construction or building services), BIM software potentially supports AEC companies in automating many repetitive tasks, thus saving time if they streamline their workflows towards standardised BIM objects (Yusuf Arayici et al. 2011). For example, once a typical door has been modelled and placed into a plan, it automatically appears in any section or elevation or other plan in which it ought to be visible; and when that door is modified, all the views update as there is only one instance of that door in the model. Creating BIM based libraries and templates is time and effort consuming but is feasible because each company owns the whole process of change such as allocating resources to support the organisation's strategic goals of BIM, setting in-house standards and providing in-house training for internal staff (Davies et al. 2015).

7.5.6.2.4 *Cross-firm or disciplinary collaboration is more challenging*

However, at the project level, interorganisational and cross-disciplinary collaboration toward BIM is found to consume more time than expected.

First, wider adoption of BIM does not change the fragmented nature of the construction sector (Lu, Zhang & Rowlinson 2013). Architects, engineers and contractors operate in an asynchronous manner. There is usually a time-lag between design changes proposed by the architects, the response from the engineers who run their analysis and the interpretation of the design information by the contractors (Holzer 2011).

Second, the lack of software interoperability may cause several compatibility and clash problems which result in project delays. Each project participant prefers tools which are specialised and tailored to their individual roles (Walasek & Barszcz 2017). There has been an increase in different software and platforms being adopted, thus data loss and corrupted files may occur during the information exchange among project teams, requiring more BIM coordination meetings to solve interoperability issues (Lai & Deng 2018; Stapleton, Gledson & Alwan 2014).

Third, the copyright issue possibly slows down the whole BIM process. The identified theme implied the copyright concern of interviewees due to their uncertainty as to the ownership of the model and the chance of inadvertent sharing of trade secrets or patented processes (see Theme 1). Also, there is no guarantee that the authors of the model receive additional payment if the model data is reused in future projects by other parties. Therefore, the companies usually withhold design elements in order to protect their intellectual property. As the result, each party relies on very basic project information to start modelling from scratch which increases time spent waiting for rework. Lastly, the unclear responsibility of each participant specified in a BIM based contract may lead to the hesitant handover of the BIM model (see Theme 4). The company that transmits the model to others does not want to be responsible for any work created from it when the model is shared with others. This has resulted in the development of disclaimers that limits how the companies which receive the model are able to rely on the model, which drives organisations to recreate their own models, usually from 2D drawings, since it is uncertain if the received model is correct and they can rely on it (Englund & Grönlund 2018).

7.5.6.3 Contradictions of cost

7.5.6.3.1 *Cost of BIM implementation*

There is also the question of compensation when using digital models. Without a clear reward system between project stakeholders, added costs can become a legal risk factor (Englund & Grönlund 2018). The AEC companies would like to reclaim the costs associated with BIM technology such as the purchasing of software and hardware, training, BIM specialists' salary and consultancy fees (Manderson, Jefferies & Brewer 2015). It is argued that a client requiring a BIM model can be responsible for compensating for the relevant costs of a BIM service (Englund & Grönlund 2018). While clients may be willing to pay consultancy fees to use BIM on their projects, the AEC companies are more likely to have to cover a higher proportion of their BIM investment themselves (Thurairajah & Goucher 2013). In other words, extra payment may be approved for BIM deliverables but does not cover other upfront costs of BIM.

7.5.6.3.2 *Cost saving in BIM based projects*

To date, construction activities incur the majority of total project cost including labour, machinery and materials. However, BIM is mostly used in the pre-construction stage such as design and planning where temporary works serving construction activities have been not paid much attention (Bargstädt 2015). Despite the significant impact on safety, site access and workspace, temporary works such as scaffolding, stair towers and site arrangement exist for a certain period of time based on specific tasks and are dismantled or removed when the permanent works become self-supporting or are completed.

Often temporary objects are manually inserted into BIM and thus cannot automatically generate information on their impact on construction operations (Kim & Cho 2015). Designers are reluctant to incorporate temporary works into BIM models because most of them are not trained in temporary works design. Further, clients may not satisfactorily pay for the part of work that is not permanently integrated and is useless in the final model.

It was recognised that the full benefits of the project can only be realised if all parties in the building process transparently contribute to the development of the BIM model (Yusuf Arayici et al. 2011). However, due to the low profit margins within the industry, there is a high likelihood that one or more parties will act opportunistically in exploiting their commercial relationships within the project, and thus increase their profit relative to the other parties involved. For example, the contractors may exploit the lack of supervision of clients by substituting inferior materials or taking shortcuts that will ultimately be hidden by the additional work when it becomes difficult to detect and rectify. Often, this results in an inefficient and financially unsuccessful project, because the total cost for the project is higher than the gain for some opportunistic parties (Forsythe, Sankaran & Biesenthal 2015). In addition, BIM does not significantly reduce the overall project cost because of the imbalance of level of BIM proficiency among project parties. BIM is still very new to the Vietnamese construction industry and many construction companies are not BIM proficient (Nguyen et al. 2021). The BIM process involves many parties working together and therefore much depends on all parties to deliver a project on time. The inefficiency or weakness of just one party can cause the entire project to slow down and cause cost overrun even though the other parties are efficient (Kong et al. 2020).

7.5.6.4 Contradictions of quality

7.5.6.4.1 *Quality of virtual models*

It was noted that BIM is unlikely to be adopted on small simple projects where conventional CAD is still adequate (see Theme 2). In the case of complex projects requiring BIM, when people are rushing to get things started they are not likely to take the time required to go outside the traditional approach (McGraw Hill Construction 2014). It is very common in the Vietnamese AEC industry that companies use a hybrid system of CAD and BIM that considers whether BIM or CAD matches which specific parts of their business for flexible implementation (Bui 2019). However, asking for 2D while requiring 3D work makes the design work incomplete as both 2D and 3D require matching. Problems arise when clients, project managers or even contractors demand 2D output from BIM models for tenders to be on par with construction issue status (Byun & Sohn 2020; Holzer 2011). The dual system of CAD and BIM carries a range of hidden deliverables and additional work by designers who often need to coordinate their 3D BIM work to a level far exceeding their traditional 2D deliverables, in order to achieve a set of higher-quality 2D documents (Byun & Sohn 2020; Holzer 2011).

Also, the BIM tools currently available, even though they represent a significant step forward from conventional CAD practice, are not yet fully developed to satisfy the requirements of many procurement and contractual arrangements which presently exist (Bui 2019; Kouider, Paterson & Thomson 2007; Sardroud et al. 2018). Thus many firms will be dissuaded by the unresolved legal issues which may arise from implementing BIM in their practices, such as ownership and control of the model, use and distribution of the model, and intellectual property rights (Fan et al. 2018; Lu & Korman 2010).

7.5.6.4.2 *Quality of physical works*

It is assumed that a better BIM based design or an error-free model could significantly increase the quality of actual building (Wong, Zhou & Chan 2018).

However, the quality of the completed project remains unchanged because most construction works are still labour intensive with many manual tasks associated with raw material handling on site such as cast-in-place concrete and masonry (Er 2017; Nguyen Phuong, Birkeland & Demirbilek 2010). The large proportion of site works means changing working conditions where unpredictable factors such as human errors, climate or delays in material supply negatively impact the finished works.

As there is a small amount of automated manufacture and a direct transition from BIM to built artefact is not commonplace as a mainstream means of delivery (Holzer 2011), the construction performance tends to heavily rely on the effectiveness of the problem-solving process exercised by construction managers' experience, particularly in planning and rough estimating, rather than BIM technologies (Mäki & Kerosuo 2015). Further, the as-built models are unlikely to be updated regularly and the data quality is not optimal, thus bringing post-handover problems (Lin et al. 2016). Often the developed models were not able to capture the quickly as-built conditions so that the site works have to continuously progress even before the availability of an updated model. It is relatively simple to corrupt the digital records, or amend dates, times and other data to regularise the current status of building instead of using BIM to simulate and predict obstacles which may improve project quality (Enshassi, Hallaq & Tayeh 2019).

7.6 Discussion

7.6.1 Interpreting the findings using the combined framework of Diffusion of Innovation Theory and Activity Theory

7.6.1.1 Theme 3: Tools

Generally, both BIM specialists and non-BIM specialists perceived BIM as not a disruptive technology but a gradually developing set of interoperable tools that are used simultaneously with non-BIM tools (Kerosuo et al. 2015). Tools mediate human activity. They are an integral part of the activity and cannot be considered separately from the context of their use (Engeström 1987). To make them instruments for local practice, they need to be interpreted and reconstructed by the subjects to meet the specific requirements of their activity (Kaptelinin, Kuutti & Bannon 1995).

Kerosuo et al. (2015) suggested that a process in which a new tool becomes an instrument in a local activity can take place on different levels. On the first level, the tool is used in specific circumstances, in which it is given a temporary function. On the second level, the properties of this tool are linked more permanently to functions that it can perform. On the third level, the tool itself is modified to perform new functions. In the case of Vietnam, the adoption of BIM represents the first level of maturity when its applications are spontaneous and experimental (Bui 2018).

BIM is not simply a digital technology. BIM aims to create a virtual environment in which most interactions of project stakeholders take place. However, the transition from physical to virtual environment requires changes in the legal framework, supplementary technologies, culture and norms, and division of labour which organisational readiness cannot currently adapt to. This explains why traditional communication tools such as conversations, meetings, telephone, email and video conference remain dominant for multidisciplinary collaboration in projects (Azouz et al. 2014). BIM tools are expected to facilitate design, collaboration and communication among project teams but, to date, only the design function is widely adopted while the two functions of collaboration and communication are still evolving.

7.6.1.2 Theme 4: Objects and Theme 6: Outcomes

Previous BIM research using Diffusion of Innovation Theory explained slow adoption as the result of the inability of adopters, technical complexity, inefficient communication and a discouraging environment (Jayasena et al. 2019; Panuwatwanich & Peansupap 2013; Rogers 2003). Activity Theory, on the other hand, contributes to BIM research by providing an alternative interpretation, arguing that the "collective" aspect of joint activity (e.g. BIM collaboration) make it difficult to transform the fragmented and paper-based CAD system to the social-collaborative and digital BIM platform (Singh, Gu & Wang 2011). In a joint activity, the object is shared and constantly negotiated rather than being individual based and prescribed (Engeström 2009). The outcome of a joint activity is perceived as the collective contribution of different subjects involved in different activities (Said et al. 2014). As a result, participating subjects felt frustrated to reconcile multiple objects which are sometimes conflicting, unrealistic or ambitious (Theme 4).

The assessment of BIM outcomes is also challenging as BIM values are often intangible, and thus are unable to be validated through traditional criteria such as return on investment. There are also concerns associated with BIM outcomes such as the authority of shared models, benefits and risks of sharing between contributors and receivers such as royalties for reusing models, infringement of copyright, security and confidentiality of the information (Fan et al. 2018; Olatunji & Sher 2010). Theme 6 represented these challenges and implied that they are not related to technical issues but emerge through social interactions which significantly impact post-adoption behaviours. Recent studies confirmed Theme 6, showing that companies take a 'wait-and-see' position despite early engaging in 3D technologies (Liao et al. 2020). Until social problems are reconciled, many companies are hesitating in pursuing higher level BIM applications beyond 3D BIM (Gledson & Greenwood 2017).

7.6.1.3 Theme 5: Subjects

It is noted that subjects perform a collective activity within the context of unequal power relationships (Wheelahan 2007). The combined framework of Diffusion of Innovation Theory and Activity Theory distinguishes BIM adoption activity by non-BIM specialists (e.g. decision makers) and BIM implementation activity by BIM specialists (e.g. employees). Decision makers used their power relations through rules and hierarchies to make the initial decision to adopt BIM and govern the employees' behaviours to conform to the BIM mandate. Although employees' behaviours were constrained by the system's boundaries, they manifested the expectations of empowerment by becoming involved in the decision making process, developing autonomy through trial and error, and achieving social recognition through defined BIM titles to bargain their power during the implementation of innovation. The initial attempt of decision makers to adopt a top-down approach to achieve speedy adoption was not possible due to the resistance of employees (Maali et al. 2020). Therefore, BIM implementation activity should have a bottom-up approach rather than a top-down approach in order to engage employees in the adoption, ensure that employees' skills and understanding increase and companies build up their capacities, apply successful change management strategies, and reduce any potential resistance to change (Arayici et al. 2011).

7.6.1.4 Theme 7: Mandatory setting

The Vietnamese government as decision makers used the BIM mandate to externally force AEC companies to adopt BIM while the internal readiness of companies was not mature. In particular, the BIM mandate mediates the movement towards transparent information sharing and collaborative working, but it also raises the need to secure that information and the professional liability when multiple parties could be involved in producing a shared model. When a technology is forced on organisations, the adoption rate is either higher as a consequence of the innovation being forced on the adopting unit, or the opposite, where the adoption rate is lower as a consequence of the unit's resistance to adopting a compulsory technology (Tscherning & Damsgaard 2008). Consideration must be given to the specific context of the adopting unit to determine the level of government intervention. Case studies in developing countries including Malaysia, Indonesia and Vietnam, showed that whether it is mandatory or not, the commitment and vision of decision makers are perceived as more important for adopting units to shape their post-adoption behaviours such as postpone (wait and see), reject or continue (Ismail, Chiozzi & Drogemuller 2017). Rather than mandating BIM, the government should, for example, first support emerging data marketplaces facilitating the trade of digitised building objects, which project stakeholders can reuse to improve productivity. If potential adopters perceive BIM as a disruptive innovation which possibly creates a new market and significantly changes system norms, they may embrace new technology to streamline and enhance their work (Meuer et al. 2019).

7.6.1.5 Theme 8: Contradictions

Theme 8 showed that although BIM is a new tool, challenges of implementing BIM were seen as equivalent to traditional project constraints of scope, time, cost and quality. Presenting a certain degree of similarity may make a technology easier to penetrate into the adopting community at the entry level but when knowledge of innovation is cumulative, the degree of difference makes this technology distinct and determines whether the technology can change system norms (Kant et al. 2018). Old technology survives when the new technology does not create a strong enough social influence to displace the community of non-users (MacVaugh & Schiavone 2010).

7.6.2 Cross-case analysis

Table 7.7 summarises BIM collaboration activities of case organisations in the second round of case studies.

Table 7.7 BIM collaboration activities in the second round of case studies

Case organisations	BIM specialists	Non-BIM specialists
D_5 (architecture)	- Pilot projects - Not very confident in BIM practices	
D_6 (engineering)	- High level of implementing BIM and open to collaboration - Lack of client demand and competent partners to collaborate with	- Have long-term vision of BIM - Concern about ambition of the government BIM mandate
C_2 (contractor)	- Lonely BIM	- Inconsistent adoption of BIM
O_2 (owner)	- Adopt BIM to better control Bill of Quantity	
GA (government agency)		- Less impact on BIM implementation

The case organisations have various levels of BIM readiness, capability and maturity because of their different disciplines and sizes. The architecture company D_5 has recently started to use BIM in pilot projects, thus BIM specialists of company D_5 are not very confident in their BIM collaboration activities. They may suffer losses or only break-even in the initial years but may gain experience and learn lessons along the way.

On the other hand, the MEP engineering company D_6 demonstrates a high level of BIM adoption. Non-BIM specialists of company D_6, the directors, have a long-term vision of BIM and are open to collaborate with other partners in the supply network. However, the lack of client demand is seen as a main reason for not adopting high-level BIM in projects although company D_6 still provides their clients with free access to basic 3D models to facilitate visual presentation and marketing. The lack of competent BIM partners is another barrier to BIM collaboration as the workload shifts to BIM specialists of company D_6. Architectural models passed from company D_5 are not qualified for instant use but may need remodelling to continue engineering analysis.

The contractor company C_2 has a problem with collaboration between the BIM team and site teams. The BIM team coordinates design models from companies D_5 and D_6 and shares the integrated model with site teams. However, due to tight schedules, site teams may not put effort into model updates and instead rely on traditional 2D drawings to make quick decisions on site. In addition, the complexity of collaborative design consumes more time to rectify and cannot catch up with site progress. At present, the connection between the BIM team and site teams is loose. The BIM team attempts to perform design coordination, but its effort remains optional for site teams.

The involvement of the owner company O_2 in BIM collaboration activities is not significant as senior managers of O_2 admit they only use BIM outcomes for internal checks of the Bill of Quantity. Managing work items against prices is still the priority of the owner despite the potential of BIM to increase safety and be environmentally friendly.

The Vietnamese government agency GA expects to diffuse BIM through the construction industry through its BIM mandate but its ambition may not be feasible, particularly as the organisation GA has less experience in BIM implementation. The intervention of GA has a relatively small influence in the current business of other partners in the supply network such as D_5, D_6, C_2 and O_2 because it may take several years to complete pilot BIM projects in the public sector to revise the legal framework that creates radical change in the way partners work together.

7.7 Triangulating themes

7.7.1 Validating Theme 3: Tools

Figure 7.3 represents popular BIM software used in the Vietnamese AEC industry. Rather than having an integrated virtual model created by a defined set of tools, a variety of BIM models were used together with other software and tools. Different technical solutions have been suggested for data sharing and exchange of information. The comprehensive single BIM "has been the holy grail but it is doubtful whether there is the will to achieve it" (Howard & Björk 2008, p. 273). Usually members belonging to an activity system of a single firm tend to give priority to their single object over shared objects with other activity systems. This explains why the BIM software was constructed to be used in the specific task of functions such as architect's design, modelling of lightning or fire simulation to meet separate contractual requirements. Further, people are prone to use preferred or available tools to address emerging issues rather than relying on a powerful but unfamiliar new tool. This reflects the situation that BIM is implemented as part of 'hybrid practices' where BIM tools are used in parallel with other digital tools and also with many non-digital tools.

Figure 7.3 Common BIM tools used in Vietnam (developed from observation)

Figure 7.4 shows that the general contractor, particularly the site manager, took full control of BIM coordination meetings while subcontractors had less authority to access the model. Despite the support of the 3D visualisation tool, the blame game still occurred between the subcontractors of steel and formwork. This was because the two subcontractors did not engage in the BIM process early to avoid conflicts or overlap between their work and others. Knowledge transfer between BIM specialists and non-BIM specialists was insufficient and technology alone cannot completely address it.

Figure 7.4 Disputes in a BIM coordination meeting (GC indicates general contractor) from direct observation (snapshot during site visits)

7.7.2 Validating Theme 4: Objects

Analysing secondary data (see Figure 7.5, Figure 7.6 and Figure 7.7) showed that BIM is adopted at different levels across different organisations as they have quite different needs and interests. This finding matches the theme 'object'. Similarly, Spinuzzi and Guile (2019) argued that the case companies tend to include objects that are fractional rather than unified, emergent rather than established, and transformed through multiple, loosely synchronised cycles rather than a single developmental cycle.

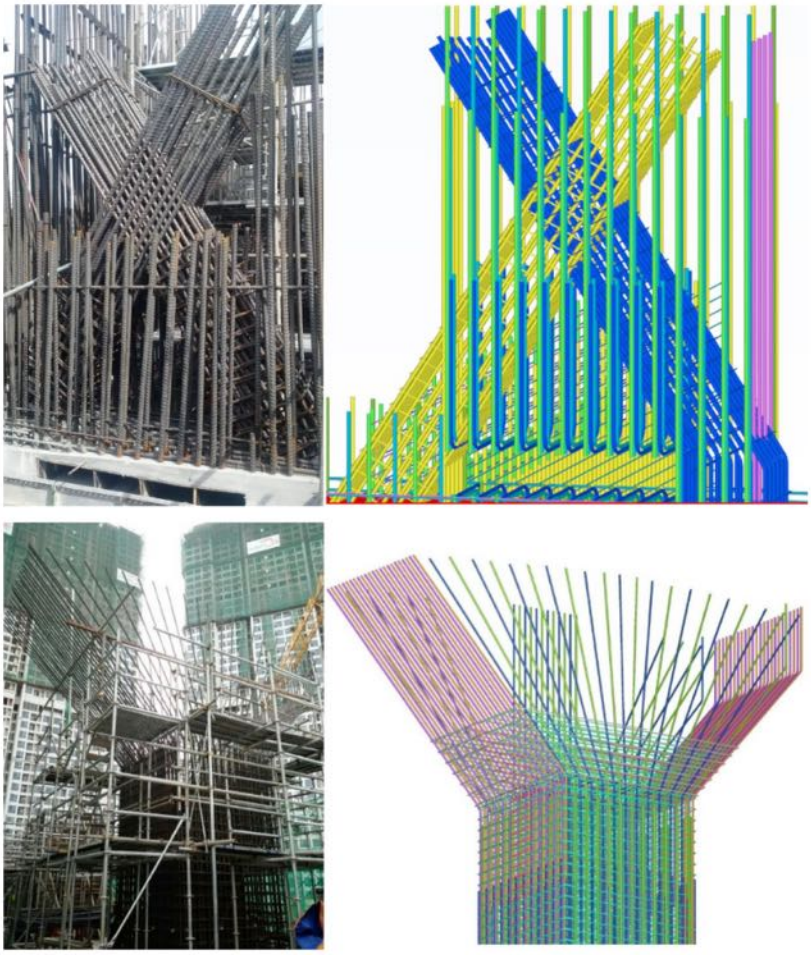

Figure 7.5 Object of designers is an error-free model (documents shared by company D_5)

Figure 7.6 Object of contractor is flexible construction solution (documents shared by company C_2)

Schedule: I- - TD-03_DS-AR_CT3_2015-06-30-Render 3 Bedroom.rvt

<I->

A	B	C	D	E	F	G	H
Assembly Code	Assembly Description	Family and Type	Manufacturer	Model	Type Mark	Count	Cost
E2010100	Fixed Artwork	3BR-K01c: Material	Casta	Kệ bếp BT01	I-BT01	1	8,000,000₫
E2010100	Fixed Artwork	3BR-K01b: 3BR-K01b	Casta	Kệ bếp BT03	I-BT03	1	12,000,000₫
E2010100	Fixed Artwork	3BR-K01: 3BR-K01	Casta	Kệ bếp đảo BD03	I-BD03	1	10,000,000₫
Casta: 3							30,000,000₫
E10	Equipment	3BR-K01d: Material	Electrolux	Tủ lạnh Side by side EX02	I-EX02	1	45,000,000₫
Electrolux: 1							45,000,000₫
E2020200	Furniture & Accessories	Haworth_Bay-Table-Re	Haworth	Haworth_Bay-Table-Rectangle	I-BA01	1	20,000,000₫
Haworth: 1							20,000,000₫
E2020200	Furniture & Accessories	3BR-01-006 Bed Cabin	IKEA	Bed Table 01	I-TB01	4	12,000,000₫
E2020200	Furniture & Accessories	Chair-Breuer: Chair-Bre	IKEA	Breuer 01	I-GA01	6	18,000,000₫
E2020200	Furniture & Accessories	Table-Coffee Mies: 40"	IKEA	Coffe Table	I-BC01	1	5,000,000₫
E2020200	Furniture & Accessories	LF_B01 Bed: LF_B01 B	IKEA	MALM Bed frame, high, w 4 storage boxes	I-G01	2	32,000,000₫
IKEA: 13							67,000,000₫
E2010100	Fixed Artwork	Fabic Curtain2: Type 1	Màn Việt	Màn 2 lớp voan + màn cotton màu ghi	I-MA01	6	12,000,000₫
Màn Việt: 6							12,000,000₫
E2020200	Furniture & Accessories	LF_B02 Bed: LF_B02 B	Mộc Việt	Giường 2 tầng G02	I-G02	1	8,000,000₫
E2020200	Furniture & Accessories	3BR-01-J01: 3BR-01-J0	Mộc Việt	Tủ quần áo + Bàn trang điểm TA01	I-TA01	1	10,000,000₫
E2010100	Fixed Artwork	3BR-Pa1 Partition: 3BR-	Mộc Việt	Vách trang trí bọc vải V02	I-V02	1	6,000,000₫
E2010100	Fixed Artwork	3BR-Pa3 Partition: 3BR-	Mộc Việt	Vách trang trí dán Venner V01	I-V01	1	10,000,000₫
E2010100	Fixed Artwork	3BR-Pa2 Partition: 3BR-	Mộc Việt	Vách trang trí dán Venner V03	I-V03	1	6,000,000₫
Mộc Việt: 5							40,000,000₫
E2010100	Fixed Artwork	3BR-J04: 3BR-J04	Nhà Xinh	Kệ giày dép TG01	I-TG01	1	5,000,000₫
E2020200	Furniture & Accessories	3BR-01-002 TV Cabinet	Nhà Xinh	Kệ Tivi TV01	I-TV01	1	6,000,000₫
E2020200	Furniture & Accessories	3BR-01-007 TV Cabinet	Nhà Xinh	Kệ Tivi TV02	I-TV02	1	4,000,000₫
E2010100	Fixed Artwork	3BR-J02: 3BR-J02	Nhà Xinh	Tủ âm tường TA04	I-TA04	1	6,000,000₫
Nhà Xinh: 4							21,000,000₫
Grand total: 33							235,000,000₫

Figure 7.7 Object of client is clear Bill of Quantity (documents shared by company O_2)- Refer to Appendix 17 for full page figure

7.7.3 Validating Theme 5: Subjects

Site engineers are the main BIM users during the construction phase but their working conditions are not as suitable as the BIM department at head office due to poor internet connection, lack of IT equipment and compact meeting room (see Figure 7.8). Site engineers still need to abstract the ‘smart 3D assemblies’ from coordinated BIM models into 2D representations in order to communicate design intent. In addition, they cannot rely on actual 3D construction information when communicating with builders or workers, as they base their work on ‘traditional’ 2D plans and sections. A good portion of relevant building information never gets modelled when considering a level of detail at the magnitude of 1:20 and below. At that scale, communication of intent can be handled more easily in 2D compared to the effort that would be required to produce the same level of information in 3D and considering the file size and computing power required to manipulate or visualise a large amount of detailed 3D information.

Figure 7.8 Coordination BIM meeting on site (snapshot during site visits)

7.7.4 Validating Theme 6: Outcomes

Figure 7.9 illustrates the actual outcomes achieved through the use of BIM. To date, better site arrangement for site access, safety and workspace is one of the most obvious outcomes that BIM can offer adopters along with the visualisation of design. BIM helps contractors and project management staff to 'see' where works are to be carried out and further review any areas of difficulty that may be apparent. This results in a cleaner and safer construction site compared to a congested construction site when not implementing BIM (see Figure 7.10 and Figure 7.11). Workers in Figure 7.10 split in groups and worked in separated locations at the site. In particular, the assembly of steel components into a frame on site was carried out at the rear while the erection of structural steelwork was performed in the middle. Due to the good arrangement, the working space is tidy which may increase the productivity. On the other hand, workers in Figure 7.11 had to wait until others completed tasks. There was less room for co-working or manipulation and some people has to work in uncomfortable positions (e.g. bending back and knees).

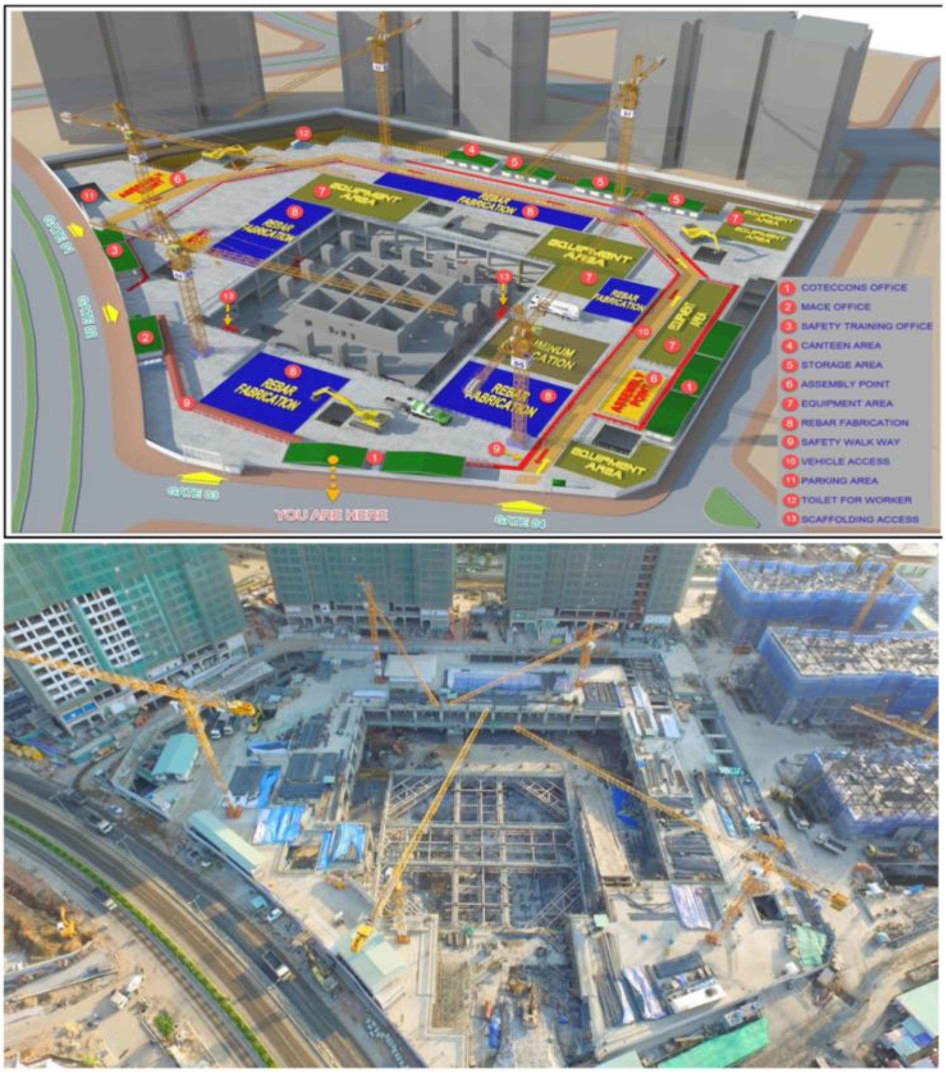

Figure 7.9 Site arrangement simulated by BIM tools (documentation shared by company C_2)

Figure 7.10 Clean and safe construction site (snapshot during site visit)

Figure 7.11 Congested construction site (snapshot during site visit)

7.7.5 Validating Theme 7: Mandatory setting

The researcher was not permitted to access BIM based strategy documents of the case companies but data from interviews suggested that the uses of BIM have been mandated and are considerably advanced in projects where project sponsors or owners may delegate authority for certain decisions to the case companies (e.g. main contractors or BIM consultants).

7.7.6 Validating Theme 8 using member checking

The results of the main cases were sent to key participants for their review and feedback. The selected receivers included senior managers of companies (e.g. TM_2D_1, MM_1D1, MM_2D_1, MM_1C_1, MM_1C_2, MM_2C_2 and MM_3D_5) or experienced employees (e.g. E_1C_1 and E_2C_1). The response rate was 100% as the researcher built strong rapport with participants during the first round of case studies. All comments indicated that the themes reflected quite correctly the status of BIM adoption in the Vietnamese AEC industry. Most reviewers agreed with the contradictions emerging through the BIM process found in the main cases and suggested the further investigation of current solutions which their peers in different companies used to tackle these contradictions.

7.8 The evolution of the combined framework

The beginning of Chapter 7 proposed the first version of the combined framework of Diffusion of Innovation Theory and Activity Theory (see Figure 7.12) to guide the data analysis during the second round of case studies. The main components of this combined framework help to generate deductive codes[26] which often form main themes such as subjects, tools, objects and outcomes.

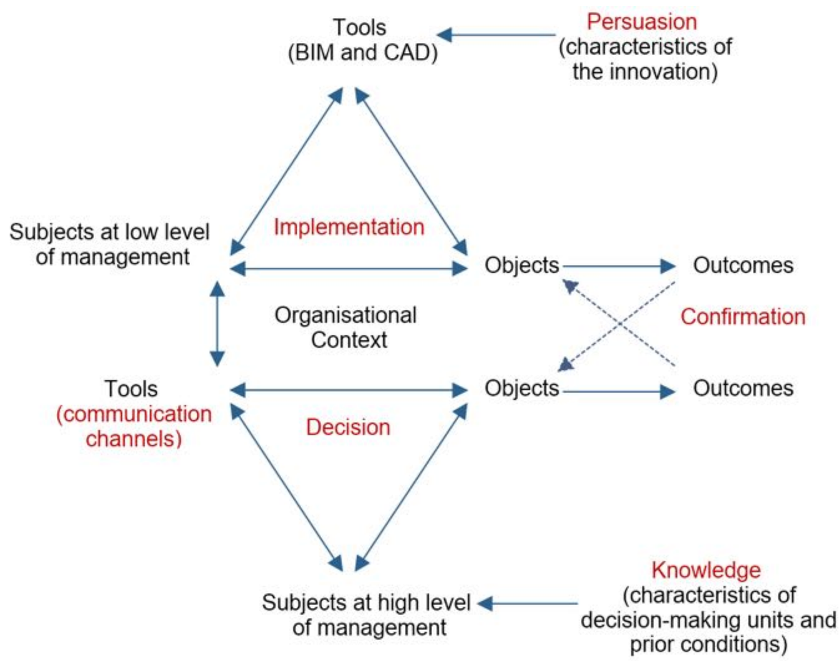

Figure 7.12 The first version of the combined framework of DOIT and AT (replication of Figure 7.2)

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[26] Deductive codes: Codes were firstly fitted into a pre-existing coding framework to provide detailed analysis of aspects of the data of most interest in exploring (Nowell et al. 2017).

In addition to deductive codes, some inductive codes[27] were generated from raw data (e.g. interview data) and unexpectedly resulted in emerging themes such as organisational characteristics, personal re-evaluation and environmental characteristics. These emerging themes were subsequently added into the first version of the combined framework, expanding it into the second version (see Figure 7.13).

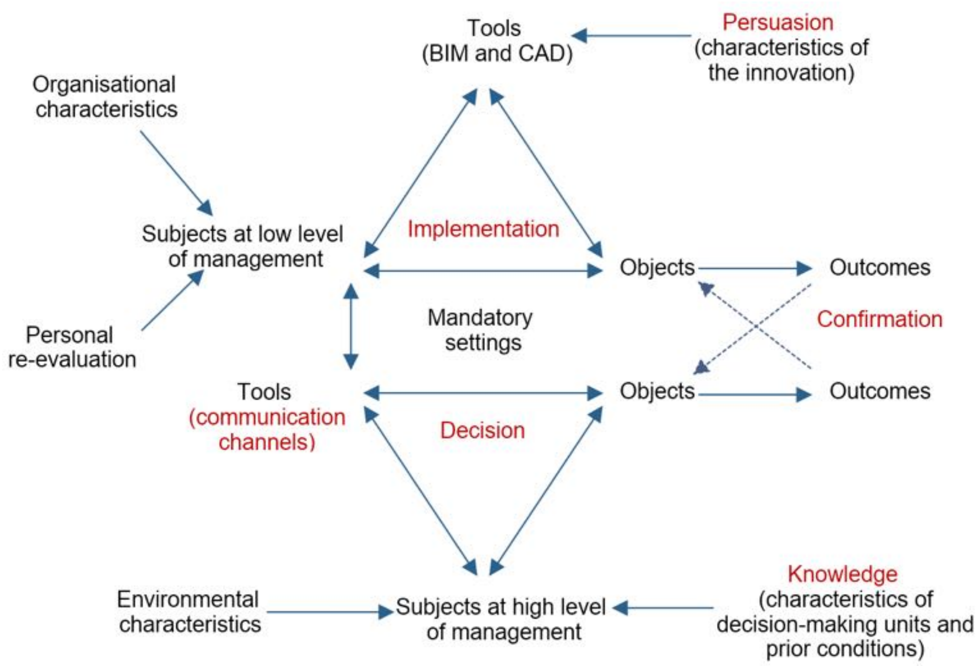

Figure 7.13 The second version of the combined framework of DOIT and AT

7.9 Summary

This chapter addressed the second research question: How do BIM specialists and non-BIM specialists in the Vietnamese construction industry carry out BIM collaboration activities? Using the first version of the combined framework of Diffusion of Innovation Theory and Activity Theory, fragmented interview data was categorised in a well structured manner which assisted the analysis of the dynamic interplay between BIM specialists and

[27] Inductive codes: Codes were data-driven without trying to fit it into a pre-existing coding frame or the researcher's analytic pre-conceptions (Nowell et al. 2017).

non-BIM specialists. Main themes were established and presented according to key elements of the combined framework such as subjects, objects, tools, outcomes and mandatory settings. The contradictions in the inter-relationships among key elements were also examined.

The next chapter finds more cases to run cross-case analysis to confirm the main themes and to examine how different companies may respond to these BIM contradictions. The second version of the combined framework (Figure 7.13) is used to guide data analysis in the next chapter to further improve the combined framework depending on the findings.

CHAPTER 8 Findings from the third round of case studies

8.1 Chapter objectives

The purpose of this chapter is to investigate the responses of BIM specialists and non-BIM specialists to contradictions occurring during BIM collaboration activities. As noted at the end of Chapter 7 Findings from the second round of case studies, the second version of the combined framework of Diffusion of Innovation Theory and Activity Theory is applied to guide the analysis of the third round of case studies (see Figure 8.1).

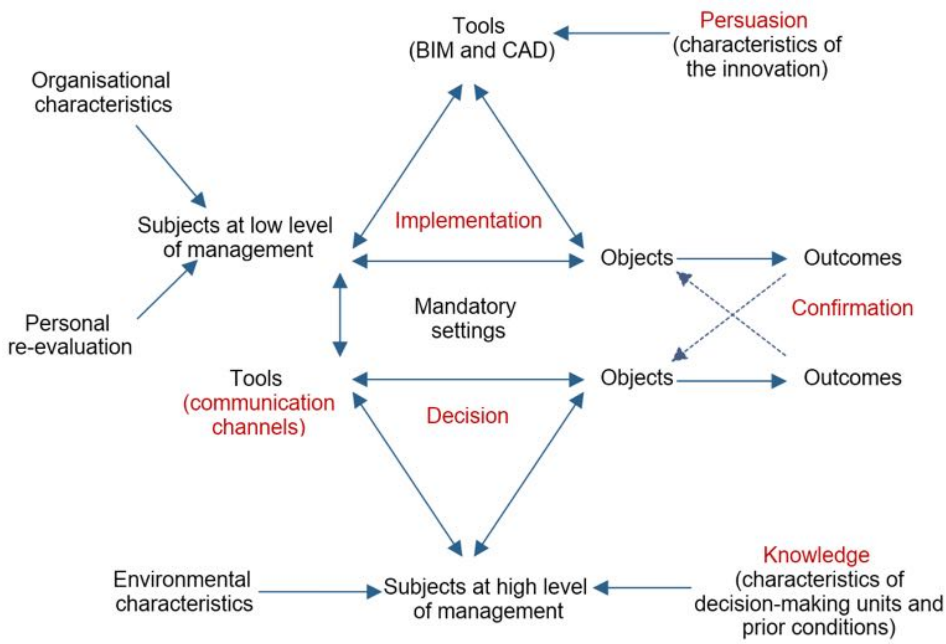

Figure 8.1 The second version of the combined framework of DOIT and AT (replication of Figure 7.13)

In particular, this chapter aims to achieve the research objectives:

- To validate the combined framework to explain BIM collaboration activities among BIM specialists and non-BIM specialists

- To explore the responses of BIM specialists and non-BIM specialists in the Vietnamese construction industry to contradictions occurring during BIM collaboration activities.

8.2 Context of organisations adopting BIM in the third round of case studies

Table 8.1 provides the context of case organisations including their name, size and scope of business, BIM tools used, and their current BIM uses.

Table 8.1 Context of case organisations in the third round of case studies

Company	Size and scope of business	BIM tools	BIM implementation
GA - Government Agency - Under the management of the Vietnamese Construction Ministry	- 10 government employees - 20 voluntary BIM specialists and industry senior managers - Conducts the national BIM diffusion program (since 2016) co-sponsored by the UK government - Influenced by the UK's BIM standards and policies	- Cooperates with BIM software vendors and developers to carry out research on various BIM tools matching the Vietnamese context	- Cooperates with project owners to conduct BIM pilot projects to get data for publishing case studies and practical experience - Supports project owners in the initial phase (setting BIM system, preparing BIM based contract, recommending BIM consultants, giving incentives)
D7 - Architecture company - Local private owned enterprise	- 50 employees - Specialist modelling - BIM coordination - BIM documentation - Outsourcing modelling services	- Architecture design: Revit - Structural and MEP coordination: Navisworks	- Provides BIM implementation strategy to projects at various stages and levels - Provides BIM implementation strategy to companies according to specific requirements
D8 - Engineering company - Global enterprise (100% foreign capital)	- 300–350 employees - 3D BIM: documentation and rendering and animation - 4D BIM: quantity take-off	- Architecture design: Revit and Navisworks - Structural and MEP design: Tekla	- Provides BIM solutions to designers, owners and contractors - Shares digital design and documentation expertise and

	- 5D BIM: time simulation - Visualisation: AR, VR - Computational design	- Design management: BIM 360 Team - Programming: Dynamo	becomes part of clients' team, sometimes acts as project management - Has R&D department to develop BIM tools
C_3 - Construction company (general contractor) - Local private owned enterprise	- 6,000 employees - Main contractor of building and infrastructure projects - Design–Build projects - Real estate trader - Trades construction machines - Trades construction materials and furniture	- Modelling: Revit - Coordination: Navisworks - Site management: BIM 360 field	- Has in-house design management - Established BIM team in 2011 - Mandatory BIM application for all Design and Build projects (since 2016) - Focuses on BIM for coordination: clash detection and site arrangement - Experiments with BIM for site safety
O_3 - Owner - State owned enterprise	- 10,000 employees - Manages and operates most international and domestic airports in Vietnam	- Not yet	- Not yet

Note: small size (10–100 employees), medium size (100–200 employees) and large size (>200 employees) based on the classification of the Vietnamese government[28].

8.3 Units of analysis

Table 8.2 presents the units of analysis of case studies including BIM specialists and non-BIM specialists in case organisations. To maintain confidentiality, names of companies and respondents were coded. The abbreviations TM, MM and E represent the position of the participant in the company as top management, middle management or employee, whereas D, C, O and GA refer to the type of organisation such as design company, contractor, owner or government agency. For instance, the full code TM_1D_7 means participant 1 at top management level working at design company 7. The background of BIM

[28] https://english.luatvietnam.vn/ecree-no-39-2018-nd-cp-dated-march-11-2018-of-the-government-on-detailing-a-number-of-articles-of-the-laws-on-small-and-medium-sized-enterprises-160820-Doc1.html

specialists and non-BIM specialists is summarised in Table 8.3 and Table 8.4 respectively.

Table 8.2 Units of analysis for the third round of case studies

Company	Participant	Position	BIM role
GA (Government Agency)	- GA_1 - GA_2 - GA_3	Government agent Government agent Government agent	Non-BIM specialist Non-BIM specialist Non-BIM specialist
D_7 (Design)	- TM_1D_7 - MM_1D_7, MM_2D_7, MM_3D_7 - E_1D_7	Top management Middle management Employee	BIM specialist BIM specialist BIM specialist
D_8 (Design)	- TM_1D_8 - MM_1D_8 - MM_2D_8	Top management Middle management Middle management	Non-BIM specialist Non-BIM specialist BIM specialist
C_3 (Contractor)	- TM_1C_3 - MM_1C_3 - MM_2C_3 - E_1C_3, E_2C_3, E_4C_3 - E_3C_3, E_5C_3	Top management Middle management Middle management Employee Employee	BIM specialist BIM specialist Non-BIM specialist Non-BIM specialist BIM specialist
O_3(Owner)	- TM_1O_3	Top management	Non-BIM specialist

Total: 5 organisations with 10 BIM specialists and 10 non-BIM specialists

Table 8.3 Background of BIM specialists in the third round of case studies

Participants	Position	Specialty	Industrial/BIM tool experience
TM_1D_7	BIM manager	Architecture	10+/10+
MM_1D_7	Structure leader	Structure engineering	5+/5+
MM_2D_7	Architecture leader	Architecture	5+/3-5
MM_3D_7	MEP leader	MEP engineering	5+/3-5
E_1D_7	BIM modeller	Structure engineering	3-5/1-3
MM_2D_8	BIM manager	Structure engineering	10+/10+
TM_1C_3	BIM manager	Architecture	10+/5+
MM_1C_3	BIM coordinator	Architecture	5-10/3-5
E_3C_3	BIM modeller	Structure engineering	5-10/3-5
E_5C_3	BIM modeller	Architecture	1-3/1-3

Total: 10 BIM specialists

Table 8.4 Background of non-BIM specialists in the third round of case studies

Participants	Position	Specialty	Industrial/BIM tool experience
GA_1	Change agent	Structural engineering	1-3/0
GA_2	Change agent	Structural engineering	1-3/0
GA_3	Change agent	Structural engineering	3-5/0
TM_1D_8	Director	Civil engineering	20+/0
MM_1D_8	Architecture leader	Architecture	5-10/1-2
MM_2C_3	MEP site manager	MEP engineering	20+/0
E_1C_3	Site engineer	Civil engineering	5-10/0
E_2C_3	Site engineer	Civil engineering	3-5/0
E_4C_3	Site engineer	Architecture	3-5/0
TM_1O_3	Owner	Structure engineering	20+/0

Total: 10 non-BIM specialists

8.4 Summary of findings

Table 8.5 summarises the findings in the third round of case studies.

Table 8.5 Summary of findings in the third round of case studies

Main themes	Sub-themes	Sub-sub-themes
Theme 9: Responses to contradictions	Responses at the government level	- *Scope of work* - *Time* - *Cost* - *Quality*
	Responses at the project level (cross-firms)	- *Scope of work* - *Time* - *Cost* - *Quality*
	Responses at the individual level (single firm or discipline)	- *Scope of work* - *Time* - *Cost* - *Quality*

There is one main theme (theme 9) exploring the responses of participants in the Vietnamese construction industry towards contradictions occurring during BIM collaboration activities. The level of responses is divided into the government level, project level and individual level. Findings imply that, although knowing that BIM is a new tool with associated processes, research participants still considered contradictions of BIM collaboration activities in the same way as traditional project management constraints of scope of work, time, cost and quality. This social norm can still prevail and influence behaviours of adopters (e.g. problem-solving) even when BIM proves its potential in the post-construction stage such as facility management and post occupancy improvements such as efficient use of resources and being environmentally friendly.

8.5 Confirming findings in the second round of case studies using the combined framework

8.5.1 Confirming Theme 3: Tools

8.5.1.1 Tools used in BIM implementation activity

This section confirms Theme 3 Tools in the second round of case studies that non-BIM technologies such as phone, fax and email are widely used in conjunction with BIM tools. It takes a significant amount of time to change current communication behaviours of using non-digital platforms because of the availability and utility of non-BIM tools, the fragmented nature of construction projects, and the habit of using communication tools in a flexible manner and not following a communication protocol.

Most BIM adopters confirmed that phone, fax, email and social media software such as WhatsApp are the most utilised tools. A site engineer noted that *"we communicate in a number of ways every day, both verbally and nonverbally and construction communication is no different. We text, we talk on the phone and in person, we send emails and some of us in this digital age inexplicably still use the old fax machine"* - MM_2C_3. Another site engineer commented that *"on the construction site, we communicate through signs, drawings, hand signals and meetings. We compile daily reports, take photos, create requests for information and* *review change orders"* - E_1C_3. The findings match Theme 3 which described that BIM adopters were not familiar with communication in the digital environment. The potential of the communication function of BIM was not fully realised compared to its modelling function.

To optimise BIM as an effective communication tool *"all stakeholders must have access to it, have been properly trained and be committed to using it"* - TM_1C_3. However, one BIM manager conceded that *"the increased use of BIM has not caused a qualitative change to the basic ways of working in disciplinary 'silos' in construction projects"* - TM_1D_7 and *"work practices that support increased collaboration and knowledge sharing across organisational and disciplinary boundaries have been slow to emerge"* - MM_1D_7. This finding matches the previous themes, particularly Theme 3, which explored that the fragmented and dispersed structure of the building industry feeds adversarial attitudes that do not favour trust-based forms of collaboration, resulting in BIM adoption in silos and a spontaneous manner.

In addition, the Vietnamese AEC professionals shared a 'flexible' attitude that all methods of communication have their advantages and disadvantages, thus choosing the right method of communication can expedite and simplify the exchange of information. An architect noted that *"sometimes a quick email is all that's necessary while other instances may call for a meeting of all key personnel on the project"* - MM_2D_7. Similarly, another site engineer stated that *"if you can't communicate your email message in one or two short paragraphs, or if there ends up being a lot of back and forth, it may be time to pick up the phone or schedule a quick face-to-face meeting"* - MM_2C_3. However, this norm of flexibility may negatively impact the unified and consistent features of BIM as a single integrated virtual model. Usually BIM adopters, the site engineers, did not strictly follow the methods of communication for specific tasks and information sharing *"although they were established early on in the project and agreed upon by all stakeholders"* - MM_3D_7. Any deviations from the prescribed methods of communication could result in *"messages not being* *received or wrongly received by the intended parties causing delays or misunderstandings in the project"* - MM_2D_7.

8.5.1.2 Tools used in BIM adoption activity

This section implies that in the context of a developing country of low-tech status, BIM adoption in Vietnam has its roots in imitation rather than invention. Thus, the diffusion interventions of top management may focus on non-technical strategies of using the BIM team as change agents and providing training, standards and guidelines to persuade end-users rather than investing in R&D. However, such top-down approaches as administrative tools do not guarantee the commitment of end-users as they consider less the conditions of actual BIM uses such as building rapport between the BIM team and the site team, developing a reward system, accepting mistakes during pilot stages, and acting as a role model or BIM champion.

Senior managers of the AEC firms strengthened the finding from the previous cases that the BIM team is perceived as a change agent in diffusing BIM management by providing promotion, training and information, setting up new role descriptions, responsibility areas and developing internal education in several of the case companies, and by developing new digital practices in construction projects. For example, *"the BIM team was highly expected to promote and develop new work practices within the industry"* - TM_1C_3 and *"the new trend toward digitalisation has been portrayed as a key for solving communication and information sharing issues within the industry, thus high hopes have been placed on the BIM team to change existing practices"* - MM_2C_3. While the AEC firms preferred to establish their in-house BIM team, owners (e.g. developers and project sponsors) hired change agent consultants to support them in changing the organisation. *"A change agent team or key person [BIM champion] is hired to make and revise procedures then organisational members are introduced to new procedures and IT application through briefings, seminars and training"* - TM_1O_3.

BIM specialists were often empowered and funded by the head office who assigned them to diffuse innovation over construction sites. BIM use is just optional as *"site people are not selecting a practice that would support the development of new practices, but that would confirm or maintain the traditional practices, often due to a lack of time and project type (e.g. Bid–Build)"* - TM_1C_3. Most BIM team members acknowledged that they fail to build trust with site staff as the role of the BIM team was negatively perceived as a 'double agent' by site people. *"We feel isolated as site people watch us and are reluctant to support and share information for model update"* - E_3C_3. This finding coincides with Theme 3, demonstrating that BIM specialists should consider site engineers as first target adopters in a BIM diffusion program because the proximity to site and the position between site managers and workers make site engineers easier to communicate with than most people working on site.

In addition to using the BIM team as change agents, non-BIM specialists (e.g. top management) applied other tools and strategies to promote the use of BIM within the company. For example, *"the commitment to R&D including funding and equipment plus empowering the BIM team to lead BIM practices in project stages (where applicable) are highly recommended"* - MM_3D_7. However, one BIM manager implied that the top management has not established a proper reward system as an efficient tool to promote BIM adoption among current staff and to attract and retain BIM competent staff. *"Employees prefer their contribution to the company being rewarded or recognised. Top-level managers must know how to use the right kind of rewards since it can significantly stimulate or suppress creativity and innovation"* - MM_1C_3. Further, a special mechanism to drive BIM adoption is required. *"BIM specialists require higher mistake acceptance, extra time for learning and piloting in addition to financial reward"* - MM_1C_3. This finding supports Theme 3 by suggesting that decision makers (e.g. non-BIM specialists) might not necessarily manipulate BIM tools due to the complexity and learning curve associated with the technologies, but rather they can facilitate the environment for wide BIM adoption through incentive mechanisms.

The government's intervention tools such as the BIM mandate, standards and guidelines were perceived as necessary to quickly diffuse BIM through the AEC industry. A government agent noted that *"by forcing the industry to catch up, it has become more accepting of innovations"* - GA_1. However, the level of intervention of government remained questionable. A senior manager commented that *"it is very difficult to force various construction players with different sizes, interests and technological abilities to agree on one 'hypothetical' set of standards or requirements by which BIM based projects will happen"* - MM_3D_7. Currently the public sector, including government agencies, is behind the private sector in BIM practices. If the government body is not a true champion for an innovation, then the likelihood of the intervention having an impact on the industry's adoption is diminished because *"BIM competent companies may not respect instructions from people not as qualified as them"* - TM_1D_7. Thus, *"the role of government toward BIM diffusion should be the mediator instead of the guider or the leader"* - MM_1C_3.

8.5.2 Confirming Theme 4: Objects and Theme 6: Outcomes

This section confirms the relationship between Theme 4 and Theme 6, showing that the object and outcome of BIM activities are not determined by a single group of subjects regardless of their socioeconomic level. In fact, object and outcome are collectively constructed by all subjects involved in BIM activities.

Negotiation and decision making processes appear to be activities that are the most difficult for BIM to facilitate. Both activities are hard to complete virtually because *"every participant has their own preferences, intention, and pay-off optimum, and conflicts are difficult to avoid"* - GA_3. Thus, *"face-to-face communication and negotiation are soft skills required to mediate objects-outcomes"* - TM_1D_7. As shown in the combined framework (Figure 8.1), each activity system develops its 'objects' but its 'outcomes' are not used by the same activity, but instead by another activity. A BIM manager disclosed that *"to* *generate unique outcomes and at the same time enable negotiation for profit, our activity must differentiate itself from the others, developing a different object, instrument, rule, community or division of labour. However, this process of differentiation has the side effect of creating boundaries among activities, perpetuating the contradiction"* - TM_1C_3. This finding reinforces Theme 4 and Theme 6, implying that objects and outcomes of joint activity such as BIM collaboration are not prescribed but constantly negotiated during the project lifecycle.

The researcher also observed that BIM specialists' attempt to produce innovative outcomes was questioned because *"if BIM outcomes cannot prove their advantages over CAD outcomes, the existence of the BIM team might be questioned by decision makers"* - E_1D_7. The problem is that decision makers (e.g. owners or senior managers) were educated and familiar with practices in the CAD tradition and therefore likely to remain in an 'old mindset' when specifying objects and assessing outcomes despite the use of innovation. Further, decision makers might establish impractical or ambiguous objects along with assuming ambitious outcomes since they are *"often not direct BIM implementers"* - E_5C_3. The advantage of BIM is widely known but BIM adopters, particularly non-BIM specialists, must be realistic as to their current capability, the availability of BIM tools and the maturity of the supply chain.

8.5.3 Confirming Theme 5: Subjects

8.5.3.1 BIM specialists

This section confirms that the commitment of subjects (i.e. BIM specialists) to BIM adoption is influenced by social recognition of the BIM profession.

Similar to previous themes, even with the increasing involvement of BIM specialists in projects, the status of BIM as a professional role is still not established. Many BIM specialists expressed feelings of insecurity regarding their current position, suggesting that it is necessary to provide greater clarity around expectations, education and certification, and career progression so that *"BIM practitioners can be assured that such roles have value and recognition"* - MM_1C_3.

8.5.3.2 Non-BIM specialists at employee level in site team

This section confirms that non-BIM specialists in the site team are reluctant to reuse the models developed by BIM specialists because site teams are not the authors of BIM models whereas the function of BIM team is often unclear within project teams.

Site teams are not formally trained in BIM and are also not interested in modelling techniques. The advantage for the site team is that with BIM they can provide more accurate and more cost effective ways to manage budgeting and scheduling. The site team was found to be more concerned about *"reading the models and retrieving data from models to facilitate decision making during project execution"* - MM_2C_3. However, as mentioned above, the roles of BIM specialists were not socially recognised, thus their BIM products might not be a legally reliable source for the site team to rely on. Often the models would be *"labelled for reference only or with some other disclaimer of accuracy"* - E_4C_3. Such disclaimers, in turn, could result in fewer site engineers using the technology. This finding confirms Theme 5, arguing that the interaction between BIM specialists and non-BIM specialists was interrupted or failed due to social issues instead of technical issues.

8.5.3.3 Non-BIM specialists at top management level – decision makers

The findings are similar to Theme 5, affirming that the environment of the fragmented nature of construction projects and personal characteristics such as education have an influence on the adoption decision of subjects.

Decision makers (e.g. senior managers, project owners and the government agents) are expected to lead the BIM effort. However, BIM leadership is challenging because of the fragmented nature of the industry.

"BIM coordination is perfected through practice, learning from mistakes, and from getting to know the strengths and weaknesses of your teammates. That repetition and learning does not happen in the building industry due to the temporary alliance of disparate organisations" - GA_3. A senior manager admitted that *"the more parties involved in developing an integrated model, the wider range of knowledge covered and the more difficult the decision making process will be"* - TM_1D_8.

It was found that decision makers relied less on emotional factors in their decision on adopting an innovation. For example, they evaluated the use of the innovation based on concrete evidence of time and cost saving, and energy efficiency. Also, BIM managers with overseas learning experience may become innovators who *"are characterised as adventurous, comfortable with uncertainty and risk, and competent with technical knowledge"* - MM_2D_8. The innovativeness of decision makers, however, did not vary by company size. For example, decision makers of small and medium companies might adopt BIM earlier than those of larger companies simply because of *"their structural agility to move quickly to BIM"* - MM_2C_3.

8.5.4 Confirming Theme 7: Mandatory setting

The push by the Vietnamese government to implement BIM in all public sector projects and level one projects by 2020 received a mixed reaction from research participants. Some felt that this is an unachievable goal, whereas others embraced the change in the process. The supporters of the government mandates, guidelines and standards are usually owners or project sponsors (i.e. innovation laggards) who are seeking very basic BIM knowledge, and small to medium size companies who see BIM as *"an opportunity to gain status"* - MM_1D_7.

On the contrary, the BIM competent companies (often large companies) perceived the centralised BIM diffusion approach as just not right for them because they do not want their innovation process and product to be greatly influenced by the government. *"Established, persistent, rule-bound and* *measurable process is favoured by the bureaucratic authority, but it is often seen as an impediment to innovation by adopters, especially the rapidly evolving digital tools"* - TM_1D_8. One senior manager admitted that *"we really appreciate if the government creates the pre-conditions for wide BIM adoption such as e-submission for processing building license or bidding, e-commercial for selling BIM models or BIM objects and relevant legal issues (e.g. ownership of models, BIM contracts, fee structure for BIM services)"* - MM_3D_5. The standards for green buildings and mass off-site fabrication are also welcome as they are naturally associated with BIM and thus beneficial for BIM adopters. *"We innovate because we want to be 'distinct' and remain 'competitive' against other companies but not being moulded by any concrete system"* - MM_1D_8. The findings match Theme 7, supporting the negative attitude of BIM competent companies toward the BIM mandate.

8.5.5 Confirming Theme 8: Contradictions

8.5.5.1 Contradiction of scope of work

This section confirms that each company is bound by a particular scope of work specified in the contract which the company has to give priority to fulfil. Unless an integrated BIM contract where all parties own the consequences together is applied, the contradiction of scope of work still exists.

Similar to previous themes, even in projects using BIM, there were contractually defined points where the model can be handed over to the next profession, rather than having multiple professions work on it simultaneously. This is *"the continuation of the same model of role-based project delivery but with a new tool"* - TM_1C_3. For example, designers are legally only contracted to supply advice, or suggestions for how a building may be executed. *"Design firms are instructed, due to risk management, to never advise means or methods, leaving the contractor (directly or through others) with responsibility for the design and implementation of the construction, methods, procedures, sequences and techniques"* - MM_2D_7.

Organisational separation between architects, engineers, the general contractor and the subcontractors created a culture among the project team in which commitment to individual scopes of work often overshadowed their expressed commitment to the project as a whole. For example, the BIM team was delegated to work hand in hand with the site team to develop a BIM model but when key personnel, the BIM experts, returned to head office, the site team expressed *"less commitment to the modelling job than to getting their own scopes completed"* - E_3C_3. BIM specialists, on the other hand, had very little influence over the building project, and they felt constrained by project decisions in which they had no voice. *"Site managers exercise full authority over BIM implementation – when and where BIM is applicable in construction stages"* - E_2C_3.

As a result, instead of predicting problems and facilitating decision making to solve problems, BIM was used mostly for construction documentation (e.g. report and presentation) when the execution had been done. The most common conflict found was that site job tasks overlap while involved parties start blaming others to protect themselves. In particular, site engineers were frustrated with the MEP coordination process. *"They never give enough time for plumbing, never. It's like the sprinkler guy can just take his sprinkler pipes and he doesn't have to worry about being inside walls or piping up to a toilet or a bathtub and all the fittings and offsets that are involved and all this. That's my attitude, nobody really cares how it impacts us"* - MM_2C_3. Thus, it is understandable that a site engineer was not feeling motivated by the project as a whole, as his focus was on his field personnel who would be installing the building system that he managed, saying *"my priorities are always to support my field guys. It's just like nobody cares about my job and keeps rushing me. I have to live with it and am fighting for more time"* - E_2C_3.

8.5.5.2 Contradiction of time

While most participants qualitatively assessed that BIM reduced overall schedules, there were differences over how those time savings were realised as below.

8.5.5.2.1 *Perspectives of designers on time saving*

Designers were more likely to remark that BIM added time to the schematic design and conceptual design phases. The BIM automation function, even when it results in an optimal solution, does not help the designer, especially in the initial stages of the design, to better understand the complexity and potential solution for the problem. In particular, BIM is not yet sufficiently developed for conceptual design in comparison with detailed design. *"Tools for early design phases and integration of conceptualisation tools are lacking at the moment, making it time consuming to manage design change during conceptual design"* - MM_1D_7. The advantages of BIM tools over CAD tools such as automation and optimisation are mostly realised at detailed design stage. As the project shifted to detailed design, participants were more likely to see time begin to decrease. *"Once the concept design is approved, changes made in the detailed floor plan, for example, will be updated in all relevant elevations, section, etc. which considerably reduces the amount of time and risks of losing or omitting data involved in making those changes with traditional methods"* - MM_3D_7.

8.5.5.2.2 *Perspectives of site engineers on time saving*

In the construction stage, BIM design coordination among contractors and subcontractors often encounters 'clashes' which sometimes takes months to resolve due to the debate on liability and who is responsible for solving the clash. In the traditional linear construction process, the work keeps going despite technical conflicts. *"We had to work around technical conflicts, whoever went on site first, took all clearance and spaces, and all other trades had to go by what was built already"* - MM_2C_3. In BIM coordination among multiple parties, not only technical issues but human issues also need to be considered, requiring more time to negotiate. *"It's about saving face. There was a protracted debate on why one's issue was flagged as a 'danger' over those of others"* - TM_1C_3. Sometimes, too many voices make the conversation endless and futile. A BIM manager of a construction firm stated that *"it's really time consuming to convince all subcontractors of the transparency of BIM coordination, particularly when individual benefits of some parties may be sacrificed for the advantage of the whole project (collective benefits)"* - TM_1C_3. One site manager commented that *"while issues were identified, subcontractors did not know how important these issues were, often they did not know the urgency of these issues and how vital their resolution is. There is little time available in coordination meetings to document the causes of clashes due to time pressure so that I (site manager) end up with the mandatory instructions of their work"* - MM_2C_3.

8.5.5.2.3 *Perspectives of BIM specialists on time saving*

One BIM specialist admitted that developing an error-free model is an exhausting job. *"Sometimes an entire floor duct had to be re-modelled and re-routed to rectify a coordination issue, taking so much time for rework. A BIM model is not 'perfect' as simply its creator (a human being) is never as 'perfect' as a machine"* - MM_1C_3. It is not necessary to completely re-model to just fit all available coordination issues. *"When time runs out, some issues should be prioritised while others are 'hold-on' or negotiated to get the job 'done' anyway. Don't wait for perfection, just get started"* - TM_1D_7.

8.5.5.2.4 *Perspectives of main contractor and subcontractor on time saving*

Further, it was found that different sized construction firms perceive the value of time saving differently. Subcontractors (smaller companies and often in financial constraint) saw time saving as 'money' because *"getting the job done faster means they get paid sooner and have more time to seek more jobs"* - E_3C_3. On the other hand, main contractors which are large companies with hundreds of people, had a 'neutral' attitude of time saving as they did not get extra benefits or rewards by doing things more quickly than the clients' expectation:

First, *"we have to keep our guys 'busy' as much as possible within the contractual schedule including the 'right' time extension claim. It's a good way for marketing as people see our long-term presence in many big projects. Also, it's not easy to allocate many guys to another project within a short period of time (e.g. one month saving). Our workers still need to get paid even they have nothing to do"* - TM_1C_3.

Second, a main contractor takes responsibility for project progress until the last subcontractor has left the site and the project is handed over to clients. *"Our key personnel keep staying on the construction site at the 'last' minute to work side-by side with subcontractors to support and back-up their work. Some specialised subcontractors can save time in their part of work but at the overall project, we cannot save much time"* - MM_2C_3. In other words, the team is only as good as the 'weakest' member. The level of BIM maturity of supply chains must be improved and evened out for the time saving to be significant (e.g. several months) and thus widely appreciated by the industry. *"Only a couple of days or weeks saving have not proven whether the time reduction was a result of BIM adoption or better traditional management"* - MM_1C_3.

Third, despite the recognition of time saving in manual tasks such as documentation using automating functions, the main contractors did not feel that collaboration has improved due to BIM. They thought that collaboration is more a human issue characterised by inconsistent and unpredictable factors (e.g. emotion, trust and mutual understanding), thus "*requiring BIM champions who are not only expert in technology and construction but also are respected by team members to mediate the whole process"* - TM_1C_3.

8.5.5.2.5 *Perspectives of clients on time saving*

On the client side, a project manager said that *"some processes save time while others consume more time instead. However, the overall project duration doesn't differ much compared to conventional methods"* - TM_1O_3. He also pointed out that the total project duration could possibly increase because *"some of the consultants only know basic modelling, hence are not able to keep up with the standards. As a* *result, more time is needed to recheck and ensure the model is in accordance with the standards"* - TM_1O_3.

8.5.5.3 Contradiction of cost

This section confirms that engaging all stakeholders through the project lifecycle may not be realistic due to the imbalance of cost and benefit. There is no beneficial reason for a party who has completed their scope of contracts to continuously support others. Further, the distribution of cost and benefit is perceived as unfair as while upstream users (i.e. architects) make a great effort to develop a model, downstream users (i.e. facility management staff) can simply reuse this integrated data model for personal affairs. In addition, clients are reluctant to pay for a high level of BIM use (e.g. 6D BIM) because it is costly in terms of external consultancy and internal upskilling.

It was found that financial expectations of project parties drive the willingness to collaborate on projects. A site engineer explained the unwillingness of the MEP subcontractor when needing to get information. *"They [MEP subcontractors] told us that they don't have any money left on this job to work on it. So that's typical when there's never anybody that has any money to do things right after the job is already out"* - MM_2C_3. Some parties who have close relationships may be happy to answer the request for information but *"working outside of the budget constraints to help answer questions is seen as being 'kind' to others working on the project, not as the expectation for successful projects"* - E_4C_3.

Further, BIM is more resource intensive in earlier stages of the project than 'traditional' systems. *"A BIM model requires more information earlier in the project than traditional systems, like sketching and 2D CAD, calling for the employment of additional specialist staff (designers and IT) and high economic investment in expensive software and hardware and training"* - TM_1D_7. The costs of BIM implementation (e.g. BIM team's salary) and maintenance (including updating software) may outweigh its usefulness. The compensation for effort of BIM specialists was seen as unfair. This is because the benefits of a BIM based project may be only realised at the O&M stage such as efficient use of resources saving water and energy as well as asset management such as quicker access to all service history and specification, and contract information in advance of a maintenance visit reducing repeat visits and improving response times. A BIM manager admitted that *"the benefit of the project is not shared within BIM participants when the project is handed over to clients"* - TM_1C_3.

In addition, there is a debate on who incurs the cost of a high level of BIM uses. For example, BIM specialists asserted that 4D BIM (schedule management) and 5D BIM (cost management) are means by which 6D BIM (environmental design and energy management) is delivered to clients, thus *"clients should be charged extra fees of 4D and 5D for getting a 6D model"* - MM_1C_3. Clients, on the contrary, argued that *"the fees for 4D and 5D deliverables should be shared because other parties such as the contractor, subcontractors and suppliers also get benefits from them"* - TM_1O_3. Further, clients may feel dissatisfied because the financial risk is shifting to them when the return has been not proven in the post-construction stage. An owner noted that *"even though we got a 6D BIM model at the project closure, we don't have 'knowledgeable' guys to manipulate rich information embedded in the model to earn tangible benefit (e.g. time and cost savings) from it"* - TM_1O_3.

8.5.5.4 Contradiction of quality

The increase in quality of BIM based product is questionable. Most participants appreciated the better production quality of designs. *"Documentation output is flexible and exploits automation"* - TM_1D_8. However, the quality of physical product, the actual building, was perceived as not directly relevant to BIM. *"Digital product data can be exploited in downstream processes and used for manufacturing and assembly of structural systems"* - MM_2C_3. That means if BIM models were used to facilitate the manufacturing of construction components which were later erected on site. it would *"reduce field labour cost and time and increase accuracy in a good quality construction"* - E_1C_3. Otherwise, the quality of physical products still relies heavily on human performance. *"It* *is unrealistic for team members to rely completely on a BIM model because BIM can merely visualise the problems rather than solve them automatically. Engineers with rich project experience are still of great importance for the success of BIM projects"* - E_2C_3. A site engineer stated that *"I don't see direct impacts of BIM on construction works but its functions of visualisation and simulation may facilitate our guys' working environment, e.g. accommodating condensed space, safety and access to site, which may increase employees' health and productivity, thus somehow linked to quality of works"* - E_2C_3. Another site engineer admitted that *"I'm holding a 'neutral' position regarding BIM adoption on site as the cost of its implementation may outweigh the benefit. Further, on-the-job-training likely distracts our staff from core operations which results in loss of productivity"* - E_1C_3.

8.6 Theme 9: Responses to contradictions

8.6.1 Responses at the government level

8.6.1.1 Responding to contradiction of scope of work

This section explores the effort of the Vietnamese government to reduce the conflicts regarding the scope of BIM related work with undefined or confused BIM roles and responsibilities in projects. Some common interventions include the delegation of a BIM committee to promote BIM diffusion to the construction industry by increasing awareness of potential adopters, providing training, and piloting BIM projects, and the collaboration with advanced BIM organisations to develop formal BIM guidelines, standards and contracts.

The national BIM steering committee was established to drive the BIM diffusion program such as enforcing the BIM mandate and providing BIM guidelines and standards. *"This committee is based on an alliance between* *government and influential groups which aims to coordinate efforts across government, industry and research to increase the use of BIM"* - GA_1. The BIM committee was also seeking support from international organisations. For example, the BIM committee has collaborated with Autodesk and signed an MOU in 2016 to drive BIM awareness and application in construction and facility management activities. *"Autodesk will provide their experts to help the public sector with BIM software training and guidance on BIM global best practices which could be adapted to the Vietnamese context"* - GA_3. Further, the BIM committee signed an MOU in 2018 with the UK government to cooperate in applying BIM in the Vietnamese construction industry. *"Under the MOU, the UK government will work with the BIM committee to develop standards and guidelines and support the implementation of a number of BIM pilot projects in Vietnam"* - GA_1.

BIM education and training are required to help BIM adopters with clarifying roles, responsibilities and legal issues during the BIM process. The BIM committee organised training courses to provide basic BIM knowledge to pilot projects' owners and sent BIM experts to work hand-in-hand with these owners in early project stages, particularly *"in preparing BIM documentation such as BEP, EIR and BIM contract"* - GA_2.

8.6.1.2 Responding to contradiction of cost

To resolve the debate on BIM cost among project stakeholders, a government agent announced that *"the Ministry of Construction issued Circular 06/2016/TT-BXD, which allows including BIM implementation costs in construction budgets"* - GA_2. Table 8.6 represents the fee structure of BIM specified in the temporary national BIM guideline. The researcher analysed the secondary data which was provided by the government agent research participants.

Table 8.6 Fee structure of BIM specified in temporary national BIM guideline (participants agreed to share documentation)

Fee structure	Description	Formulation
BIM experts (C_1)	Salary of BIM experts	
BIM management (C_2)	Salary of administration staff and office rental	$C_2 = 50 \div 55\% * C_1$
Additional cost (C_3)	- Conference and seminar - Stationery - Depreciation of equipment and software	
Taxable income (C_4)		$C_4 = 6\% * (C_1 + C_2)$
GST (C_5)		$C_5 = 10\% * (C_1 + C_2 + C_3 + C_4)$
Contingency cost (C_6)		$C_6 = 1 \div 10\% * (C_1 + C_2 + C_3 + C_4 + C_5)$
Total BIM cost (C_7)	$C_7 = C_1 + C_2 + C_3 + C_4 + C_5 + C_6$	

The temporary national BIM guideline gives examples of estimated BIM costs for key design stages (e.g. basic design, construction design or as-built) according to project capital (see Table 8.7). The government agent believed that *"by providing a framework to estimate costs for BIM design services, architects and engineers could demonstrate this to clients and receive fees in proportion to the value they add"* - GA_1. The decision of the Ministry of Construction, no. 79/QĐ-BXD issued in 2017 promulgated the regular fees of traditional design services in which the expenses of BIM design were amended to be twice as much as these regular fees. *"The design fee structure (with BIM) was adjusted, increasing up to double those fees without BIM"* - GA_3. However, the government agent admitted that *"the fee adjustment is based on experience and anticipation of policy makers rather than reference to average charge of community of practice (e.g. BIM consultancy firms)"* - GA_3. Thus, this may not reflect the proper compensation which should be awarded to BIM specialists due to the value they add to the project.

Table 8.7 Estimation of BIM cost for design stages (participants agreed to share documentation)

Project capital (Billion VND)	<200	500	1,000	2,000	5,000	8,000	≥10,000
Basic design (Billion VND)	0.1-0.2	0.15-0.3	0.25-0.5	0.45-0.75	0.6-0.9	0.8-1.2	1.0-1.4
Construction design (Billion VND)	0.2-0.4	0.3-0.7	0.6-1	0.9-1.8	1.7-2.8	2.1-3.5	2.3-4.0
Shop drawing, as-built drawing and Bill of Quantity (Billion VND)	0.3-0.5	0.4-0.8	0.7-1.2	1.1-2.0	1.9-3.3	2.8-4.0	3.0-4.5

8.6.1.3 Responding to contradiction of quality

The government proposed some solutions to ensure the model quality. These solutions were listed in the temporary national BIM guideline (see Table 8.8). The government agent noted that *"BIM processes only work if there is something those processes can act upon. No BIM models, no process"* - GA_1. Another government agent added *"without good quality models, no matter how good BIM processes or standards are, it will be extremely difficult for anyone to do anything useful"* - GA_2.

Table 8.8 Quality assurance of BIM models (participants agreed to share documentation)

Checking	Description	Person in charge	Tools
Observation	- Not including undefined models - Meeting design requirements	- BIM consultancy firms - Design firms	- Visual check - Experience
Clash detection	- Spatial conflicts (components) - Software interoperability - Out-of-date hardware	- BIM consultancy firms - Design firms	- Navisworks (Autodesk Inc)
Standards	- Font - Scale - Layer - LOD	- BIM consultancy firms - Design firms	- Visual check - Filter tools (manual) - Experience
Model data	- Overlapping data - Names, categories and types	- BIM consultancy firms - Design firms	- Filter tools (manual) - Experience
Automatic check	- Quality of model - Quality of data in the model	- BIM consultancy firms - Design firms	- Solibri model checker (Solibri Inc)

8.6.1.4 Responding to contradiction of time

While being strict in mandating responsibility (scope of work), cost and quality of BIM services, the issue of time had less importance in the national guideline. A government agent noted that *"we try to release pilot projects' BIM adopters from time pressure, for example, facilitating the approval of building licenses or extending the document submission date"* - GA_1. The government allowed pilot projects' stakeholders to determine when BIM would be applied in their project stages. *"The pilot project's owners could choose the proper time to join with BIM. Other BIM practitioners freely decide the time and frequency of their BIM coordination meetings"* - GA_2.

8.6.2 Responses at the project level (cross-firms)

8.6.2.1 Responding to contradiction of scope of work

This section describes different responses of case companies to conflicts regarding scope of work in BIM projects (i.e. BIM collaboration). While the main contractor company takes an active role in BIM leadership, the architecture firm is reluctant to expand their scope of work beyond 3D modelling. The MEP engineering firm showed their interest in engaging early in the BIM process but they had to negotiate BIM uses with the architecture firm as their work relies heavily on architecture layouts. The owner company exposes hesitant attitudes on BIM adoption due to the lack of guidelines from the government. On the contrary, the government is cautious about developing BIM standards because they are afraid of losing reputation if BIM standards do not meet the requirements of users.

To reduce the conflicts of BIM leadership and management in projects, the main contractor C_3 established in-house architects and a BIM team to self-manage full BIM based projects. Also, it was believed that a young architecture firm capable of innovating with BIM could take over the design leadership from traditional architecture offices when they have accumulated architecture knowledge and experience in a much shorter time. One senior manager of an architecture firm admitted that *"traditional architects lost power due to the emergence of BIM consultants"* - MM_2D_7. Another chief architect (TM_1D_7) remained optimistic because the business scope could be extended to modelling services (convert from 2D to 3D) and 3D drafting (outsourcing jobs). However, the work using a low level of innovation is not sufficient to help architecture firms gain their position in the AEC industry. *"3D modelling and rendering, 3D computer animation is increasingly imitated by other competitors. 3D applications only can't make us distinct and competitive"* - MM_2D_7.

In contrast to the architecture firm D_7, the engineering firm D_8 was more eager to early adopt BIM in projects. A senior manager of an engineering firm explained by stating that *"parametric design fits well with engineering thought. It's about less artistic activity and more engineering process. Codes, mathematic relationships and logics are inherently part of our normal activities"* - MM_2D_8. However, as the design delivery was still led by an architecture firm, the engineering firm had to constantly negotiate with the architecture firm for the use of physical space in the building structure. For example, architects may want to move the column not for technical reasons but because it subjectively looks nice. Conversely, the engineer desires to design a simple, yet sound building structure. *"For architects' belief, it's just simply a re-sketching of one element but this would result in countless revisions of safety or even re-analysis of the whole design"* - MM_1D_8.

The project owner presented a *"wait-and-see attitude about BIM to avoid financial and legal risks"* - TM_1O_3. On the contrary, the government agency was reluctant to be the BIM champion because of the pressure of society which is less tolerant of government failure. The reality was that *"when government fails, there is public outcry and silence when it succeeds"* - GA_3. The isolated effort of the government was not adequate to diffuse BIM over the industry. The engagement of major stakeholders is necessary to reach a *"consensus guidance* *on where to start, what tools are available and how to work through the legal, procurement and cultural challenges"* - GA_1.

8.6.2.2 Responding to contradiction of cost

This section displays numerous responses of case companies to cost saving associated with BIM adoption. Due to the high upfront cost, architecture firms have to employ "fake BIM"[29] to meet clients' demand by adopting BIM in a superficial manner to be eligible for contract reward. Engineering firms, on the other hand, focus on developing an open BIM platform to take advantage of reusing BIM models developed by architecture firms. Generally, local firms prefer to adopt BIM in private projects than public projects as the fee structures of BIM services have been not standardised in cost estimating policy. Contractor companies attempt to adopt BIM in manufacturing to reduce the dependence on suppliers, thereby increasing their profit margins.

Architecture offices in Vietnam are typically small-to-medium sized firms, thus they tend to search for immediate benefits for their own business. To save design cost, the local architecture design firms may employ 'fake' BIM which means they pretend BIM was applied whereas, in reality, a traditional CAD workflow was used to deliver a project. The reasons for such deception may be to impress clients who may not know the difference, or to conform to client or regulatory requirements. A senior manager of the architecture firm admitted that *"the most common occurrence of fake BIM is applied by those who use BIM tools simply to produce their 2D documentation"* - MM_2D_7. At the project level, this usually plays out as a delay when downstream users receive an untouched copy of the model still containing all its housekeeping and drawing creation setup. *"The contractors have to convert the design model to a construction model by themselves or they need to pay us extra to get access to the authority model"* - MM_1D_7.

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[29] Fake BIM: (1) Using unlicensed BIM programs to save cost and enable BIM, but this suffers the risk of data insecurity (Bui, Merschbrock & Munkvold 2016); Or (2) Creating a BIM model just for virtual presentation, and faking the digital records, or amending date, time and other data (Enshassi, Hallaq & Tayeh 2019).

Another strategy applied by the architecture office was hybrid BIM – a half BIM and half CAD solution, which may occur for a number of reasons. The most likely is a *"lack of skill or support infrastructure to sustain continuing a BIM approach"* - E_1D_7. Also, it is likely the project leaders who postpone the use of BIM when they *"lose confidence that imminent submission deadlines can be met"* - MM_2D_7. Further, an IT trick was used to avoid high expense on multiple software licenses: *"We purchase one or two authority keys but then use virtual computers to share the access to more members"* - MM_3D_7.

As engineering firms face a number of risks regarding criminal prosecution for matters like safety, health and welfare in design, they recognised the benefit of BIM towards anticipating risks. *"BIM reduces repetitive tasks, improves quality control, promotes thinking in 3D and improves communication with architects. We have more time for design alternatives, optimisation and risk reduction (automated clash checking and simulation)"* - MM_2D_8. The engineering firm, therefore, accommodated BIM adoption to an 'open' platform to maximise the opportunity to reuse architecture models. *"We set up an in-house BIM system which could 'read' any type of file from common tools (e.g. Revit or ArchiCAD). This will reduce labour costs when remodelling from existing files rather than from scratch"* - TM_1D_8.

The local design company D_7 demonstrated increasing enthusiasm for the use of BIM in private projects but was reluctant to adopt BIM in public projects. The barrier was the regulations for cost estimates do not have items for applying new technologies, which meant individuals in charge of the state budget would refuse to reimburse for such items. *"BIM adoption in state funded projects had to strictly follow the cost estimate regulations or we have problems with legal issues (e.g. audit)"* - TM_1D_7. Foreign design company D_8 showed their lack of interest in the immature Vietnamese BIM market. *"We will return our focus to local projects when we see a more transparent and fair market. Now, our core business is outsourcing jobs"* - TM_1D_8. The project costs have been considered as a secret issue which remains hidden and is known only to the top management of a project. *"BIM adoption possibly fails to build trust among participants in the working environment not supporting transparency and reducing information asymmetry"* - MM_1D_8.

To maximise the profit and cut down waste, contractor firm C_3 has begun to adopt aspects of BIM for off-site fabrication. *"Façade (exterior side of a building) and manufactured products (windows and doors) are our extensive business activities along with existing construction execution"* - MM_1C_3. A private contractor company did not perceive BIM services as an opportunity to charge clients more, instead they increased profits by taking back the jobs which they previously had to share with subcontractors (e.g. window traders). *"Now we save the fees of managing several subcontractors and bring the jobs back to our men"* - TM_1C_3.

8.6.2.3 Responding to contradiction of quality

This section represents common methods of ensuring model quality by design firms such as developing a protocol of quality assurance. On the other hand, the contractor firm improves the quality of BIM coordination through delegating a BIM team to work side-by-side with the site team and/or training subcontractors to a level qualified to undertake BIM tasks individually.

Some common methods of quality assurance adopted by design companies are presented as below:

- Modelling validation (visual check) ensures that the model is created according to the modelling guidelines in the BIM standard.
- Dataset validation (adopt standard objects) ensures that the datasets are populated with correct data.
- Interference validation (computer-assisted) detects any clash between building components using clash detection software.

- Exchange validation (contractual commitment) ensures that the model is published and received based on the exchange protocol as defined in the project execution plan.
- Constructability validation (simulation and experiences) detects sufficient space clearance between building components for installation and maintenance purposes.

Contractors, on the other hand, were more concerned about the quality of real-time communication and interaction between site and head office. A BIM model is mostly completed in head office and passed to site for use. Poor conditions at site such as poor internet connection are barriers to virtual team working which is the means of real-time information exchange. The approval documentation process was also seen as bureaucratic. *"When the revisions of design finally came to the site team, they were in 2D Acrobat PDF format, dated three months prior, and stamped 'not for construction purposes'* - E_2C_3. As the result, the slow update of as-built models and release of shop drawings did not inspire trust or confidence in the information quality among the site team. One possible solution which contractors used was to send the BIM team to work side-by-side with the site team to better update changes. But a site manager argued that *"the use of BIM is misaligned. It's not about the BIM team attempting to chase and catch construction progress to properly release latest shop drawings, though it's one of the BIM uses. It's about training the site team to apply BIM to anticipate problems for better decision making"* - E_4C_3.

Unlike the ability of a design firm to work independently, the contractor relies heavily on subcontracting to reduce their risks such as *"unpredictable workload and a need for a multitude of specialised skills"* - MM_2C_3. Thus, the contractor was taking an 'on hold' attitude, not because of their unreadiness but due to the immaturity of the supply chain. *"We have to slow down the adoption to help subcontractors otherwise their incompetence may impose a burden on BIM collaboration"* - TM_1C_3. To explain why the company was not expanding the current supply network to select a more competent partner to share the risk of adopting an innovation, a senior manager of a contractor stated that *"high cost and trust building are barriers to cooperating with a talented but unfamiliar party"* - MM_1C_3.

8.6.2.4 Responding to contradiction of time

8.6.2.4.1 *Time conflict is seen as an unavoidable event by design firms*

Currently, the contradiction of time (e.g. delay of design delivery) is not resolved as to whether to use BIM or not. Participating design companies still relied on traditional contractual commitment to hand over their products. *"There is nothing changed. Different tool but same delivery method. Instead of 2D drawing, the design model is passed to other design disciplines at the end of the submission date"* - MM_1D_7. Real-time communication or interaction is expected to save time due to re-work and waiting time, but the approval process has been conducted stage by stage. *"Architecture design needs to be accepted first, then structural design comes after architectural design. Later, MEP design initiates based on approved architectural and structural layouts"* - MM_3D_7. In addition, BIM collaboration requires all project stakeholders to share the risk of delivery delays because a change made by one project stakeholder on an interdisciplinary BIM model may impact others' performances. *"You can't just tell people work as a team but impose a fine on an individual"* - MM_2D_7.

8.6.2.4.2 *Time conflict is a negotiable issue during construction phase*

The researcher observed in the BIM coordination meeting that BIM participants often negotiated to get extra time for any revision or update before considering the quality of information needed or relevant costs of the amendment. This is because *"the reward you got for one-week submission early is nothing in comparison to the penalty of late submission"* - TM_1C_3. Further, although the time saving was qualitatively recognised by BIM adopters, it was perceived to be difficult to calculate quantitatively. *"Due to its immaturity, the result from BIM adoption (e.g. time savings) is ad hoc and cannot rely on it to make the better BIM plan"* - MM_1C_3.

Both private and public sector owners were not concerned about the constraint of time for the use of BIM. Surprisingly, time was viewed as a negotiable matter while cost and scope of work was more difficult to alter. The constraint of time was not seriously seen as a legal liability unless the main contractors or owners unilaterally withdrew from the project. *"It goes both ways. When the contractors may accept late payment as a norm, the owner may sympathise with contractors' few weeks delays"* - TM_1O_3. Both owner and contractor were trying to avoid legal proceedings and because of cheap labour costs and a preferential interest rate, owners assigned the negotiation of time to the project manager and main contractors. *"Unless the project direction is not on-track, a few weeks delay could be accepted no matter what tools are being used"* - TM_1O_3.

While the matters of costs and work items are fixed in contracts, the behaviour of accepting a certain flexibility of time maintained the harmony and relationship among project teams. The root causes for this behaviour arise from construction norms and low-skilled labour. *"Saving time means saving costs. Yet in the construction norm, contractors may appreciate when additional time is allocated to fulfil their work"* - TM_1O_3. Another senior manager of a construction company explained by noting that "*time pressure negatively affects the performance and wellbeing of employees. In particular, Vietnamese construction is dominated by cheap and seasonal workers who likely quit their jobs under that pressure*" - MM_2C_3.

8.6.3 Responses at the individual level (a single firm or single discipline)

8.6.3.1 Responses of architects

8.6.3.1.1 *Responding to contradiction of scope of works*

Participants with an architecture background decided to not further develop the scope of work beyond 3D modelling because of the complexity of more advanced BIM uses which involved much engineering knowledge and severe working conditions on site.

Architectural professionals have not been educated and trained to produce buildings. Their responsibility is to produce drawings and plans to define how buildings should be constructed. This explains why architects were reluctant to engage in BIM training programs or retained their CAD workflow despite their attendance at BIM courses. In the BIM process, architects must understand and be aware of the construction logic behind every design decision such as the host–guest relationship of some elements with regard to others like a wall hosting a window. *"After all, BIM tools are production and optimisation oriented not necessarily design thinking focused"* - MM_1D_8. That is, BIM can be a powerful tool for technical construction and material specifications, but creativity is probably the skill which may be neglected by a BIM approach. To date, architects were using BIM as a new marketing tool (3D visualisation) as it might help attract clients to select their firm for a project.

BIM specialists with an architecture background who were assigned to support the site team showed their negative attitudes towards the poor working environment. An architect said that *"I feel homesick and cannot get used to the boring rhythm at site. It may take many years to finish a project"* - E_3C_3. Another architect commented that the site atmosphere is not suitable for creative work. Further, architects were not prepared to risk their mental and physical health to work long-term on site. *"Honestly, we are not as enduring as site engineers. We can't stand noise, dust and severe climate"* - E_1D_7. The researcher observed that BIM specialists did not see the construction site as their 'home' office, thereby renouncing their duty to work as a team with site people. *"We teach them how to add and retrieve data from the model. However, we didn't get close to them to understand their actual requirements"* - MM_1C_3.

8.6.3.1.2 *Responding to contradiction of quality*

A limited number of options are used to validate the quality of a BIM specialist. Most BIM knowledge was self-taught by architects, and it was exchanged in the form of software-based courses rather than process. There are two BIM certificates recognised by a group of influential Vietnamese companies, the large private firms, however the endorsement of these certificates is from well known software vendors instead of the government or professional associations. *"The master use of design tool (Revit) and structural analysis tool (Tekla) are two common skills possibly validating the BIM competency of an AEC professional"* - TM_1D_7.

8.6.3.1.3 *Responding to contradiction of cost and time*

Participating architectural professionals gave their consensus on the time and cost savings regarding design delivery but admitted the financial risk of being stuck in endless and futile coordination meetings. By reducing repetitive works by reusing library object families and automatic drafting functions, the time and cost per drawing may be reduced. However, *"there are so many coordination meetings unnecessarily binding our hands and feet. We cannot just send our men there to hear others' problems or discuss scenarios which would or would not happen in future"* - TM_1D_7.

In particular, it was less likely that architects actively engaged in collaborative work if the model was not used in the construction process. One architect noted that *"cost and time are important, yet the meaningfulness of the action is essential too. We are curious about the possibility of a precise replica of a physical building for post-construction uses"* - E_5C_3. Once their aspiration is not satisfied, for example, by the organisational limitation of BIM uses to the design stage, it is likely that architects leave their jobs to look for new positions which could help them fulfil the unfinished object. The researcher observed a high rate of turnover in BIM teams, particularly staff with an architecture background. They moved to smaller companies to take the role of BIM manager instead of keeping the role of BIM specialist in a large company. *"A* *small organisation is more agile to adopt BIM. I have a chance to try full BIM in smaller projects which are less complicated and bureaucratic"* - E_1D_7.

8.6.3.2 Response of structural and MEP engineers

8.6.3.2.1 *Responding to contradiction of scope of work*

This section explores that due to specific expertise, structural engineers may coordinate with architects to a greater extent while MEP engineers are closer to building contractors.

Structural engineers mainly shared BIM information with architects but seldom with MEP engineers. Structural analysis cannot commence until the conceptual architecture design has been completed. *"There is no way to start the structural analysis when the architectural conception is still evolving with endless revisions"* - MM_1D_7. The assumption that all design disciplines working simultaneously on a single shared model was not practical, at least in the conceptual design. Structural engineers have to rely on architectural layouts to develop their engineering solutions. *"Solutions are not only based on pure technical problem-solving criteria but result from compromises between the architects and engineers"* - E_1D_7. In short, solutions are negotiated.

In Vietnam, basic design is required to be submitted to the council to get the building license. It includes completed solutions of architectural and structural disciplines but requires a very basic MEP solution. This is because architecture significantly impacts the surrounding built environment (social factor) while structure impacts safety and human wellbeing. MEP systems, however, are internally installed in a building and perceived as custom-made products which allows project owners to alter them during the construction stage. *"Owners could change the types of MEP equipment if they don't affect the built environment"* - MM_2C_3. The details of MEP solutions are, in fact, undertaken by specialist subcontractors for HVAC, plumbing and electrical. *"During the construction stage, specialist contractors propose their shop drawings to get approval of owners before installation"* - TM_1O_3. This explained why MEP engineers shared less information with structural engineers but shared more extensively with building contractors. *"MEP engineers (of specialist subcontractors) work side by side with building contractors to ensure their equipment was put in the 'right' position before the concrete is poured"* - E_3C_3.

8.6.3.2.2 *Responding to contradiction of quality*

Empowering architecture discipline to communicate engineering issues to clients

The assessment of engineering quality for constructability was unclear as structural engineers were indirectly informed through builders' and owner's feedback. *"The satisfaction of owners and builders and repetitive business are evidence for engineering design quality"* - E_3C_3. However, the disadvantage for structural engineers was that they take the role of back-office supporter with a limited client-facing role. *"Owners may not communicate directly with us, the architects or BIM consultants are in charge of design interpretation"* - E_1D_7. The clients, therefore, might be less likely to be involved during the engineering design process and attend coordinating meetings when the design is finalised and represented in forms of papers or models.

The engineering issues themselves were not owners' interests, but their relative effects on architecture. For example, *"how a building element is performed is not as important as how dimensions of this element (over-sized) may challenge aesthetic or space use"* - E_4C_3. The glossary of engineering terms may fail to convey 'understandable' messages to audiences due to its technical nature. A BIM manager suggested his strategy to gain the attention of participants in coordination meetings was that *"I work around by discussing architectural challenges resulted from engineering design. Simple language and relevant topics are critical in BIM communication"* - MM_1C_3. Another solution was to allow architects to lead the BIM coordinating meetings. *"We discussed architecture-engineering issues with architects a couple of days prior to the meeting. Then, the leading architect would be the key oral speaker"* - TM_1D_7.

Issues of structural safety and durability are manually checked by senior engineers instead of BIM specialists

Senior engineers are still a reliable source of knowledge respected by junior and intermediate engineers. *"No technology can replace the role of senior engineer - a key person can reliably adjust the accuracy of results and lead the structural optimisation"* - E_3C_3. BIM applications for structural safety and durability were often not adopted within the engineering team. A senior engineer said that *"I could loosen the process of detailing and drafting so younger engineers (junior or intermediate level) could adopt the new tool through trial and error. But it's not the case for analysis and optimisation process"* - TM_1D_8. Traditional engineering method would see the structural analysis and optimisation occur after the structural design is finalised. Intermediate engineers carried out the analysis job while junior engineers performed the detailing job. BIM reduces this fragmented division of labour by enabling structural optimisation results that can be generated in parallel with structural design. This means that the BIM specialist with a structural engineering background takes over the job of structural analyst, drafter and documenter. The problem with this was that the BIM specialist may be distracted by coordinating the job and computational design (e.g. visual representation) instead of embracing structural analysis which is inherently their core identity. Senior engineers noted that *"structural engineering is first defined as a technical area, then second as a neat graphic representation. Younger engineers with proficiency in computational skills but less experience may get lost when changing this order"* - TM_1D_8.

MEP engineers prefer to work side by side with site engineers to improve the quality of installation

The quality of BIM based engineering design for constructability may be better observed in the MEP discipline. MEP equipment is mostly manufactured or ordered from overseas, while a small portion of MEP work is manually made on site. For example, a sleeve is used both by the electrical and mechanical trades to create a penetration before concrete is poured. MEP engineering design accepts smaller tolerance than structural engineering because *"when there is a problem of wrong sizes in MEP fitting, it is likely that the equipment must be returned to the manufacturer and purchased again"* - MM_2C_3. That explained why MEP engineers had to participate in the execution process to oversee the work of installers.

8.6.3.2.3 *Responding to contradiction of cost and time*

This section shows that the responses of engineers to cost–time conflicts vary according to their positions and organisational size. Senior engineers are more concerned about the costs of BIM implementation, thus they try to optimise the resources used. On the other hand, junior engineers consider a steep learning curve, instead of cost, as a barrier to BIM adoption. Engineers in a larger company may have a chance to test numerous types of BIM tools to fulfil a single objective while engineers in a smaller company attempt to use one BIM platform to adapt to multiple objectives.

Senior engineers (structural and MEP) were interested in understanding hidden costs as well as possible revenue opportunities whereas junior or intermediate engineers considered BIM return on investment not directly relevant to their job as the BIM decision is typically not theirs to make. A senior engineer noted that *"BIM work requires more computing power and more network power than traditional CAD work, and that power comes with a cost"* - MM_2C_3. Another senior engineer cited training cost as one burden to their duty. *"When we originally looked into BIM, we knew it was going to be a huge investment to train the staff how to use it, and how to use it efficiently"* - TM_1O_3. Thus, the senior manager allowed BIM staff to take turns using IT equipment: *"Who is in charge of a current project and at a critical phase is prioritised to use the BIM facility"* - MM_3D_7. Another solution was to borrow or rent BIM licenses from the peer network. Software subscription within the time of delivery commitment was also a possible method. To save the cost of training, senior engineers often purchased multiple licenses associated with the free tutorials provided by software vendors' experts. Online learning sources could be an alternative, but they were more about the instruction of tool use rather than process or industrial practices.

Engineers in small offices tended to adopt one software program and then adapt all aspects of their design and design development workflows to this program within the office. This implementation usually requires a degree of customisation which puts costly pressure on a small office's IT infrastructure, technical skills, workflows and business processes. Arguably, engineers in larger offices are sufficiently funded to try, mix and coordinate several tools to find the appropriate option. This explained why engineers in small companies focused on BIM application for representation and documentation to attract clients and reasonably charge them more. Engineers in large companies, on the other hand, attempted to save cost by improving internal design productivity whether using BIM or not. *"BIM is an added value to the project, and we do not intend to charge clients extra for its applications. However, we will consider adopting BIM where applicable instead for the entire project"* - MM_1D_7.

The time constraint was not cited as a concern by senior engineers because they were not direct BIM implementers. Junior engineers, on the other hand, were responsible for modelling and thus perceived time pressure on delivery commitment. From the start, junior engineers were selected for training rather than experienced engineers, on the assumption that they would have less difficulty in 'un-learning' work patterns suited to 2D CAD. However, to conform with the regulation, much time was invested in attempting to achieve templates as close as possible in style and content to those traditionally used in the firm. This means junior engineers were, actually, exhausted due to both CAD and BIM work.

8.6.3.3 Response of site engineers

8.6.3.3.1 *Responding to contradiction of scope of work*

This section explains that site engineers do not perceive the BIM team as a vital role driving change in execution performance but as an optional supplement to the decision making process.

Site engineers described the BIM team as a supporting division to help them with better decision making but they did not consider BIM team as a leading role on site. This is because BIM insufficiently mediates mobile working conditions of site engineers who spend a large amount of time outside. *"The lack of mobile devices integrated with BIM applications and weak internet connection make BIM benefits difficult to realise"* - E_1C_3. As a result, site engineers had to use 2D drawing papers as a means of communication and problem-solving on site.

Some site engineers employed fly-cam to give the BIM team an overview of the construction. Also, pictures and videos of on-spot errors or doubts were recorded and sent to the BIM team for revision. However, the responses of the BIM team to requests for information from the site team took a long time to approve. A site engineer noted that *"an instant response is often stamped 'for reference only' or 'not for construction purpose' while an official approval may take a month"* - E_2C_3. As the BIM team appeared to not share the risk with the site team, it is likely that *"site engineers put BIM aside and make decisions based on experience when the deadline approaches"* - E_3C_3.

8.6.3.3.2 *Responding to contradiction of quality*

Participating site engineers evaded the question of quality assessment of BIM products. This situation could result from the Vietnamese culture of 'saving face' when evaluating other people's working quality is seen as an impolite behaviour. The received answers, hence, were often in a 'neutral' manner which challenged the researcher in theme identification: for example, *"I don't know. The results should be OK"* - E_1C_3, *"I have no idea of what they are doing"* -

E_2C_3 or *"I'm not a qualified BIM person to assess BIM work"* - E_4C_3. Even site managers showed their caution when discussing the quality of BIM products. *"The BIM team is not under my supervisor but was assigned by head office to help us with BIM applications. Their work should be fine with us, but I don't know the quality assessment criteria of head office"* - MM_2C_3.

However, when asked about how the quality of site work could improve during BIM applications, site engineers were open-minded in their answers. The common response was 'making the task dominate and making the tool invisible'. Customisation, flexibility and simulation of problem-solving were cited as expected benefits of BIM by the site team. This means that *"BIM tools should be used to address specific needs on site"* - E_1C_3, *"there should be the flexibility of outputs to adapt to different standards"* - MM_2C_3 and *"alternatives of problem-solving could be achieved through the simulation of problems possibly occurring on site due to disadvantaged conditions (e.g. adding constrained variables)"* - E_2C_3. As none of these expectations were obviously obtained on site, site engineers did not recognise BIM tools as part of their daily work. *"Graphic representation and clash detection are not enough to persuade the wide diffusion of BIM"* - E_1C_3.

8.6.3.3.3 *Responding to contradiction of cost and time*

This section illustrates that the use of an innovation may be constrained by an industry norm rather than its competence. Theoretically, BIM has the potential to control both time and cost parameters but only time issues are widely addressed using BIM.

BIM has a 4D scheduling function to display animated construction sequences and this was increasingly used by construction planners to show even unskilled workers how, when and where the building will be constructed. In particular, the simulation of site planning was accomplished to facilitate the construction process, including the site entrance, temporary fence, tower crane location, hoister location, temporary generator, temporary water tank and other elements. *"The site planning can be examined, simulated, and scenario tested* *to reduce risk of accident or injury (delays for legal inspection) and to mediate site movement (delays for congestion)"* - MM_2C_3.

On the contrary, 5D BIM for cost management was limited in use by site engineers. There is some sensitive cost data such as hidden subcontracting deals or competitive prices which site engineers were reluctant to put in the shared model. Each construction site acts as an independent temporary firm decoupled from the parent company (head office). Site engineers also have to work in poorer conditions than peers in the main office, thus they believed they deserve compensation. *"Not all transactions are completely reported to main office as to reserve for extra incentives"* - E_1C_3. As a result, when the BIM team was sent to site to improve the transparency of cost and quality, the BIM team was negatively perceived as a 'double agent' by the site team. It was observed that the site team was reluctant to support the BIM team to share cost information for model update.

8.7 Discussion

8.7.1 Confirming findings in the second round of case studies using the combined framework

The combined framework of Diffusion of Innovation Theory and Activity Theory proves its strength in explaining BIM collaboration activities of participants in the Vietnamese construction industry. Tools used by participants in the third round of case studies are similar to those in the second round of case studies. While decision makers (often non-BIM specialists) employ non-BIM tools such as mandates, standards and guidelines to promote the use of BIM by staff members, staff members (both BIM specialists and non-BIM specialists) are negotiating the uses of BIM tools together with current non-BIM tools (e.g. CAD software). The BIM tool may not become a disruptive technology in a short period of time because its advantages over the CAD tool are mostly realised at the post-construction stages such as facility management, building performance and energy management. Meanwhile, AEC firms still survive using CAD tools which can sufficiently undertake most design and construction jobs. The roles of BIM specialists are quite special as they act as a bridge connecting non-BIM specialists at top management level (e.g. head office directors) and at employee level (e.g. site teams). However, as BIM titles are still not well defined in the division of labour, BIM specialists' performances are constrained by both boundaries (rules and community) of head office and construction sites, resulting in difficulty in building trust with site teams and gaining credibility with the top management.

Objects and outcomes of BIM collaboration activities of partners in the third round of case studies are found to be in an evolving process similar to the second round of case studies. The demands of the project owner are not always met due to the unavailability of BIM technologies in the current market and incompetent BIM practitioners. Some legal issues such as model ownership, protection of sensitive or confidential data and royalties for each reuse of a model are also unclear. Thus, objects and outcomes of BIM collaboration are constantly negotiated throughout the project lifecycle and require communication and leadership skills rather technical skills.

Similar to the second round of case studies, the mandatory setting has a neutral effect on behaviours of participants in the third round of case studies. This is because AEC firms in the private sector have overtaken the public sector in BIM adoption and the government requirement to submit basic 3D models is within their capacity. A reason for wait-and-see attitudes towards BIM adoption is the expectation of AEC firms to see the long-term vision of the government to facilitate the environment for digital transformation such as a digital data marketplace and e-tendering system.

The contradictions identified through BIM collaboration activities between the two case studies are not very different. These contradictions are still bounded in traditional project criteria: scope, time, cost and quality.

8.7.2 Explaining findings in the third round of case studies using the combined framework

8.7.2.1 Responses at the government level

As shown in the combined framework (Figure 8.1), the policy makers (subjects of adoption activity) attempt to use political tools (e.g. BIM mandate) to change the rules governing implementation activity which possibly changes behaviours of BIM practitioners (subjects of implementation activity). It is noted that this study separates BIM activities into adoption activity where people at management level make the decision on mandating the use of BIM among staff members, and implementation activity where members of staff actually use BIM tools. These two activities, adoption and implementation, are interrelated and mutually shape each other. For example, outcomes of implementation activity are used to justify the achievement of objectives of adoption activity.

Findings indicate that the Vietnamese government's interventions towards BIM collaboration focus on modified conditions of BIM contracts, modified reward system (fee payment) and modified professional standards and specifications. While technical issues have been sufficiently addressed, the division of labour (e.g. defined BIM titles) and informal rules (e.g. copyright infringement and information transparency) remain unsolved. The government's BIM policies did not also pay attention to supporting tools such as new procurement and delivery systems facilitating BIM adoption (e.g. e-tendering) and new evaluations of objects (e.g. real-time and simultaneous manipulation of data) and outcomes (e.g. post-construction benefits). Further, a community encouraging BIM adoption such as a digital data marketplace where BIM objects can be transacted is paid less attention by policy makers. This narrow approach to rules through a BIM mandate on technical aspects underestimating tools, community, division of labour, object and outcome is unlikely to significantly transform current implementation activity, thus prolonging the shift of AEC firms to a digital platform.

8.7.2.2 Responses at the project level

Findings show the efforts of design companies in architecture and engineering in developing BIM tools which work properly with current non-BIM tools. This will reduce the up-front costs of BIM equipment and not disturb too much the current division of labour where the majority of staff members are CAD experts. Main contractors, on the other hand, are eager for change and are willing to restructure the division of labour such as establishing a BIM team to coordinate BIM models from design firms. However, the lack of demand from project owners for BIM outcomes as well as the unclear objects of the government's BIM mandate (e.g. whether the submission of basic 3D models is enough) are barriers to further investigation of BIM by main contractors. To date, partners within the supply network reduce the use of internal resources to promote BIM which is costly and risky with poor return on investment. Instead, they use external networks to share resources and find competent partners who can supplement their weakness of implementing BIM.

8.7.2.3 Responses at the individual level (single discipline)

Findings imply that architects are more vulnerable to digital change. It is noted that high level BIM applications involve parametric design which requires the upskilling of coding, logic of building objects' relationships and understanding of construction methods to reflect real-time and as-built progress. All of these skills are not rooted in traditional architecture practices and education and differ from existing rules and community which frustrates architects' motivation due to steep learning curves. Engineers (structural or MEP), however, may find it easier to adopt BIM as parametric design is close to the engineering field. The barrier is that architects are still considered as leaders of design deliverables. But what will happen if engineering firms start hiring architects or subcontract conceptual designs to an architecture firm?

The future of traditional architecture offices could become uncertain when the rules change and engineering firms take over digital design jobs.

Main contractors did not seem to invest in creating the models but in managing data embedded in the models. Rather than modifying BIM tools, main contractors tend to modify rules (e.g. contracts) which give the main contractor the authority to use models provided by design firms. Senior managers of head office establish a BIM team and use it as a change agent to promote BIM adoption at construction sites. However, the fragmentation of division of labour between head office and site teams makes it difficult to apply a top-down approach to regulate BIM collaboration. The head office functions and the site functions operate fairly independently. As a consequence, there is a great deal of decentralisation and much decision making is made at the construction site level while it is very difficult for head office to control the actual implementation of BIM on sites on a day-to-day basis. To date, the non-standard BIM procedures are often undertaken on sites where site managers determine where and when to use BIM, and where BIM is not the priority, placed behind scope, time, cost and quality.

8.7.3 Cross-case analysis

Table 8.9 summarises how BIM specialists and non-BIM specialists in the case organisations respond to contradictions emerging during BIM collaboration activities.

Table 8.9 Responses to contradictions during BIM collaboration activities

Case organisations	BIM specialists	Non-BIM specialists
D_7 (architecture)	- Hybrid adoption of BIM tools and CAD tools - Fake BIM	
D_8 (engineering)	- Contact early and frequently with architecture firm - Develop open BIM platform to take advantage of architecture models	- Wait-and see until other partners gain competence as qualified as the engineering company expects to collaborate with them
C_3 (contractor)	- Set up BIM team to manage BIM collaboration	- BIM is not a priority - Work independently with BIM team
O_3 (owner)		- Hire external BIM consultants to manage BIM process
GA (government agency)		- Mandate the uses of BIM in relation to technical aspects

The architecture firm D_7 adopts the hybrid system of BIM and CAD solutions to create models to reduce the upfront costs. When being in time pressure, company D_7 sometimes generates "fake" BIM, where the architectural model will look correct physically, but the engineering firm D_8 will not be able to use the data for analysis or design without refining it. As professional liability is more strictly imposed on matters of structural safety than on architecture firms, BIM specialists of company D_8 have to start contact early and frequently with architects to reduce conflicts between the two disciplines. Further, BIM specialists of company D_8 have developed an open BIM platform which can read and convert various types of architecture models into proper files facilitating the analysis. Non-BIM specialists of company D_8 (i.e. senior managers), however, are reluctant to resolve interoperability issues due to the time, cost and effort required. In particular, the BIM capacity of architecture firm D_7 is not as qualified as D_8. Currently, engineering firm D_8 has decided to wait until other partners' capacity is mature enough to collaborate with.

Main contractor company C_3 established a BIM team to manage the BIM collaboration to reduce design conflicts. However, BIM is not a priority on site compared to the completion of projects according to time, cost and quality. Site teams of non-BIM specialists hold neutral attitudes towards BIM adoption and see BIM as an optional choice. Site teams may not oppose the trial of BIM in some aspects of the project but will not allow the BIM team to intervene much in their decision making.

Owner company O_3 does not play an active role in solving conflicts in BIM collaboration as they often hire external BIM consultants to lead the BIM effort. However, the roles of BIM consultants sometimes overlap with design managers (typically architecture firm D_7), resulting in confusion among partners within the supply network.

The government agency GA tries to resolve conflicts in contracts, fee structures and interoperability issues through enforcing BIM regulations, standards and guidelines. Such interventions only transform rules in the activity system while other elements such as tools, division of labour, community, objects and outcomes remain unchanged. As a result, the interventions of the government agency have little impact on conflict resolution among partners in BIM activities.

8.8 Triangulating themes

8.8.1 Using secondary data to validate Theme 9

8.8.1.1 Responses at the government level

Through the interviews with government agents GA_1, GA_2 and GA_3, the researcher was informed of recent policies promoting BIM applications in Vietnam. This helps save time for triangulation because the relevant information of BIM may get lost within various regulatory documents and be scattered over lengthy articles or clauses. At the point of time the data collection was carried out, there was no official source of knowledge like the

NBS national BIM library[30], sponsored by the UK government, to gather and share BIM based documents on guidelines, standards and legal framework among the AEC industry members. All Vietnamese BIM legislative documents were still preserved in a centralised government website[31]:

- The Construction Law, which was adopted by the XIII National Assembly on 18 June 2014, and effective on 1 January 2015, mentions a number of issues related to BIM such as applying technology, information system on construction activities (Item 3, Article 4), and the management of information system for the building (Item 1, Article 66).
- Decree No. 32/2015/ND-CP on 25 March 2015 of the Construction Ministry about management of construction cost mentions the regulation of project management fee for the project uses the specific project management method (Item 2, Article 23) (Section 2, Article 25).
- Decision 79/QD-BXD dated 15 February 2017 of the Construction Ministry about "Standard project management and construction consulting costs" points to the method to calculate consultant fees when using BIM application in consulting services (Section 2, Article 2).
- Decision No. 134/QD-TTg dated 26 January 2015 about the restructuring plan of the construction industry in association with the transformation of the growth model to enhance quality, efficiency and competitiveness in the period 2014–2020 issued by the Prime Minister also defines the application of the Information Technology Project (BIM) as one of the main solutions to the objectives set out in the scheme.
- The stipulation of Resolution No. 26/NQ-CP dated 15 April 2015 of the government on "The Promulgation of the Government's Action Program" promotes the application and development of information

[30] NBS BIM national library: nationalbimlibrary.com
[31] Vietnam Government Info Gate: http://www.chinhphu.vn/portal/page/portal/English.

technology to meet the requirements of sustainable development and international integration.

- In Decision 362/QD-BXD in 2018, the Vietnamese government launched its adoption plan by selecting 20 pilot projects to experiment with BIM implementation.

These documents confirm the effort of the Vietnamese government in promoting BIM adoption, particularly taking account of BIM consultant fees as valid transactions in construction projects. Further, 20 pilot projects were selected to be implemented in order to gain knowledge of BIM related challenges in regulation, procedure, training and procurement. The pilot projects include 11 residential and office buildings, 5 transport projects, 3 hospitals and a water reservoir.

8.8.1.2 Responses at project level

Figure 8.2 represents the reaction of one design company to the issue of BIM coordination in a project. The naming rule including colour, tag and code was emphasised as a tool to unify and classify BIM elements. However, the researcher observed that there are various types of templates which are created and used in an ad hoc manner. The project outcomes could become frustrating if members followed strict rules while others did not.

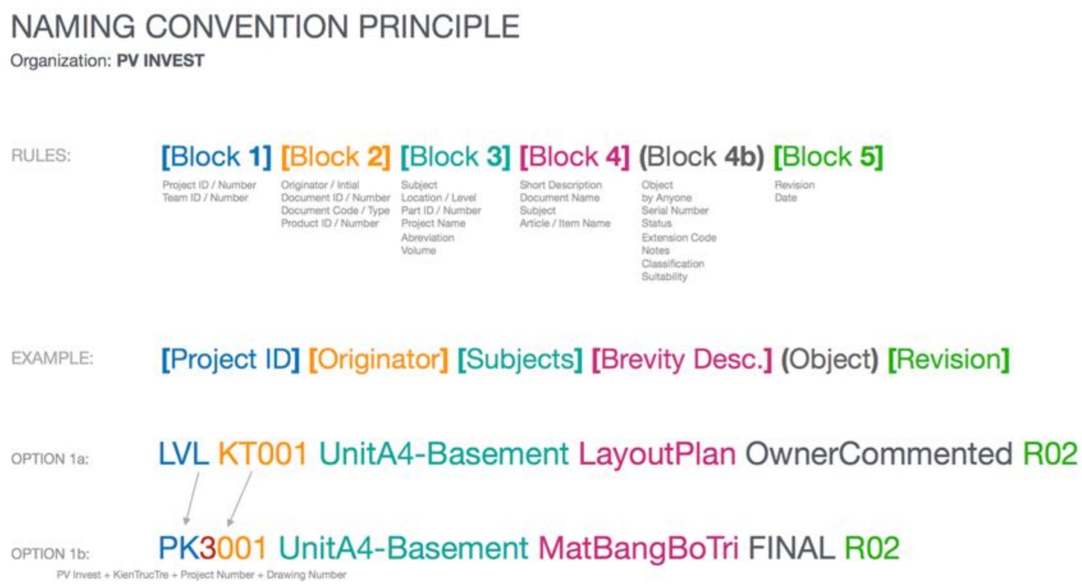

Figure 8.2 Naming rules for BIM coordination (document shared by company D7)- Refer to Appendix 18 for full page figure

Contractors quickly responded to the BIM mandate by adopting a 3D view in site safety solution, an important aspect in the bidding process which can determine the possibility of winning the contract (see Figure 8.3). However, the Revit-BIM elements cannot directly export to current analysis software to calculate safety and performance of elements, leading to manual modelling updates when there are any modifications of structural solutions.

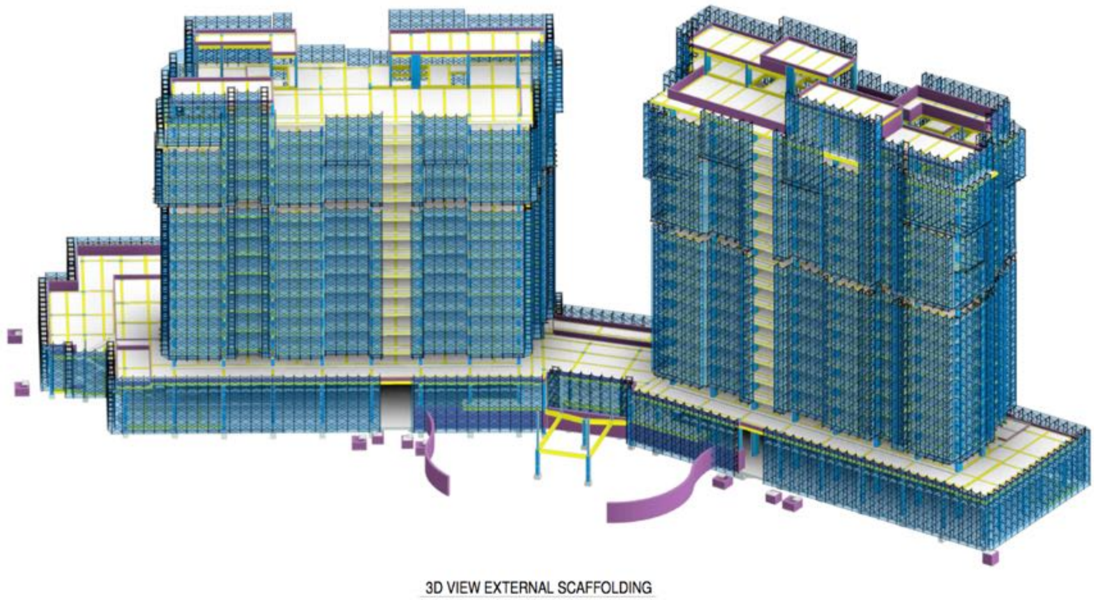

Figure 8.3 Site safety solution created by Revit (document shared by company C3)

The supplementing of 3D views on traditional 2D drawings was another response of designers to the BIM mandate. But site engineers perceived this application to be not so useful as there is less information contained in the same A4 sheet due to the extra representation of 3D objects (see Figure 8.4).

Unless the very sophisticated elements require the additional 3D explanation, normal sections are good enough with 2D drawings. Also, engineers showed their negative attitude when mandated to use BIM. For drawings to be powerful as a tool to maintain occupational jurisdiction, they must be somewhat unclear to other groups (e.g. manual workers), because if every aspect of the work was easily codified and understood, engineers would be unable to maintain their status as experts (Bechky 2003).

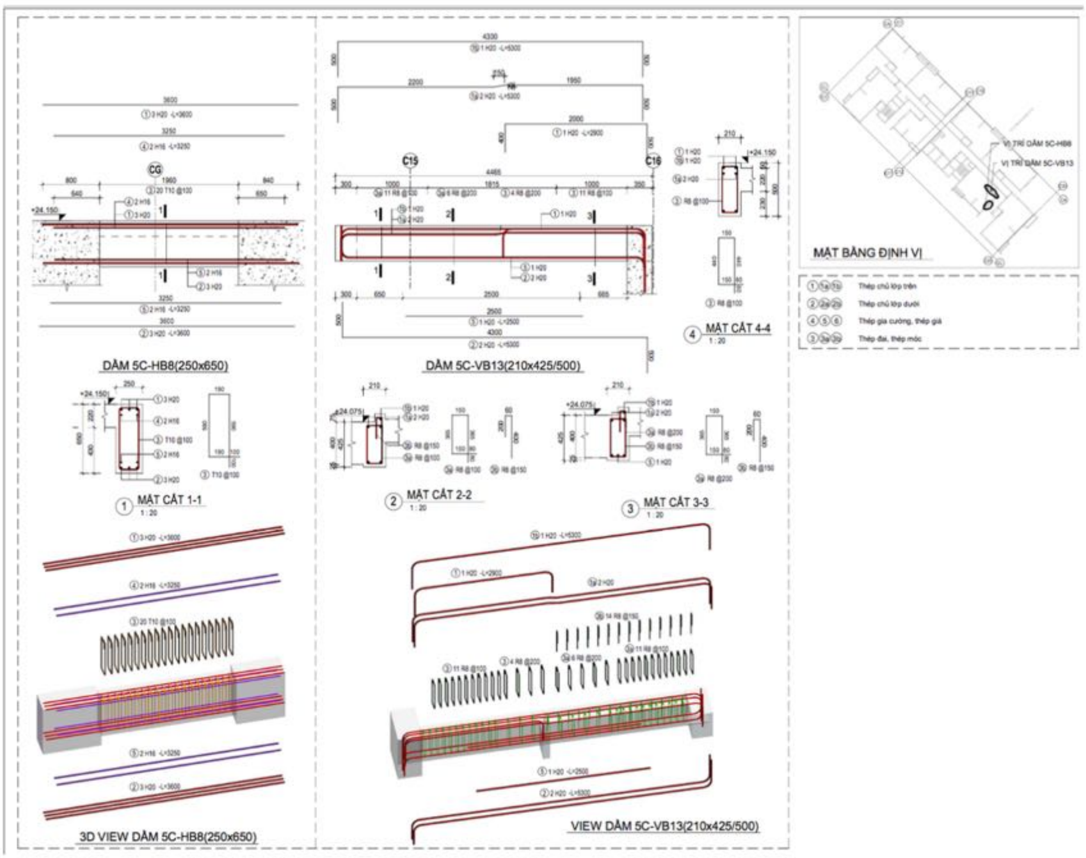

Figure 8.4 2D and 3D views of beam sections (document shared by company C_3)- Refer to Appendix 19 for full page figure

8.8.1.3 Responses at individual level (a single firm or single discipline)

Figure 8.5 shows the strategy of a BIM team (e.g. a group of professionals) aiming to promote individual skills of modelling. Because BIM is too new, many faults inevitably occur during the modelling process. BIM staff had to constantly amend their activities and record the updated solutions in a folder template such as updating manuals, guidelines and checklists every two months or after delivering a project. But participants have divergent feelings on the priority of upskilling. For some participants, it is important to address only the most important, in terms of impacts, or complex problems (see Figure 8.6). For others, the strategy is to solve easier problems first, the ones that are simpler yet frequently happen and require quick resolutions (see Figure 8.7).

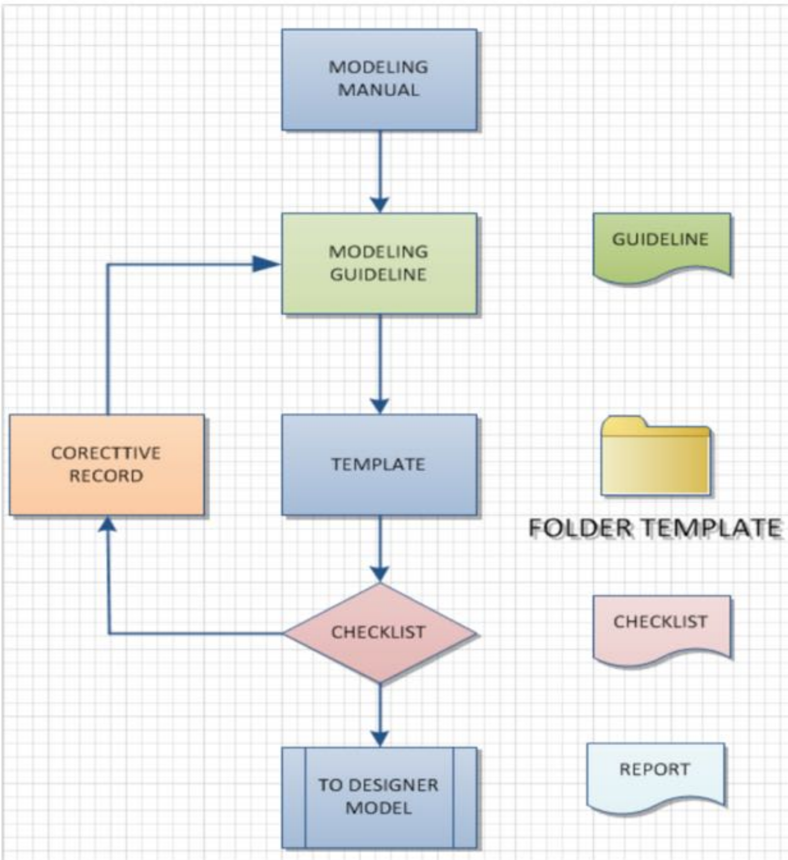

Figure 8.5 Strategy of improving individual modelling skills (documents shared by company D_8)

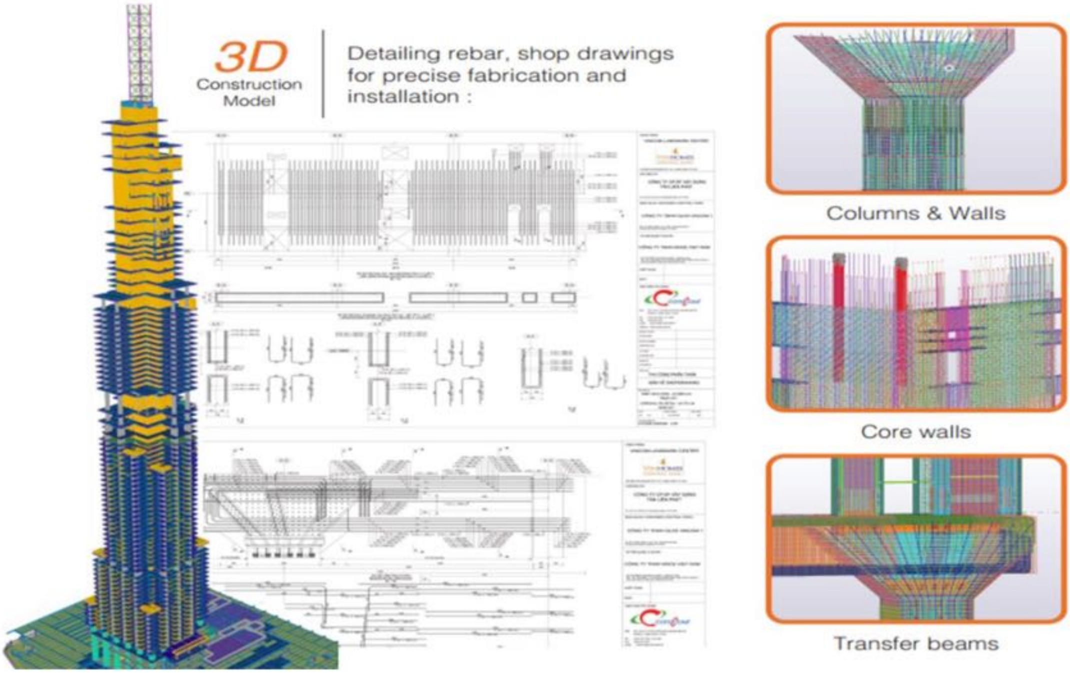

Figure 8.6 Complicated rebar detailing of transfer beam (document shared by company C3)- Refer to Appendix 20 for full page figure

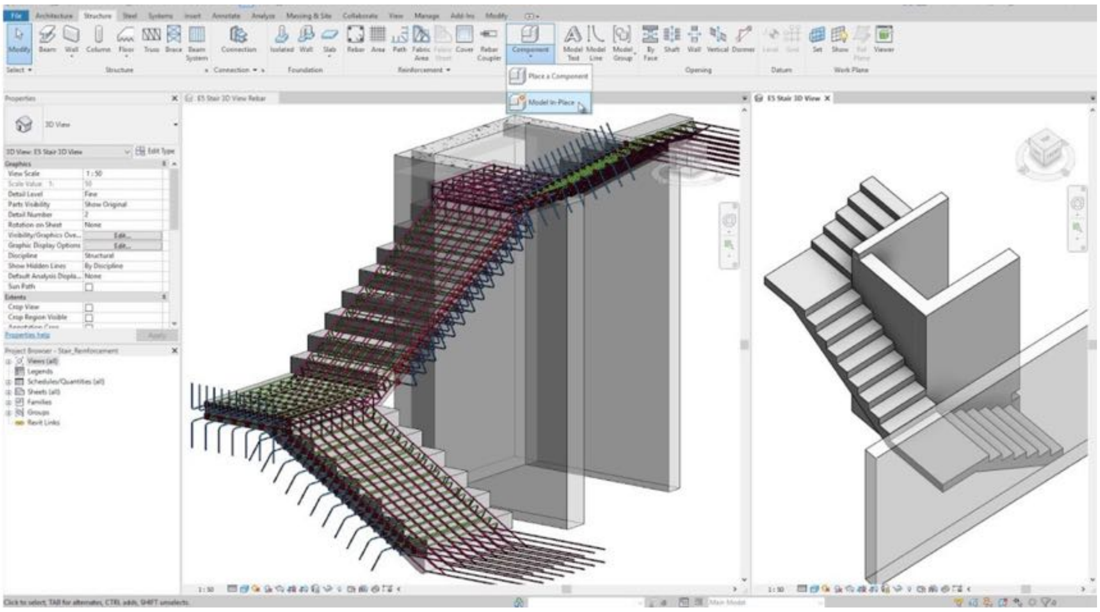

Figure 8.7 Less complicated stair component but commonly occurs at every floor (document shared by company C3)

8.8.2 Using direct observation to validate Theme 9

To manage its multiple projects spread across geographical locations, one main contractor, company C3, started using Autodesk solutions in 2011. It has a BIM team of over 60 members, who leverage a suite of Autodesk technologies to accurately capture design intent and improve project outcomes (see Figure 8.8).

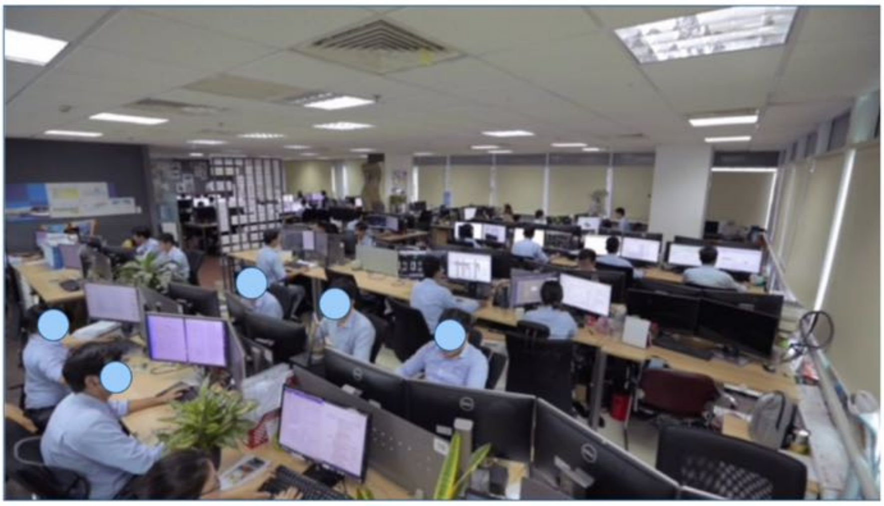

Figure 8.8 BIM team of company C_3 (snapshot during site visit)

Some prominent achievements observed are mobile BIM tools and BIM for Virtual Reality (see Figure 8.9 and Figure 8.10). However, these BIM applications are costly and mainly used for improving the new experiences of clients in a virtual environment rather than widely diffused over construction sites.

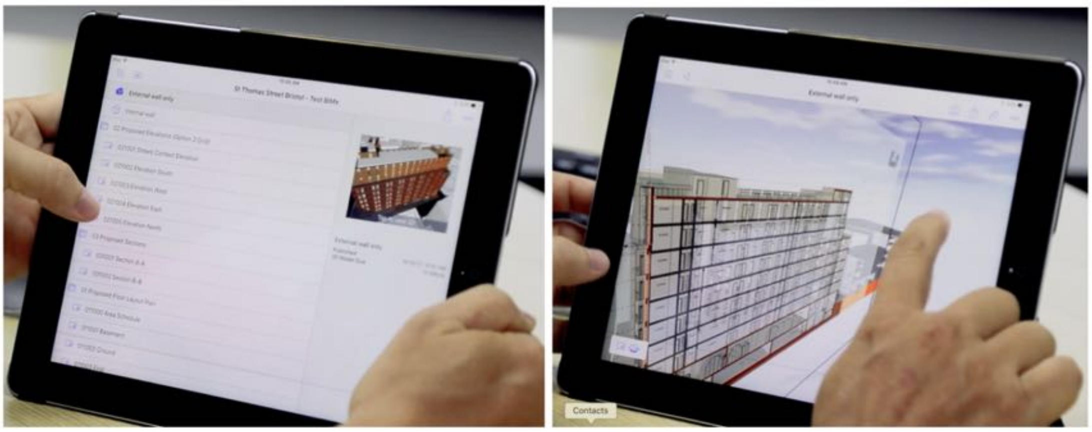

Figure 8.9 Mobile BIM tools (direct experience by the researcher at company C_3)

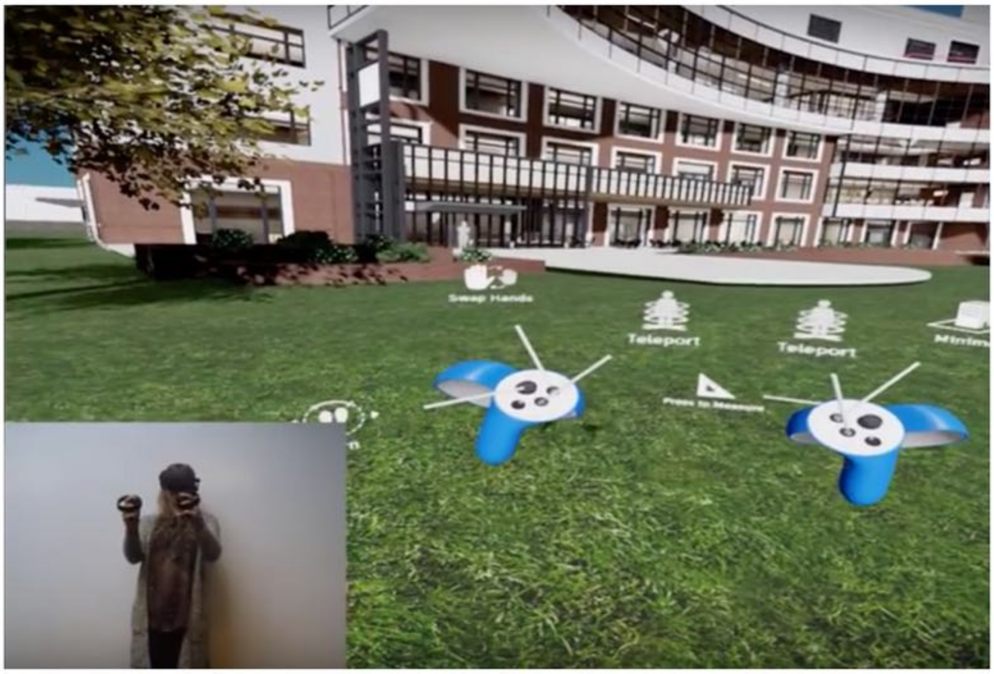

Figure 8.10 BIM for Virtual Reality - Users can step inside the 3D model (direct observation and experience by the researcher at company D_8)

8.9 Confirmation of combined framework

The second version of the combined framework developed from Chapter 7 was applied to guide the data analysis in Chapter 8 (see Figure 8.11). Findings from the third round of case studies (Chapter 8) replicate previous findings of the second round of case studies (Chapter 7) and hence strengthen the credibility of the second version of the combined framework.

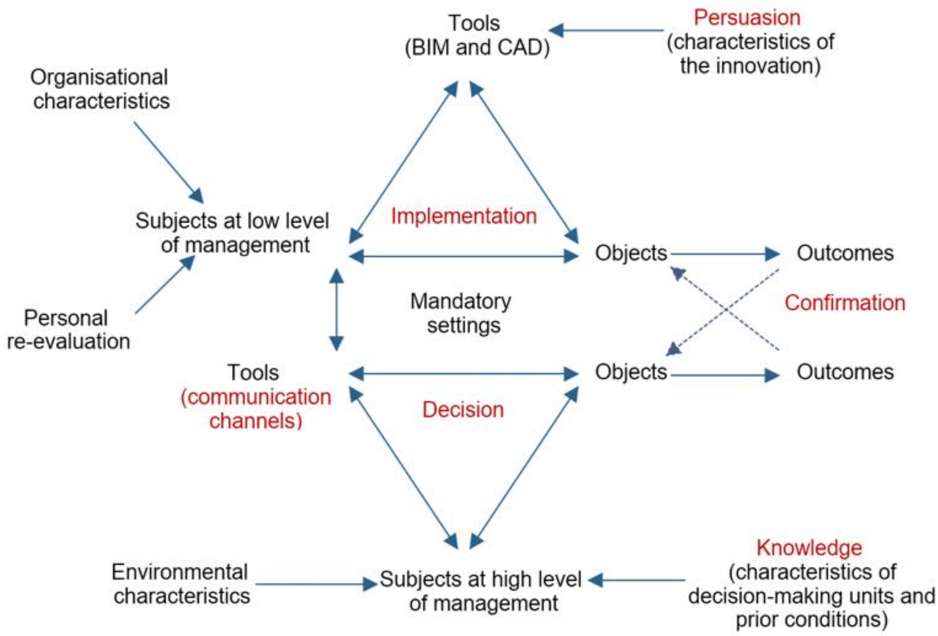

Figure 8.11 The second version of the combined framework of DOIT and AT (replication of Figure 7.13)

Considering the emerging sub-themes during the analysis of the first, second and third round of case studies, the third (or final) version of combined framework is established (see Figure 8.12).

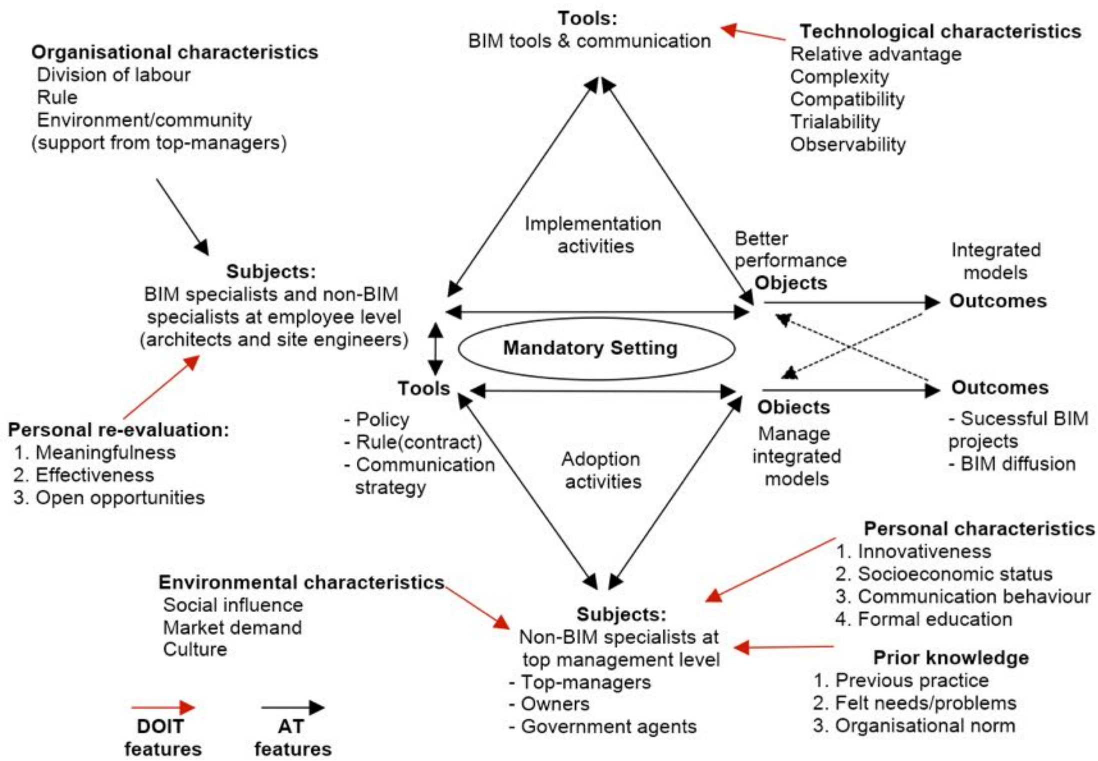

Figure 8.12 The final (third) version of the combined framework of DOIT and AT

The final version of the combined framework preserves the basic shapes or functions of the second version but details sub-themes to elucidate the interactions between two activity systems: adoption activity and implementation activity. Activity is defined as the process of a “subject” working towards an “object” using a “tool” to bring about an “outcome” (Hasan & Kazlauskas 2014). In an organisational context, particularly a mandatory setting, the outcome (e.g. a behaviour change of using innovation) may not be a desired or anticipated result but a result of constant negotiation between a subject at higher status (the mandator) and a subject at lower status (the implementer).

Subjects at higher managerial levels (e.g. non-BIM specialists at top management level) make unilateral strategic decisions to implement technical innovations across the organisation which subjects at lower status (e.g. BIM specialists and non-BIM specialists at employee level) must adhere to. Subjects at higher status use non-technical tools including rules, incentives and change agents to influence behaviours of subjects at lower status (e.g. BIM compliance). However, most senior managers have little practical knowledge or actual use of BIM tools compared to their employees. It is important to note that senior managers focus on traditional enterprise outcomes such as increased profit and market share as the collective outcome of BIM use whereas employees focus more on individual outcomes of successfully navigating the use BIM such as promotion or social recognition. The knowledge gap and disparity in individual interests result in conflicts between two activity systems which may impede the adoption of BIM across the entire organisation, manifested by the lack of commitment from top management and the resistance of employees to use BIM.

The final framework also describes that the performance of subjects at lower status is greatly influenced by internal factors such as division of labour (organisation hierarchy), community (working environment), organisational rules and personal values (e.g. motivation, satisfaction). On the other hand, the decision making of subjects at higher status is impacted by external factors such as market demand, social influences (competition) and culture.

In addition, Figure 8.12 indicates that initial adoption decisions are mediated by behavioural preferences of senior managers represented by their personal characteristics such as innovativeness, socioeconomic status, communication behaviour (extroversion or introversion) and formal education (overseas learning). However, the commitment of senior managers to a long-term vision of BIM adoption relies on their prior knowledge, for example, previous practice (piloting BIM), felt needs and problems, and organisational norms for the creation, storage, sharing and dissemination of BIM data in a collaborative manner.

8.10 Summary

8.10.1 Justifying data saturation

Data saturation refers to the point in the qualitative research process when no new information is discovered in data analysis, and this redundancy signals to researchers that data collection may cease. In other words, data saturation indicates that on the basis of the data that has been collected or analysed hitherto, further data collection and analysis are unnecessary (Saunders et al. 2018). In this research, three methods were used to justify data saturation. First, during interviews for data collection, the researcher began to hear the same comments again and again, and data saturation was possibly reached. Second, during thematic analysis from NVivo coding the researcher found that no new codes occurred in the data or additional codes did not lead to any new emergent themes. Third, the researcher revised the literature and found no necessary reference to the theory linked to the additional data. The third round of case studies confirmed the themes found in the second round of case studies were replicated or repeated, given their high reliability. It is then time to stop collecting information and to start analysing what has been collected.

8.10.2 Summary and further work

This chapter confirmed the findings in the second round of case studies using the combined framework and addressed the third research question: How do BIM specialists and non-BIM specialists in the Vietnamese construction industry respond to contradictions occurring during BIM collaboration activities? The combined framework of Diffusion of Innovation Theory and Activity Theory serves as a theoretical lens to examine how Vietnamese AEC professionals cross boundaries within and between activity systems. Common boundary crossing actions were found including external actions (e.g. hiring BIM consultants and outsourcing BIM works), internal actions (e.g. training, self-taught and establishment of an in-house BIM team) or industry and academia partnering (e.g. inviting BIM champions into the national BIM committee). A 'wait-and-see' attitude has been popular in the Vietnamese construction industry, particularly in the public sector where operations are constrained by the slow updates of government BIM based-regulations, and in architecture companies whose BIM applications deviate from the collaborative process and are dominated by visual representation and documentation.

The next chapter concludes the study with a review of the main themes. The research contributions to methodology, theory and practice are also provided. Some recommendations to non-BIM specialists at the top management level are made to help them with better management of post-adoption behaviours of BIM specialists and other non-BIM specialists at the employee level.

CHAPTER 9 Conclusion

9.1 Chapter objectives

This chapter summarises the conclusions from the research including themes, methodology and the fulfilment of research objectives. The contributions of this research are also explained. In addition, recommendations are made to help Vietnamese AEC professionals improve BIM based collaboration. The chapter concludes with areas for future research, together with reflections on the limitations of this research.

9.2 Research process

The aim of this study was to investigate the interaction between BIM specialists and non-BIM specialists in the Vietnamese construction industry. During the study, a combined framework of Diffusion of Innovation Theory and Activity Theory was developed to facilitate data analysis. In order to achieve this aim, the following specific questions and objectives were set:

Question 1: How do BIM specialists and non-BIM specialists in the Vietnamese construction industry perceive the new BIM profession?

- Objective 1.1: to examine social recognition of BIM job titles including new positions (roles), responsibilities and career opportunities
- Objective 1.2: to examine the relevance of BIM to the current business model including workflow and organisational hierarchy
- Objective 1.3: to justify the utility of the initial theoretical framework of Diffusion of Innovation Theory to properly interpret emerging themes in the case studies of BIM adoption and implementation in Vietnam

Question 2: How do BIM specialists and non-BIM specialists in the Vietnamese construction industry carry out BIM collaboration activities?

- Objective 2.1: to identify common tools (both BIM and non-BIM) used to mediate the interaction between BIM specialists and non-BIM specialists
- Objective 2.2: to identify objects which motivate the adoption by BIM specialists and non-BIM specialists
- Objective 2.3: to describe who is responsible for which BIM adoption aspects, and their abilities and shortcomings
- Objective 2.4: to examine the expected outcomes versus actual outcomes achieved through BIM interactions
- Objective 2.5: to describe the mandatory BIM conditions at the firm level, project level and national level and their effects on project performance
- Objective 2.6: to identify possible contradictions emerging during the BIM interaction
- Objective 2.7: to apply the combined framework of Diffusion of Innovation Theory and Activity Theory to interpret emerging themes in the case study

Question 3: How do BIM specialists and non-BIM specialists in the Vietnamese construction industry respond to contradictions occurring during BIM collaboration activities?

- Objective 3.1: to describe how different AEC professionals at different disciplines, firms and project types respond to conflicts arising during their BIM interactions
- Objective 3.2: to confirm the utility of the combined framework of Diffusion of Innovation Theory and Activity Theory for properly interpreting emerging themes in the case study.

A qualitative multiple case study methodology was adopted to collect and analyse data from 17 case organisations (with 67 in-person interviews) representing architecture design, structural engineering design, MEP engineering design, contractor, BIM consultant, project owner and the government. Participants in the study included BIM specialists and non-BIM specialists involved in current BIM based projects. Interviews were audio recorded and then transcribed. As part of the analysis of the interviews, secondary data (e.g. drawings and models) and direct observation (e.g. site visits) were used as triangulation methods to validate themes emerging from interview data.

9.3 Key findings

Table 9.1 summarizes the main research findings of the study.

Table 9.1 Summary of findings (all themes)

Main themes	Sub-themes	Sub-sub-themes
Theme 1: Perspectives of BIM specialists on BIM profession	Job insecurity	- *Welfare concern* - *Not self-confident of BIM roles*
	Depleted motivation	- *Poor morale* - *Disadvantage career path* - *Feeling of isolation*
Theme 2: Perspectives of non-BIM specialists on BIM profession	BIM profession as a supporting role	- *Supporter for project deliverables* - *Simply 3D visual representation*
	BIM as emerging skills for AEC industry	- *BIM not recognised as a mainstream profession* - *BIM not of much relevance to construction business*
Theme 3: Mediating tools of BIM activities	Tools used in BIM implementation activity	- *Traditional communication tools are dominant* - *Digital tools do not actively enhance communication on site* - *Site engineers are key medium for communicating BIM data*
	Tools used in BIM adoption activity	- *Lack of experience in creating BIM Execution Plan* - *Revision of BIM Execution Plan is not considered important*
Theme 4:	Multiple objects in BIM implementation activity	- *Inefficient communication of technical intentions*

Objects of BIM activities		- *Only sharing objects with specific partners*
	Unclear objects in BIM adoption activity	- *Over-specify goals* - *Lack of competencies to comply with specific objects*
Theme 5: Subjects of BIM activities	Organisational characteristics affecting subjects of implementation activity	- *Division of labour (social hierarchy)* - *Rules (cultures or norms)* - *Community (places where actors play their roles)*
	Personal re-evaluation affecting BIM implementation activity	- *Meaningfulness* - *Feeling useful* - *Open opportunities*
	Environmental characteristics affecting BIM adoption activity	- *Social influences* - *Market demand* - *Culture*
	Personal characteristics affecting BIM adoption activity	- *Innovativeness* - *Socioeconomic status* - *Communication behaviour* - *Formal education*
	Prior knowledge affecting BIM adoption activity	- *Previous practice* - *Felt needs/problems to change* - *Organisational norms*
Theme 6: Outcomes of BIM activities	Outcomes of BIM adoption activity	- *Perceived benefits of BIM vary for different types of clients* - *Balanced framework of monetary and managerial outcomes* - *Diffusion of policies in favour of BIM adoption*
	Outcomes of BIM implementation activity	- *Automation* - *Collaboration* - *Work efficiency* - *Redundant files* - *As-built inconsistency* - *Not having formal role description to determine the outcomes*
Theme 7: Mandatory settings of BIM activities	BIM mandate is not properly enforced	- *Still using old communication methods* - *BIM mandate is not rooted in practice*
	BIM mandate affecting BIM implementation activity	- *Limitations of internal capacity to comply with BIM mandate* - *BIM mandate does not consider human-related factors*
Theme 8: Contradictions occur during BIM interactions	Contradictions of scope of work	- *Who is the leader of BIM adoption?* - *Responsibilities of BIM deliverables*
	Contradictions of time	- *BIM modelling requires more time* - *Modelling may not save time in custom design* - *Single discipline finds it easier to adapt to BIM* - *Cross-disciplinary collaboration is more challenging*
	Contradictions of costs	- *Costs of BIM implementation* - *Cost saving in BIM based project*

	Contradictions of quality	- *Quality of virtual models* - *Quality of physical works*
Theme 9: Responses to contradictions	Responses at the government level	- *Scope of work* - *Time* - *Cost* - *Quality*
	Responses at the project level (cross-firms)	- *Scope of work* - *Time* - *Cost* - *Quality*
	Responses at the individual level (single firm or discipline)	- *Scope of work* - *Time* - *Cost* - *Quality*

The findings are presented as themes. A theme is used as attribute, descriptor, element, and concept. Each theme has some subthemes as subdivisions to obtain a comprehensive view of data and uncovers a pattern in the participants' account. A theme organizes a group of repeating ideas which enable the researcher to answer the study questions.

9.3.1 Addressing research question 1

9.3.1.1 The fulfilment of Objective 1.1

Theme 1 on perspectives of BIM specialists on the new BIM profession helps fulfil Objective 1.1. Although BIM tools are increasingly used in projects, emerging BIM job titles are not socially recognised in the Vietnamese construction industry. The perception of job insecurity is influenced by the contextual conditions in Vietnam where BIM specialists feel insecure about their roles in the future organisational hierarchy.

In addition, BIM specialists do not feel satisfied and happy as they do not adequately meet the expectations of other organisational members involved in the BIM implementation process due to the lack of support from top management in funding, equipment and empowerment and from their peer network as the site team is reluctant to share information and is less involved in the process of updating the model. The responsibilities of BIM specialists are found to overlap with other existing functions such as design managers and project managers. BIM specialists perceive their career path is unclear compared to peers who are still using CAD. In addition, BIM knowledge is mostly self-taught. There is a lack of formal training courses and knowledge sharing networks to learn from. There is also no professional certification for achieving BIM competency in Vietnam which also demotivates the post-adoption intentions of BIM specialists to continue.

9.3.1.2 The fulfilment of Objective 1.2

Theme 2 on perspectives of non-BIM specialists on the new BIM profession helps fulfil Objective 1.2. The perception of BIM as only a supporting role or as new skillsets to be acquired implies that although Vietnamese contractors and owners are actively engaged in gaining all possible outcomes and benefits from BIM implementation, they do not see any significant growth with just 3D. To these stakeholders, a 3D model, even in the BIM platform, is only as good as a paper-based drawing, but is just easier to interpret and explain.

Further, BIM is viewed as being not very relevant to the construction business. Neither main contractors nor owners are satisfied with additional payment for BIM services. Contractors perceived that BIM skillsets help designers increase the speed and accuracy of the designs, but these benefits are not directly relevant to their own bottom line. For owners, their focus is on making quick profits by selling buildings faster. While BIM is perceived as a tool or skillset to help project members achieve their goals, it has been slow to change owners' business models of procurement.

9.3.1.3 The fulfilment of Objective 1.3

During the analysis of the first round of case studies, some emerging themes related to social interactions such as the impacts of the BIM mandate by top management (non-BIM specialists) on post-adoption behaviours of staff members (BIM specialists and non-BIM specialists) were found to be insufficiently explained by Diffusion of Innovation Theory. Thus, this study needed to be supplemented by another theory, Activity Theory, to better interpret emerging themes.

9.3.2 Addressing research question 2

9.3.2.1 The fulfilment of Objective 2.1

Theme 3 on mediating tools used in BIM activities helps fulfil Objective 2.1. BIM is just one of many tools mediating human activities in the project design and construction process. There are also other communication tools such as conversations and paper documents, and non-BIM tools such as 2D drafting tools and engineering analysis tools which are being used in parallel with BIM. Theme 3 described the disadvantages of BIM tools regarding technical issues including a lack of interoperability and consistency of digital formats which is a barrier for wider adoption. Using older communication methods (e.g. oral and paper-based modes) to discuss and negotiate innovative deliverables (BIM outcomes) was still seen as cost saving and compatible with current communication behaviours in Vietnam. The learning conditions, such as time, cost and effort required to master BIM tools, were also found to be a barrier to BIM adoption. In summary, advanced technological capabilities of BIM provide an introduction to the construction industry but sustaining BIM adoption or building critical mass for adoption (e.g. scale, speed and maturity) requires facilitation from social conditions (e.g. changing communication behaviours) and learning conditions.

9.3.2.2 The fulfilment of Objective 2.2

Theme 4 on objects of BIM activities helps fulfil Objective 2.2. The objectives of BIM activities were unclear to both BIM specialists and non-BIM specialists. Theme 4 demonstrated the inability of BIM specialists to communicate their design intents to non-BIM specialists due to the fragmented nature of construction projects and concerns about professional liability with confusion around who is responsible for what parts of the use of BIM. Non-BIM specialists lacked BIM experience and skills. They expected more from BIM than actual users while being less competent to comply with these higher expectations. Theme 4 implies that although BIM visions and promises are needed for BIM implementation, they need to be complemented by a more realistic view of practical steps for the implementation. The initial promises around the capabilities of using BIM were set high in order to attract attention from financial sponsors, to stimulate agenda setting (both technical and political), and to build 'protected spaces' where the recognition of BIM roles in the Vietnamese construction industry did not eventuate.

9.3.2.3 The fulfilment of Objective 2.3

Theme 5 on subjects of BIM activities helps fulfil Objective 2.3. Theme 5 explored how BIM specialists are simultaneously responsible for two tasks: first, acting as change agents to lead, guide and support site people (non-BIM specialists at employee level) to implement BIM; and second, reporting the results of BIM implementation to decision makers, the non-BIM specialists at top management level. Due to the dynamic role serving both the construction site and main office, BIM specialists have to build long-term relationships with the site team as well as meet expectations of senior managers. The role of BIM specialists became challenging because their performance is partly assessed through the compliance with the BIM mandate by the site team. If people on site are resistant to change, BIM specialists are likely to lose credibility with senior managers. Hence, the adoption failed as the aspirations were not followed through.

9.3.2.4 The fulfilment of Objective 2.4

Theme 6 on outcomes of BIM activities helps fulfil Objective 2.4. Theme 6 represented the constant negotiation of BIM deliverables against expected or desired outcomes. The use of BIM in Vietnam is relatively new, and the measurement and evaluation of BIM outcomes have not been properly defined.

BIM outcomes are assessed on conventional evaluation criteria such as time, cost and quality while less visible BIM outcomes such as improved safety, consistent and structured digital data and reusability of models are ignored.

9.3.2.5 The fulfilment of Objective 2.5

Theme 7 on mandatory setting helps fulfil Objective 2.5. Theme 7 indicates that the government BIM mandate as a push factor is a prerequisite condition for innovation adoption, but this alone is not enough to fully support the implementation of BIM. The difficulties originated from a low level of innovativeness in the government bodies themselves, manifested by innovation laggards who existed in most of the public sector. Further, members of the national BIM committee (change agents) failed to act as BIM champions. The public sector did not act as a role model and catalyst for BIM adoption and as a result the private sector did not trust the government's commitment to adopting BIM. The organisational readiness (e.g. BIM skilled staff and resources) was also seen as a key failure factor of a firm to comply with the mandate.

9.3.2.6 The fulfilment of Objective 2.6

Theme 8 on contradictions emerging during BIM interaction helps fulfil Objective 2.6. Contradictions were identified in relation to the project constraints: scope, time, cost and quality. The contradictions of scope resulted from disturbances which BIM creates within system functions (e.g. division of labour) and system norms (e.g. rules and behaviours). The contradictions of time and cost arose when subjects select, purchase, learn and manipulate BIM tools under conditions of resource shortages of skilled staff, equipment and funds. The contradictions of quality occurred due to the gaps between objects and outcomes through BIM adoption. For example, the as-built model could not keep pace with actual construction progress.

9.3.2.7 The fulfilment of Objective 2.7

The researcher applied the combined framework of Diffusion of Innovation Theory and Activity Theory to explain findings in the second round of case studies. This proposed framework not only helped develop interview questions based on theoretical concepts but also created theoretical codes to facilitate grouping the responses of research participants in a structured manner.

9.3.3 Addressing research question 3

9.3.3.1 The fulfilment of Objective 3.1

Theme 9 on responses to contradictions helps fulfil Objective 3.1. BIM was perceived as new by research participants. Their understandings of contradictions resulted from BIM interactions were still in accordance with the conventional project constraints: scope, time, cost and quality. Theme 9 demonstrated how the government agents, AEC firms and professionals related to BIM implementation faced challenges to traditional project constraints and reacted to these contradictions. The responses included short-term tactics of hiring BIM consultants, long-term strategies of BIM partnering or personal development (e.g. self-taught).

9.3.3.2 The fulfilment of Objective 3.2

To validate the findings or themes in the second round of case studies, additional cases in the third round of case studies were selected and analysed using the combined framework of Diffusion of Innovation Theory and Activity Theory. Most patterns of behaviours (themes) in additional cases replicated consistently with those found in previous cases, improving the validity of the study (similar findings or literal replication).

9.4 Research contributions

9.4.1 Contribution to theory

9.4.1.1 Contribution to BIM research

As the combination of Diffusion of Innovation Theory and Activity Theory to investigate the adoption and implementation of innovation in a holistic manner is rare (Hochscheid & Halin 2019), this study offers a new insight into the development of a combined framework which potentially employs the strengths of both popular theories and reduces the weaknesses of each theory where separately used in research on innovation adoption. Through case studies in Chapter 7 and Chapter 8, this combined framework provides an alternative theoretical lens to investigate BIM activities that encompasses the individual, organisational and project level. The study also contributes to the literature on BIM adoption in the developing country context of Vietnam that may be of relevance to other developing countries facing similar issues.

9.4.1.2 Interpretation of data using the combined framework

Figure 9.1 shows how Diffusion of Innovation Theory and Activity Theory can be organised in a combined theoretical framework. The framework distinguishes the activity of making the adoption decision of decision makers (often non-BIM specialists at management level), and the activity of implementing an innovation by staff members (both BIM specialists and non-BIM specialists at employee level).

The proposed framework adopts the basic elements of Activity Theory of Subject – Tools – Object – Outcomes and adds main features of Diffusion of Innovation Theory on the elements of Subject and Tools, for example, technological characteristics, personal characteristics and prior knowledge. Some key elements of Activity Theory are reorganised to match the condition of the mandate. Non-BIM users, usually senior managers, are affected by environmental factors whereas BIM users, usually employees such as designers, are under the influence of organisational factors. Although the employees lack opportunities to make adoption decisions at the initial stage, they could re-evaluate 'what an innovation means to them' during the implementation stage, and after that determine their behaviours or responses at post-adoption stage.

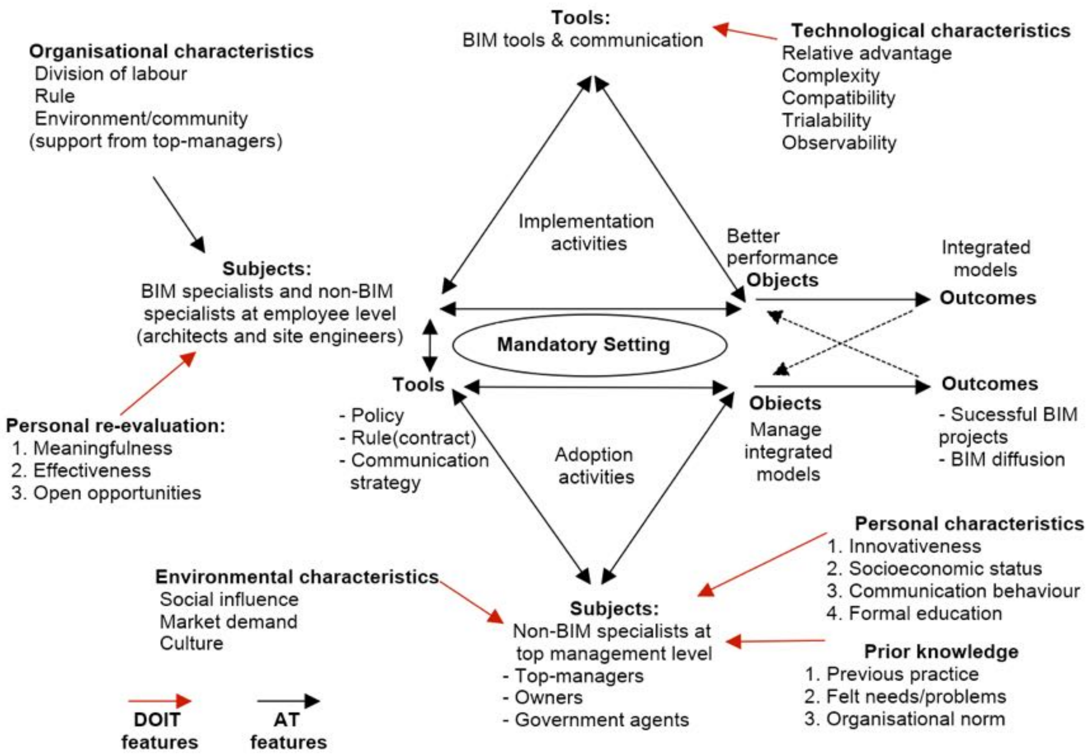

Figure 9.1 Final version of combined framework of DOIT and AT (replication of Figure 8.12)

The outcome of each activity system can impact the object of the other system and vice versa. For example, if the number of BIM adopters is accelerating, the site engineers would potentially increase their awareness and intention to adopt BIM because they see the new job opportunities as well as competitive pressures on the labour market. On the other hand, if the site engineers create useful integrated models that can reduce issues such as costly re-works, and increase quality of building, then potentially senior managers might enhance their support and commitment.

As BIM is considered a new collaboration tool to address the fragmentation among various disciplines such as architecture, engineering and construction (Eastman et al. 2011), this combined framework could be an appropriate theoretical lens for data analysis of BIM research because it advocates the socio-cultural approach of Vygotsky which posits that knowledge is collectively constructed through interaction, negotiation and collaboration in solving problems within a specific social-cultural context (Polly et al. 2018). This study implies that most BIM activities, either adoption decision or implementation, cannot be unilaterally determined by a particular group of subjects regardless of their high socioeconomic status. BIM activity is a collective negotiation which is based on empathy, options and reciprocity.

9.4.1.3 Identification of themes using the combined framework

In this study, six out of nine main themes are developed based on the main elements of the combined framework (see Figure 9.1). Six themes come together to comprehensively capture behaviours of participants, both BIM specialists and non-BIM specialists, in a specific context of the Vietnamese construction industry. In particular, the combined framework can help the researcher to identify:

- **Activity of interest:** What sort of activity are you interested in? This study focuses on adoption decision activity and implementation activity.
- **Community (Theme 7):** the place in which the activity is conducted. This study examines construction firms where BIM is mandated by the government.
- **Subject of this activity (Theme 5)**: Who is involved in carrying out this activity? The units of analysis in this study are experts (BIM specialists) and non-experts (non-BIM specialists).

- **Tools mediating the activity (Theme 3):** By what means are the subjects carrying out this activity? This study investigates the uses of BIM tools (e.g. Revit) and non-BIM tools (e.g. CAD) in parallel as BIM is a new tool which has been recently introduced into the existing community of CAD users.
- **Objects (Theme 4) and Outcomes (Theme 6):** Why is this activity taking place? What are expected results of the activity? In this study, the object of the BIM mandate is to quickly diffuse BIM to staff members and the expected outcome is the commitment of staff members. The setting of Object–Outcome needs to be constantly negotiated to match expectation and reality.
- **Contradictions (Theme 8):** The conflicts arise within and between key elements of the combined framework such as Subjects–Tools–Community–Object–Outcome or between two activity systems. In this study, the conflicts are found to relate to time, cost, quality and scope of work. Further, only large sized projects are relevant as BIM activities are resource intensive in the skilled workers and funds that large firms have.

The three remaining themes of perspectives of BIM specialists on the BIM profession (Theme 1), the perspectives of non-BIM specialists on the BIM profession (Theme 2) and responses of BIM specialists and non-BIM specialists to conflicts (Theme 9) may vary according to the social-cultural context of activities.

9.4.2 Contribution to research approach

While deductive and inductive approaches have been widely adopted in qualitative research (Mitchell 2018), the use of an iterative process of analysis based on abductive reasoning is limited (Lyon, Mšllering & Saunders 2015). Rather being constrained in the two traditional forms for presenting research, either from data to theory or from theory to data, the abductive approach allows the researcher to extend, complement and refine existing theories, as noted in the contribution to theory. The study serves as an example for other researchers who wish to adopt this approach, where research approaches still need further elaboration to interpret emerging themes.

9.4.3 Contribution to practice

Contradictions in the activity system should not be seen as problems but possibilities for developmental transformations in the creation of a need for change (Karanasios, Riisla & Simeonova 2017). However, contradictions are often difficult to observe because they result from interactions between elements of an activity system. For example, organisations are constrained by the need to achieve their objectives within the limits of organisational resources, while striving for competitiveness with their peers. This is a contradiction of Rule (e.g. organisation's budget) vs. Object (e.g. provision of professional services) vs. Community (e.g. competition with other organisations).

Contradictions may be also invisible and undiscussable (Hasan & Banna 2010). An invisible contradiction is one that is so much part of the team's everyday life that the members do not even recognise it as a difficulty. Invisible contradictions include anything that is "taken for granted" and especially cover cultural assumptions about how things are done and how relationships are managed (Murphy & Rodriguez-Manzanares 2008, p. 446). Undiscussable contradictions are those that nobody ever talks about because they are embarrassing, uncomfortable or culturally difficult to confront (Capper & Williams 2004). Offensive personal action of politically powerful project stakeholders is an example of undiscussability. Nobody is willing to talk about them openly, even though they may be seriously impeding progress towards the goal.

Thus, the identification of contradictions is not easy, but when it is done, it could help actors to focus their efforts on the root causes of tensions to make proper decisions on change. This study identified common contradictions occurring during BIM collaborative activities of Vietnamese case companies, serving as a case study for "late moving" organisations to facilitate their preparation and planning of the actual implementation of the new BIM system. This contribution to empirical evidence is valuable, particularly in the context that Vietnamese practitioners are adopting BIM with caution and at a limited number of projects due to the lack of guidance from research (Nguyen Bao & Nguyen 2018).

9.5 Recommendations

The use of the combined framework in future BIM research is suggested. In addition, some solutions to help AEC professionals to mediate their BIM coordination activities using the lens of Diffusion of Innovation Theory and Activity Theory are proposed.

9.5.1 Using the combined framework in BIM research

The combined framework provides clues which other researchers could adopt in their studies. For example, human perspectives are likely affected by personal traits, surrounding environment, and their prior knowledge of the phenomenon. Meanwhile, post-adoption behaviours are greatly influenced by organisational characteristics such as division of labour, rules, and top management support and self-evaluation of adoption behaviours on whether it feels meaningful. Through interviews, surveys and observations, other researchers could identify new factors affecting human attitudes and post-behaviours and evaluate which factors are more or less significant in their study contexts.

As the combined framework is developed based on a socio-cultural approach and aims at interpreting or understanding social interactions, its application is relevant in qualitative research or mixed research.

9.5.2 Using new communication tools to mediate BIM coordination – Diffusion of Innovation Theory approach

BIM models provide novel forms of virtual materiality (Paavola & Miettinen 2018). Thus, innovative products require advanced communication methods to allow the effective exchange of product information (Bowers, Ragas & Neely 2009). Vietnamese AEC firms can choose to adopt one of the communication methods as discussed below.

First, Hosseini et al. (2015) state that failure in diffusion of virtual team working into AEC projects will obstruct harnessing the benefits of all associated innovations, for example, BIM. The real-time cloud-based collaborative BIM platform used through mobile devices is recommended to enable users to virtually communicate. Site teams are now able to view and make responses to site issues directly from their mobile or cloud devices with the assistance of the BIM team (Abanda et al. 2018).

Second, the use of a 'big room' is suggested. The basic idea of a big room is that different stakeholders including designers, owners and consultants work side by side in the same location (see Figure 9.2). This method enables more effective information sharing between them compared to working in different locations (Muñoz-La Rivera et al. 2019). A big room set up decreases the latency of decision making in which information can be sought face-to-face instead of using remote communication tools or waiting for formal meetings (Tauriainen et al. 2016).

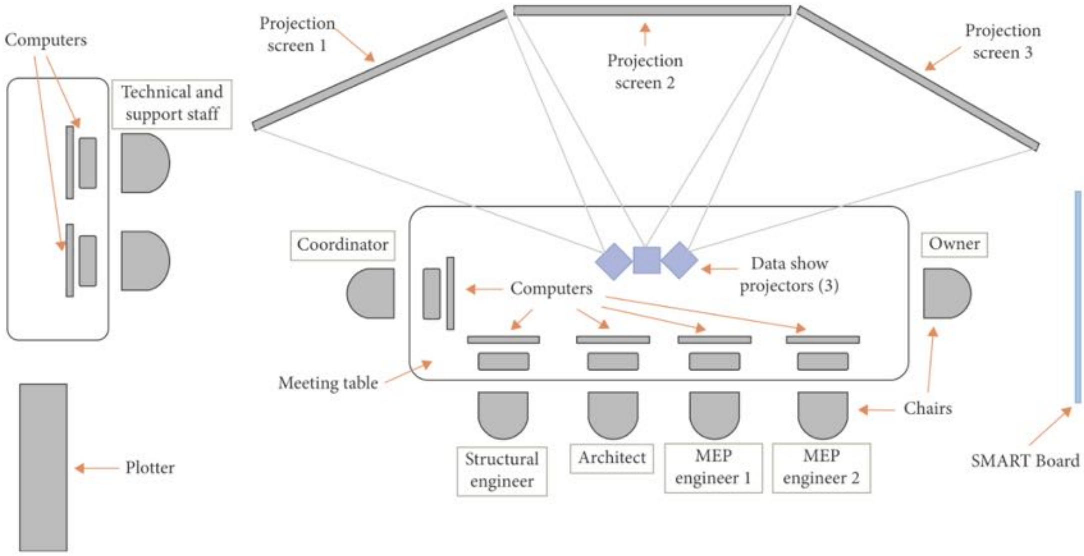

Figure 9.2 Big room mediating BIM collaboration (Muñoz-La Rivera et al. 2019)- Refer to Appendix 21 for full page figure

Third, the proposal of combining a video projector and smart touch-based whiteboard is also desirable (see Figure 9.3). Kubicki et al. (2019) noted that a video projector allows rapidly dealing with the 'simple issues', such as elements duplicated within two distinct models, by visualising errors for design teams to quickly resolve while using a smart whiteboard enhances collaboration of meeting participants to address 'hard issues' such as making decisions on design alternatives or changes.

Figure 9.3 Teamwork using both (1) video projector and (2) smart touch-based whiteboard (Kubicki et al. 2019)

9.5.3 Applying new collaborative working to mediate BIM coordination – Activity Theory approach

In addition to the uses of technical tools described above to enhance BIM coordination activities, it is suggested that cognitive tools could also be adopted. Engeström (2000) introduced the concept of 'knot-working' as a new collaborative working across organisational boundaries and hierarchies. The basic idea of knot-working is that project stakeholders meet at the same location in planned or spontaneous critical points of the project when cooperation benefits the most. These knot-working points usually last for a few days after which project stakeholders can go back to their own offices and continue to work on their respective projects (Kerosuo, Mäki & Korpela 2013). Thus, knot-working is compatible with activities performed by temporary groups, a norm in construction projects. Knot-working suggests that partners from different activity systems interact at boundaries in ways which are not limited by the rules, regulations or normalised practices of each individual intersecting activity system (Townsend 2019). Knot-working gives subjects the freedom to work with their tools because it is through the use and development of the tools that learning and innovation is happening (Klitgaard et al. 2017).

Knot-working can speed up the decision making and enable the different parties to commit themselves to the achievement of a common goal. This is because knot-working gives participants an opportunity to receive immediate feedback from others to open questions, mediating expansive learning process to understand the goals, information needs and working methods of other disciplines (Buhl, Andersen & Kerosuo 2017; Klitgaard et al. 2017). This collaborative working can replace the conventional BIM coordination activities in Vietnam which are characterised by unequal power relations such as site managers having absolute power in decision making.

9.5.4 Policy interventions

The Vietnamese policy makers expect that for all public projects such as complex infrastructure projects commencing from 2021 onwards, government clients should provide concept designs using BIM and require tender designs to be submitted using BIM (Bui 2019). To meet these objectives, policy makers require empirical data which may help them establish a program of policies and interventions to realise the desired change. This study provides case studies on how AEC professionals including BIM specialists and non-BIM specialists perceive, interact and solve problems under a BIM mandatory setting. This study could serve as a source of evidence to facilitate policy decision making.

9.6 Limitations of the study

9.6.1 Unable to access BIM collaboration meetings

The focus of this research was to investigate interactions of AEC professionals in BIM based projects. However, the researcher had little opportunity to be involved deeply in project meetings where collective problem-solving and decision making were performed, except on two occasions when the researcher was invited to attend a site meeting between a main contractor and subcontractors and a BIM coordination meeting with the owner, designers and main contractor. This could have been because the researcher was unable to build sufficient trust with research participants due to time constraints and having to travel long distances between multi-research fields of construction sites and firms. Most data on BIM interactions was collected from interviews through in-person conversations in which an atmosphere of intersected activities (e.g. human attitudes, gestures, voices etc.) was unable to be fully captured. Interviewees only gave what they were prepared to reveal about their perceptions of events and opinions. However, these perceptions might be subjective and therefore change over time according to circumstance. Such responses, thus, might be a considerable distance from 'reality'.

9.6.2 Traceability of research process using abduction

Abduction is seen as a flexible approach to case research because the unit of analysis and theoretical framework should be loosely defined when entering the field (Dubois & Gadde 2002). In reality, the researcher commenced data collection initially with a basic knowledge of Diffusion of Innovation Theory. Through the first few cases, he gradually built up knowledge of cases, literature and field context. The researcher realised that some emerging themes were unable to be explained by Diffusion of Innovation Theory such as how conflicts occur during social interactions (e.g. BIM collaborations) and returned to literature to seek answers from another theory, Activity Theory. A new theoretical framework was established combining Diffusion of Innovation Theory and Activity Theory along with the cases extending to non-BIM specialists where the original intent was to investigate BIM specialists only. Moving back and forth between cases, literature, theoretical framework and the empirical world is the biggest advantage of abduction to reduce research bias (e.g. embracing fixed theory) and to treat 'anomalies' or emerging themes as opportunities for expansive learning by questioning existing theory and finding ways to improve it.

However, an abductive approach "wherein the iterations in between, and final matching of, the empirical and theoretical domains, might be the most difficult to account for and make transparent to the readers" (Dubois & Gibbert 2010, p. 135). This means it is challenging to signal the transition points to the readers, for example when the researchers determined to travel back to literature or forth to new cases. The processes of abduction is often hidden (Dubois & Gadde 2002), thus, Huhtala et al. (2014, p. 72) recommended "making this process explicit when reporting the study… gives the study its methodological rigor". As very few researchers applied an abductive approach or they employed it but did not clarify 'milestones' during the iterative process (Dubois & Gibbert 2010), there was a lack of guideline to follow. As a result, literature and findings in previous cases may be repeated in current cases for the purposes of explicitly presenting the point-to-point switching but may make the research redundant and repetitive.

9.7 Areas for future research

Perspectives and responses of Vietnamese AEC professionals to BIM collaboration were explored in this research under the lens of Diffusion of Innovation Theory and Activity Theory. However, the interventions of facilitators (e.g. BIM consultants or government change agents) regarding the BIM collaboration process were found to be ad hoc and relied on centralised and formalised communication which may prevent adopters from expanding their knowledge out of existing disciplines.

Buhl, Andersen and Kerosuo (2017) stated that it is not possible to find a technology driven solution to match the inertia in construction and it is also unrealistic to assume that BIM or any technology can produce the needed change. But we can start by experimenting with an open-ended expansive process in which multiple solutions will persist. The implementation of the knot-working process is an innovative method of collaboration in the construction industry, which entails the disruption of the present norms, practices and rules. The use of a facilitator is a catalyst helping participants exploit the openings for knot-working by encouraging people to bring in their resources and tools in new ways and thus increase innovation (Klitgaard et al. 2017). Further research, therefore, could focus on action research where the researcher acts as a knot-working facilitator to mediate the process of co-construction of knowledge and understanding among project team members, particularly in BIM pilot projects sponsored by the Vietnamese government.

The combined framework could be adopted to simulate social interactions according to which tools are being used and to identify conflicts among project stakeholders in advance to prepare for problem-solving negotiation.

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Appendices

Appendix 1 Ethics approval (July 2017)

Dear Applicant

Thank you for your response to the Committee's comments for your project titled, "Investigating socio-technical responses of construction sectors to the Vietnamese Government Building Information Modelling (BIM) mandate: a qualitative case study approach". Your response satisfactorily addresses the concerns and questions raised by the Committee who agreed that the application now meets the requirements of the NHMRC National Statement on Ethical Conduct in Human Research (2007). I am pleased to inform you that ethics approval is now granted.

Your approval number is UTS HREC REF NO. ETH17-1421.

Approval will be for a period of five (5) years from the date of this correspondence subject to the provision of annual reports.

Your approval number must be included in all participant material and advertisements. Any advertisements on the UTS Staff Connect without an approval number will be removed.

Please note that the ethical conduct of research is an on-going process. The National Statement on Ethical Conduct in Research Involving Humans requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually from the date of approval, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

You should consider this your official letter of approval. If you require a hardcopy please contact Research.Ethics@uts.edu.au.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please do not hesitate to contact Research.Ethics@uts.edu.au.

Yours sincerely,
Associate Professor Beata Bajorek
Chairperson
UTS Human Research Ethics Committee
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Note: the thesis title has been changed since the ethics approval was obtained in 2017. This change does not involve a change in the direction or focus of the research. UTS Human Research Ethics Committee accepted this change prior to final thesis submission.

Appendix 2 Invitation letter

INVITATION LETTER

RESEARCH PROJECT

Investigating the socio-technical responses of construction sectors to the Vietnamese Government Building Information Modelling (BIM) mandate: a qualitative case study approach

Dear Mr/ Ms…; Job title…

My name is Ngoc Quyet Le (Anthony) and I am a PhD student at the University of Technology, Sydney.

I am conducting research into BIM practice in the Vietnamese construction industry and would welcome your assistance. The research will involve interview and observation. While each interview takes no more than 60 minutes, the observation has a little influence on your organisational daily working. I have asked you to participate because you are an experienced professional in the construction industry and a potential stakeholder with interest in the implementation of BIM under the requirement of the Vietnamese Government. Additionally, to investigate more deeply the use of BIM in your organisation, I would like to ask you for granting interviews with your employees as well as observation of your organisational BIM practice in 2-4 weeks.

I really appreciate if you allow me to access your organisational artefacts such as photos, drawings, videos, documents and slides of BIM practice in your company. I promise these artefacts are used for research purpose only and with your permission.

If you are interested in participating (or/and permitting me to conduct the research in your company), I would be glad if you would contact me via: ngocquyet.le@student.uts.edu.au or my supervisors: Dr. Michael. Er (michael.er@uts.edu.au) and Prof. Shankar. Sankaran (Shankar.sankaran@uts.edu.au). Or contact to my manager in Vietnam: Dr. Quang Hung Tran, email tqhung@dut.udn.vn, phone: (+84)5113 842740, Address: Faculty of civil engineering, University of Technology Da Nang, 54 Nguyen Luong Bang St, Lien Chieu Dis, Da Nang, Vietnam.

You are under no obligation to participate in this research.

Yours sincerely,

PhD candidate: Ngoc Quyet Le
UTS contact address: Faculty of Design, Architect and Building, 702-730 Harris Street, Broadway, NSW 2007
UTS email address: ngocquyet.le@student.uts.edu.au
Mobile number: (+61) or (+84)

NOTE:
This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 2478 Research.Ethics@uts.edu.au), and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix 3 Consent form

CONSENT FORM

INVESTIGATING THE SOCIO-TECHNICAL RESPONSES OF THE CONSTRUCTION SECTORS TO THE VIETNAMESE GOVERNMENT BUILDING INFORMATION MODELLING (BIM) MANDATE: A QUALITATIVE CASE STUDY APPROACH
UTS HREC APPROVAL NUMBER: HREC- ETH17- 1421

I ___ ________________ *[participant's name]* agree to participate in the research project ***"Investigating the socio-technical responses of the construction sectors to the Vietnamese Government Building Information Modelling (BIM) mandate: a qualitative case study approach"*** that is being conducted by Ngoc Quyet Le (Anthony), with the following details: email address: ngocquyet.le@student.uts.edu.au , mobile number : (+61)[redacted] and UTS HREC approval reference number: HREC- ETH17- 1421 of the University of Technology, Sydney for his degree-Doctor of Philosophy.

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney.

I understand that I will be given a signed copy of this document to keep.

I agree to be:
☐ Audio recorded

I agree that the research data gathered from this project may be published in a form that:
☐ Does not identify me in any way
☐ May be used for future research purposes

I am aware that I can contact Ngoc Quyet Le or his supervisors Michael Er (michael.er@uts.edu.au) and Shankar Sankaran (Shankar.sankaran@uts.edu.au) Or contact to his manager in Vietnam: Dr. Quang Hung Tran, email tqhung@dut.udn.vn, phone: (+84)5113 842740, Address: Faculty of Civil Engineering, University of Technology Da Nang, 54 Nguyen Luong Bang St, Lien Chieu Dis, Da Nang, Vietnam. if I have any concerns about the research.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

NOTE:
This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au, and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Appendix 4 Participant information sheet

PARTICIPANT INFORMATION SHEET

INVESTIGATING THE SOCIO-TECHNICAL RESPONSES OF THE CONSTRUCTION SECTORS TO THE VIETNAMESE GOVERNMENT BUILDING INFORMATION MODELLING (BIM) MANDATE: A QUALITATIVE CASE STUDY APPROACH

UTS HREC APPROVAL NUMBER: HREC- ETH17- 1421

WHO IS DOING THE RESEARCH?

My name is Ngoc Quyet Le (Anthony) and I am a PhD student at UTS undertaking the research under supervision from Dr. Michael Er (principal supervisor) and Prof. Shankar Sankaran (co-supervisor).

WHAT IS THIS RESEARCH ABOUT?

This research is about developing a conceptual framework which describes BIM practices in Vietnamese construction industry under the current Government BIM mandate

WHY HAVE I BEEN ASKED?

Your participation is desirable for my research as you are an experienced professional in the construction industry and a potential stakeholder with interest in the implementation of BIM under the requirement of the Vietnamese Government. You are potentially able to provide information to assist my research on the effect on the workflow of organisations implementing BIM. The interview will specifically focus on the adoption, diffusion and implementation of BIM in construction organisations. Additionally, the observation of your daily working with BIM will help me to develop a framework of your organizational implementation of BIM.

IF I SAY YES, WHAT WILL IT INVOLVE?

If you decide to participate, I will invite you to

- *Participate in a 1-hour semi-structured interview that will be audio recorded and transcribed*
- *Let me watch you as you work over the period of 2-4 weeks, for 2 hours each working day*
- *Let me access to your organizational artefacts relevant to BIM practice such as drawings, videos, photos, documents etc.*

ARE THERE ANY RISKS/INCONVENIENCE?

There will be no risks in taking part in the research but it may cause some inconvenience. The interview will take up to an hour of your time. Interviews will be digitally recorded and transcribed however all data that is able to identify you or the organisation you work for will be deidentified. For example, if you were a project manager then instead of transcribing your name you would be identified as PM 1 and the company you work for described as Construction Company 1. The observation also has a little influence on your daily working as I will keep away from you and be silent during watching. The questions (if any) are only asked in your spare time. All your artefacts are used for the research purpose only and with your permission. They are also de-identified to protect your identity.

DO I HAVE TO SAY YES?

Participation in this study is voluntary. It is completely up to you whether or not you decide to take part.

WHAT WILL HAPPEN IF I SAY NO?

If you decide not to participate, it will not affect your relationship with the researchers or the University of Technology Sydney. If you wish to withdraw from the study once it has started, you can do so at any time without having to give a reason, by contacting ngocquyet.le@student.uts.edu.au

If you withdraw from the study, all the transcripts and notes about you will be destroyed. I also will not collect additional personal information from you. However, it may not be possible to withdraw your data from the study results if these have already had your identifying details removed.

CONFIDENTIALITY

By signing the consent form you consent to the researchers collecting and using personal information about you for the research project. All this information will be treated confidentially. All data that is able to

Appendix 5 Participant information sheet (continued from appendix 4)

identify you or the organisation you work for will be deidentified. For example, if you were a project manager then instead of transcribing your name you would be identified by coding as PM 1 and the company you work for described as Construction Company 1. These data will be kept in my google driver with multi- passwords (password for google driver and password for folder containing data). Your information will only be used for the purpose of this research project and it will only be disclosed with your permission, except as required by law.

I plan to discuss the results with my supervisors and UTS academic staff to validate the research. The research information will be released in form of conference presentation, online papers & hard copies on academic journals relevant to construction industry. In any publication, information will be provided in such a way that you cannot be identified.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I or my supervisor can help you with, please feel free to contact me via ngocquyet.le@student.uts.edu.au or my supervisors, Dr. Michael Er via Michael.Er@uts.edu.au, and Prof. Shankar. Sankaran via shankar.sankaran@uts.edu.au. Or contact to my manager in Vietnam: Dr. Quang Hung Tran, email tqhung@dut.udn.vn, phone: (+84)5113 842740, Address: Faculty of Civil Engineering, University of Technology Da Nang, 54 Nguyen Luong Bang St, Lien Chieu Dis, Da Nang, Vietnam.

NOTE:
This study has been approved by the University of Technology Sydney Human Research Ethics Committee [UTS HREC]. If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au], and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Appendix 6 Sample of interview questions

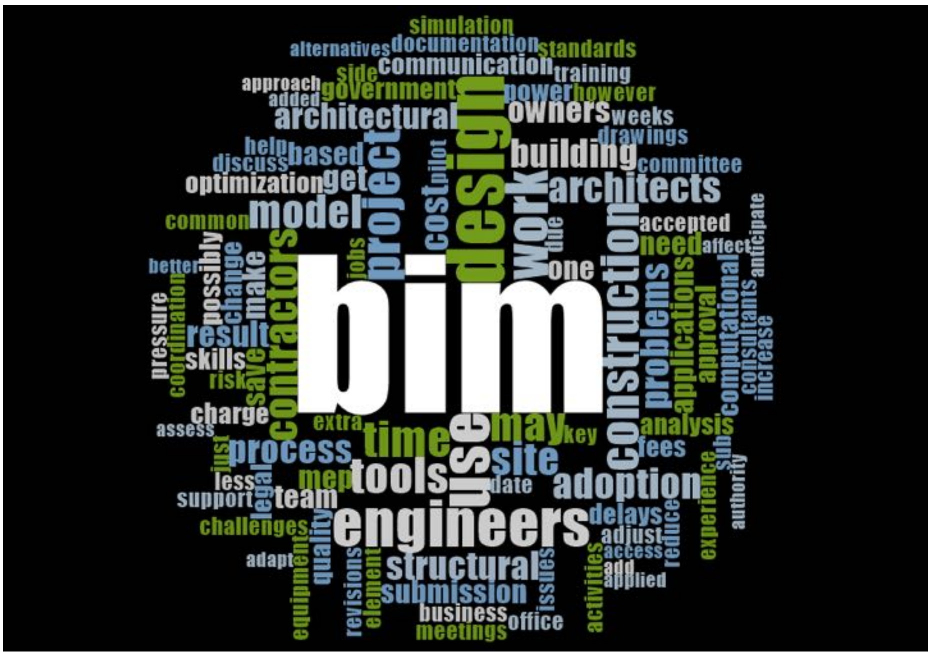
Case studies	Units of analysis (time)	Focus	Sample of Interview Questions
For all case studies	For both BIM specialists and non-BIM specialists (20 minutes)	Demographic data and general knowledge of BIM	- Age/education/position/work experience/BIM tool experience etc. - When/where have you heard about BIM? - What is your perception and understanding on BIM? - Is BIM mandated in your organisation? - (if BIM is mandatory in your organisation/or project), how do you adapt to this change? - Do you think BIM will replace the role of CAD? - In which level of BIM maturity do you believe your organisation currently is? - Do you think the Vietnamese government interventions (e.g. mandate) will promote the diffusion of BIM over construction industry?
For first case studies	BIM specialists (40 minutes)	BIM related jobs	- How are BIM titles defined in your organisation/or project? - To which extent your contributions to BIM applications are well recognised by others (e.g. colleagues, senior managers)? - Tell me your self-assessment of BIM performance? - To which extent do you get support from your colleagues and senior managers? - How much are you satisfied/enjoyed with BIM-related jobs? - Do you have any plan for self-development regarding BIM?
	Non-BIM specialists (40 minutes)	BIM related jobs (40 minutes)	- How are BIM titles defined in your organisation/or project? - To which extent are the contributions of BIM specialists significant to project performances/organisational benefits? - To which extent are BIM-related jobs relevant to your jobs? - Do you have any plan for self-development regarding BIM?
For second case studies	BIM specialists and non-BIM specialists at employee	Tools	- Describe some BIM tools which are currently used in your organisation? - How do you adopt BIM tools in parallel with non-BIM tools?
		Objects	- What are your objectives of BIM implementation?

	level (40 minutes)	Outcomes	- Which outcomes of BIM implementation do you expect? - How do you share/distribute the outcomes?
		Subjects	- Who leads BIM implementation? - To which extent do organisational characteristics (e.g. division of labour/rules/community) affect your BIM performance? - In addition to job responsibilities, which factors affect your commitment to BIM?
		Mandatory settings	- To which extent do mandatory settings affect your BIM implementation?
		Contradictions	- Tell me which conflicts arise during BIM implementation?
	Non-BIM specialists at high management level (40 minutes)	Tools	- What tools do you use to make decision on BIM adoption over the organisation/or project?
		Objects	- What are your objectives of BIM adoption decision?
		Subjects	- To which extent do environment factors (e.g. market demand, peer pressure) affect your BIM adoption decision? - To which extent do your personal traits (e.g. education, communication behaviours) affect your BIM adoption decision?
		Mandatory settings	- Do you believe that mandatory settings will promote BIM adoption over staff members?
		Contradictions	- Tell me which conflicts arise during BIM implementation?
For third case studies	BIM specialists and non-BIM specialists at employee level (40 minutes)	Similar to second case studies	- Similar to second case studies
		Responses to contradictions	- How do you respond to contradictions arising during BIM interactions?
	Non-BIM specialists at high management level (40 minutes)	Similar to second case studies	- Similar to second case studies
		Responses to contradictions	- How do you respond to contradictions arising during BIM interactions?

Note: Look for hidden issues – tacit issues not necessarily obvious to the interviewees such as contradictions during BIM interactions. The researcher needs to conduct follow-up questions to seek in-depth understandings of the issues. For example, BIM specialists may mention that the lack of BIM tools results in poor project performance which does not meet expectations of non-BIM specialists (i.e. tool-outcome contradiction). The follow-up questions could be: how do you negotiate the issue of resource shortage vs. expected outcomes prior to project start? To meet requirements of non-BIM specialists, do you find help from external partners?

Appendix 7 Word Frequency Query for the second round of case studies

Appendix 8 Word Frequency Query for the third round of case studies



Appendix 9 Theme structure of the first round of case studies (chapter 4)

Nodes

Name

- Perspectives of BIM-specialists on BIM profession
  - Job-insecurity
    - Welfare concern
      - Copyright issues
      - Lack of IT infrastructure
      - Contractual issues
      - Unfairly compensation
      - Overstating BIM capability
      - Lack of client demand
      - Extra workload
      - Late payment
      - Being replaced by new BIM professionals
    - Not-self confidence of BIM roles
      - Compatibility
      - Uncertain roles
      - Unsatisfactory BIM products
      - Complexity
      - Returning to traditional CAD
      - Lack of top management commitment and support
      - Lack of transparency
      - Lack of training and education
      - BIM is just for large and complex projects
  - Depleted motivation
    - Poor morale
      - Low creativity
      - Learning opportunities
      - Industry norms
      - Trialability
      - Unequal BIM cost and benefit
    - Disadvantage career path
      - Comparison with peers
      - Job structure

    - Turn-over
  - Feeling of isolation
    - Lack of diffusion network
    - Lack of peer support
    - Silo-BIM

- Perspectives of non-BIM specialists on BIM profession
  - BIM profession as a supporting role
    - Supporter for project deliverables
      - Marketing feature
      - Lack of government support
      - Lack of pre-conditions
    - Simply 3D visual representation
      - Buildability issues
      - Distrust in BIM models
      - Personel rotation and arrangement
      - Non-parametric data
  - BIM as emerging skills for AEC industry
    - Not recognized BIM as a mainstream profession
      - BIM as a new skill set
      - Social influence
      - Lack of IT team support
    - BIM not much of relevance to construction business
      - Still get benefits from traditional method
      - Not change the business model
      - Relative advantage
      - Observability

Appendix 10 Theme structure of the second round of case studies (chapter 7)

- Mediating tools of BIM adoption
  - Tools used in BIM implementation activities
    - Traditional communication tools are dominant
      - Telephone
      - Email and text message
      - 2D drawings
      - Technical meetings with 3D visualization supports
      - Zalo, Skype, and other social media network
      - Verbal face-to-face communication
    - Digital tools do not actively enhance communication on-site
      - Cannot convey non-verbal cues
      - Too busy or tigh schedule
      - Designs not integrating construction knowledge
      - Low IT skilled people working as good with 2D drawings
      - not effectively support brainstorming
      - Lack of skills of data mining
    - Site engineers are key medium of communicating BIM data
      - Learning curve
      - Redundant information
      - Error-free model is not practical
      - Communication habit
  - Tools used in BIM adoption activities
    - Lack of BIM execution plan
      - Lack of experiences on creating BEP
      - Contractual liability and duties
    - The revision of BEP is not considered important
      - Not being seriously aware of
      - Legal problem
      - Specification of compliance

- Objects of BIM adoption
  - Multiple objects in BIM implementation activity
    - Inefficient communication of technical intentions
    - Only sharing objects with specific partners
  - Unclear objects in BIM adoption activity
    - Over-specific goals
    - Lack of competencies to comply with specific objects
- Subjects of BIM adoption
  - Organizational characteristics affecting subjects of BIM implementation activity
    - Division of labour
      - Loose control between site and head-office
      - Site managers take control of site works
      - Resistance to change of site team
      - The position of BIM team is ambigous
    - Rules
      - Making decisions using experiences and personal contacts
      - Saving face
    - Community
      - See BIM as a child of architectural design
      - Communicating the same language with AEC professionals
      - Remoteness of construction sites
  - Personal re-evaluation affecting subjects of BIM implementation activity
    - Meaningfulness
    - Effectiveness
    - Open opportunities
    - Work-family conflicts

- Environmental characteristics affecting subjects of BIM adoption activity
  - Social influences
    - The interventions of government
    - Peer effect
    - The dominance of less educated labors
  - Market demand
    - Clients still trust large house-hold name
    - Sustainability of building is less concerned by clients
  - Culture
    - Corruption
    - Free raider
- Personal characteristics affecting subjects of BIM adoption activity
  - Formal education
  - Socio-economic status
  - Communication behavior
  - Innovativeness
- Prior knowledge affecting subjects of BIM adoption activity
  - Previous or existing business practices
  - Felt needs or problems to change
  - Organizational norms
- Outcomes of BIM Adoption
  - Outcomes of BIM adoption activity
    - Perceived benefits of BIM vary for different clients
    - Balanced framework of monetary and managerial outcomes
    - Diffusion of policies in favor of BIM adoption
  - Outcomes of BIM implementation activity
    - Automation
    - Collaboration
    - Work efficiency
    - Unmanageable file sizes
    - As-built inconsistency
    - Not having formal role description to determine the outcomes

- Mandatory setting of BIM adoption
  - BIM mandate is not properly enforced
    - Still using old communication methods
    - BIM mandates is not root in practice
  - BIM mandate affecting BIM implementation activity
    - Limitations of internal capacity to comply with BIM mandate
      - Limited libraries of standard objects
      - High demand on software and hardware
      - The emergence of new professional roles and relationships in the context of BI
      - Lack of interest in the part of professionals working with well-established non-
      - Time and cost required for training
      - Limited confidence in data security
      - Model ownership
      - Project responsibilities
      - Access rights
      - Intellectual property rights
      - Contractual responsibilities
      - Payment arrangements
    - BIM mandate less considers human-related factors
      - Trainning emphasizes on software and technical elements
      - Training by storytelling experience not by pedagogy
- Contradictions occur during BIM interactions
  - Contradictions of scope of work
    - Who is the leader of BIM adoption
      - The government is not a proper leader
      - The client is not a proper BIM leader
      - The designer is not a proper BIM leader
      - Small and medium sized company is not a proper leader
      - Main contractor and manufacturer are potential BIM leader
    - Responsibilities of BIM deliverables
      - Project taks are overlapping
      - The priority given to a task is different

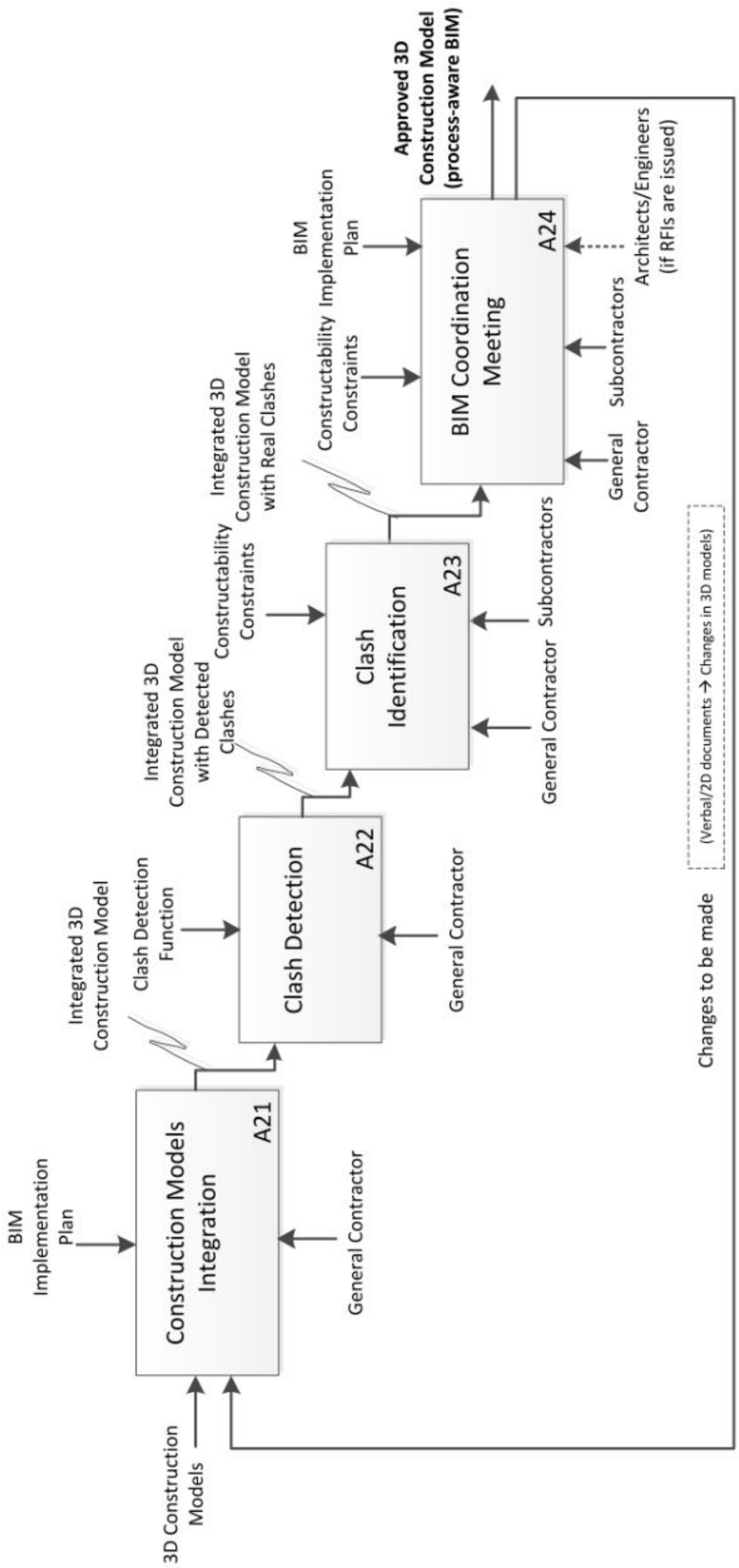
- Contradictions of time
  - BIM modelling requires more time
  - Modelling may not save time in custom design
  - Single discipline finds it easier to adapt to BIM
  - Cross-disciplinary collaboration is more challenging
  - Perspectives on time-saving
    - Time-saving means money
    - Having a neutral attitude about time-saving

- Contradictions of costs
  - Costs of BIM implementation
  - Cost-saving in BIM-based project
- Contradictions of quality
  - Quality of virtual models
  - Quality of physical works

Appendix 11 Theme structure of the third round of case studies (chapter 8)

- Responses to contradictions
  - Responses at the government level
    - Scope of work
    - Time
    - Cost
    - Quality
  - Responses at the project level
    - Scope of work
    - Time
    - Cost
    - Quality
  - Responses at the individual level (single firm or discipline)
    - Scope of work
    - Time and cost
    - Quality

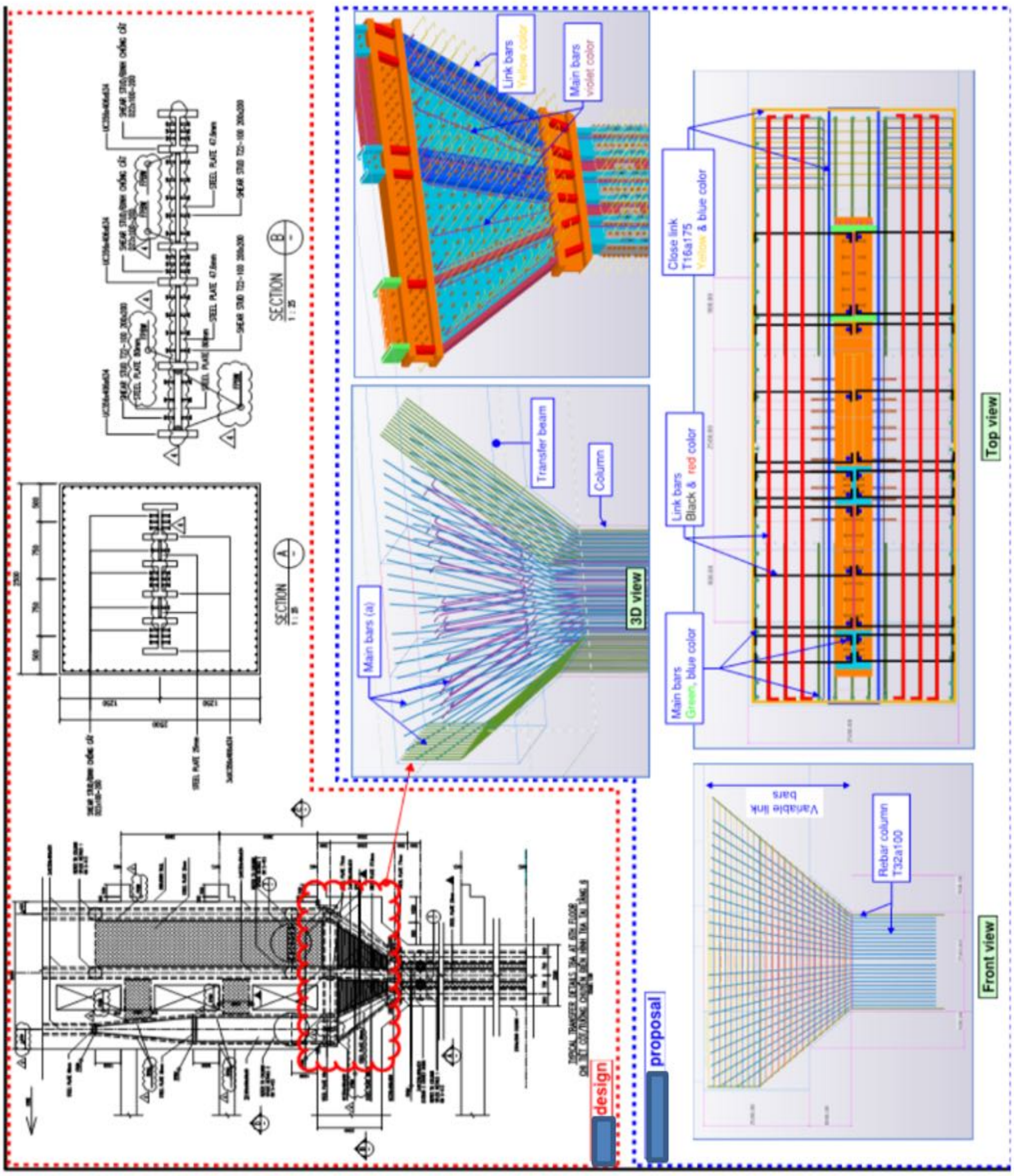
Appendix 12 Full page of Figure 2.4



Appendix 13 Full page of Table 2.8

Project manager	Project manager and BIM manager		BIM manager	
Metal fabrication	3D	Drawing	3D modeling	MEP
Modeling	Architectural design	LEED	3D studio max	MicroStation
New business development	Architectural drawings	Mixed-use	Construction safety	Piping
Steel	AutoCAD	Navisworks	Facilities management	Sketchup
Steel structures	BIM	Revit	High rise	Urban design
	CAD	Space planning	Interior design	
	Comprehensive planning	Steel detailing		
	Construction drawings	Submittals		
	Design research	Sustainable design		

Appendix 14 Full page of Figure 4.3



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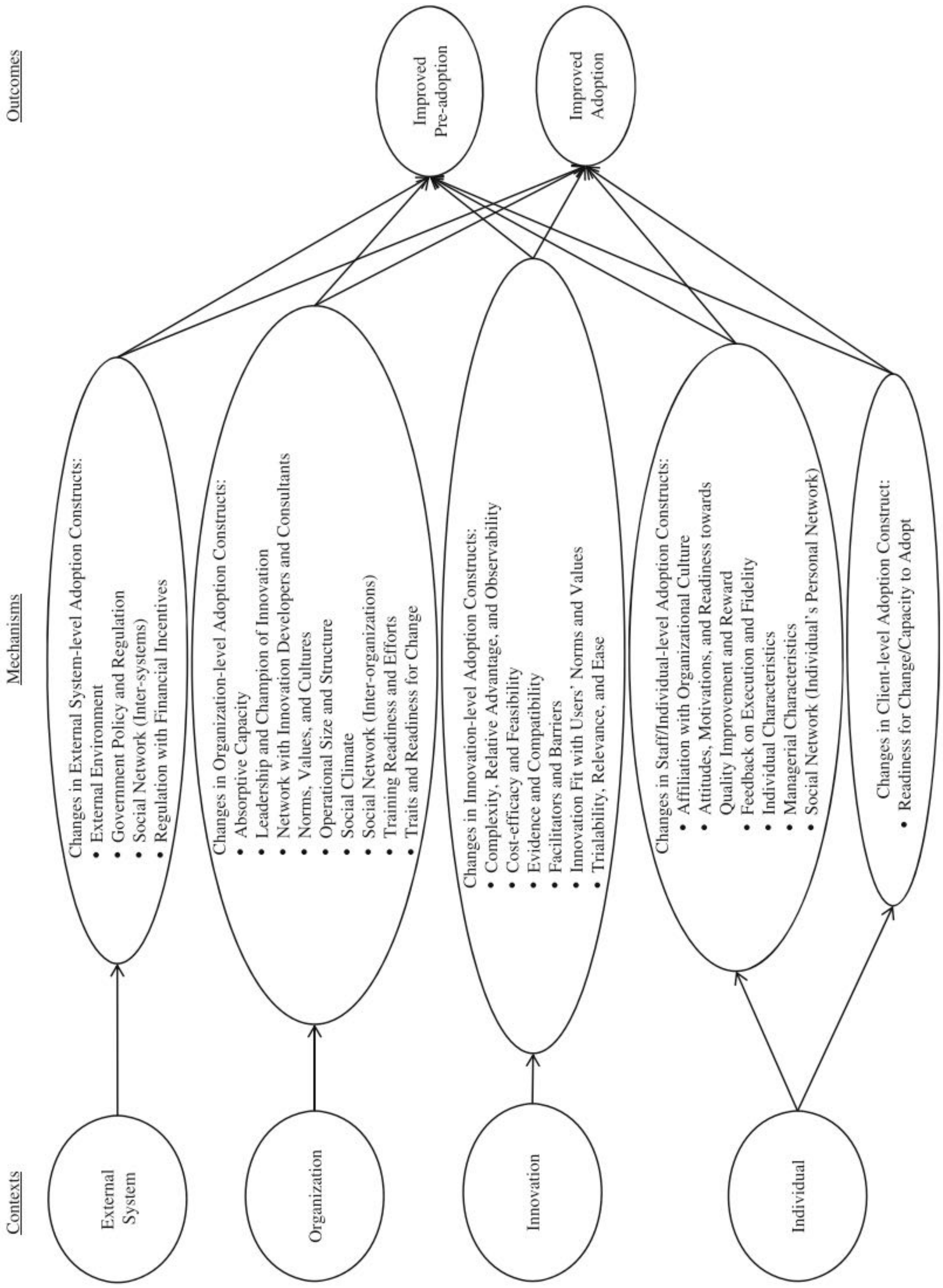

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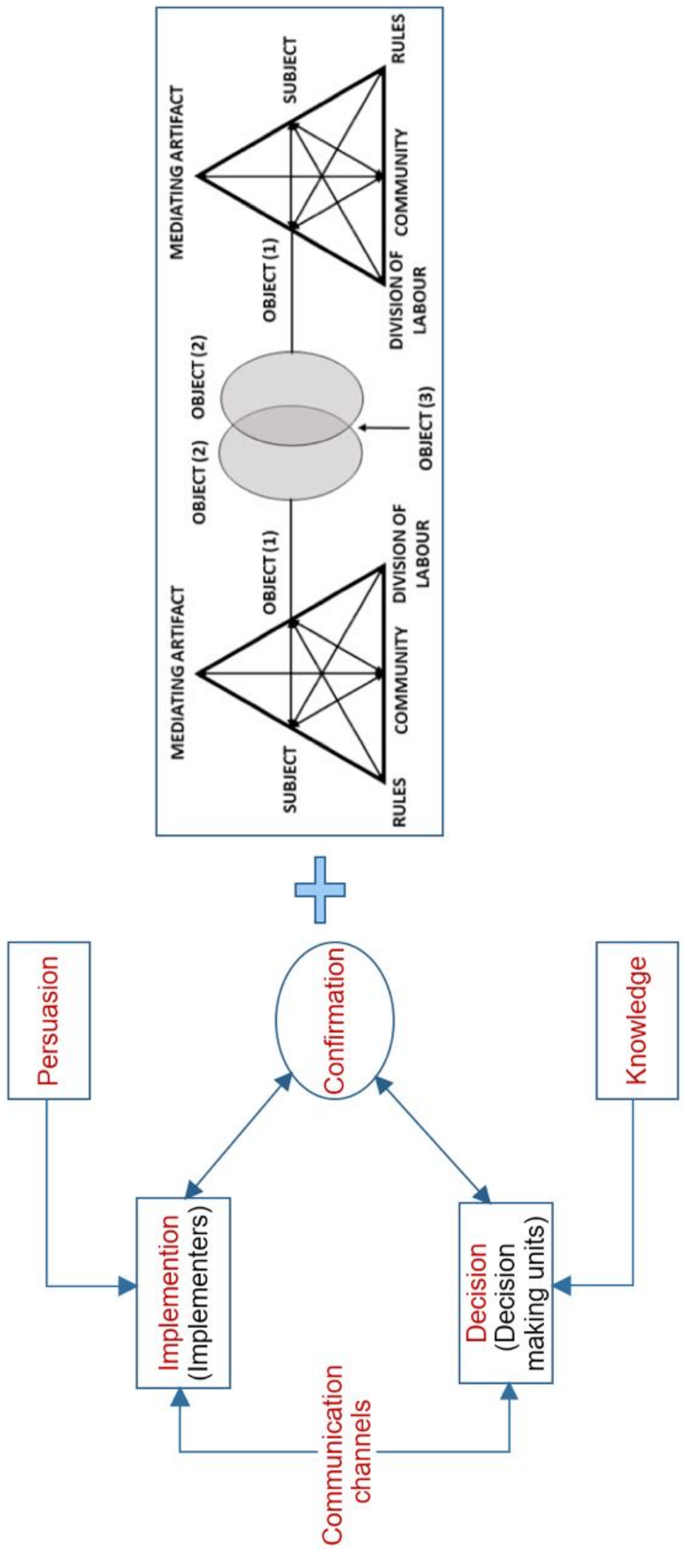

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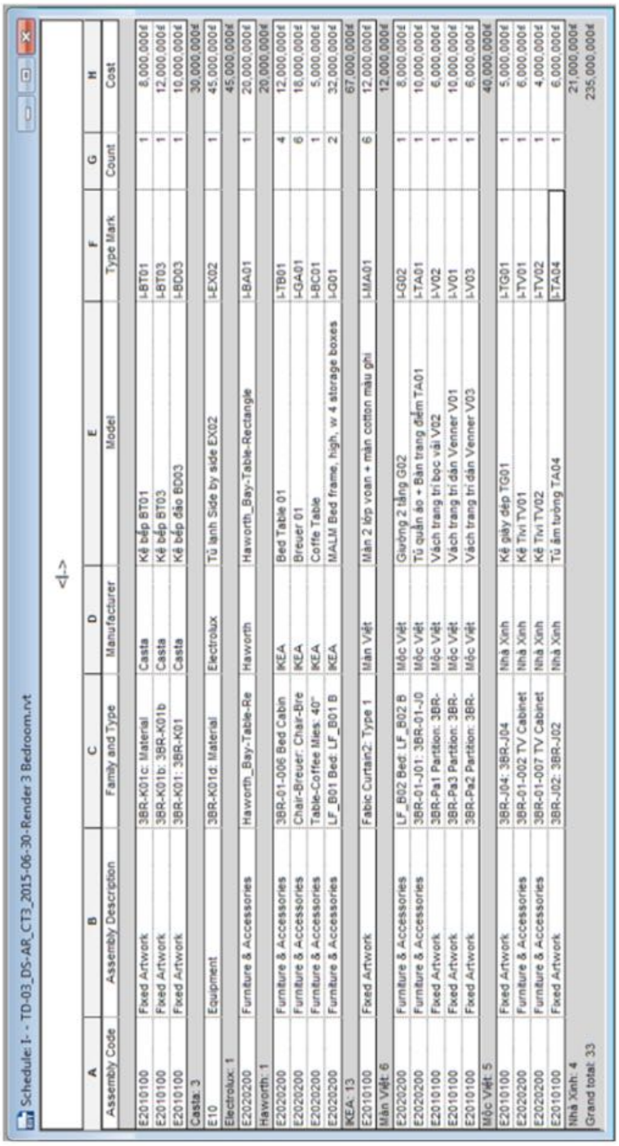
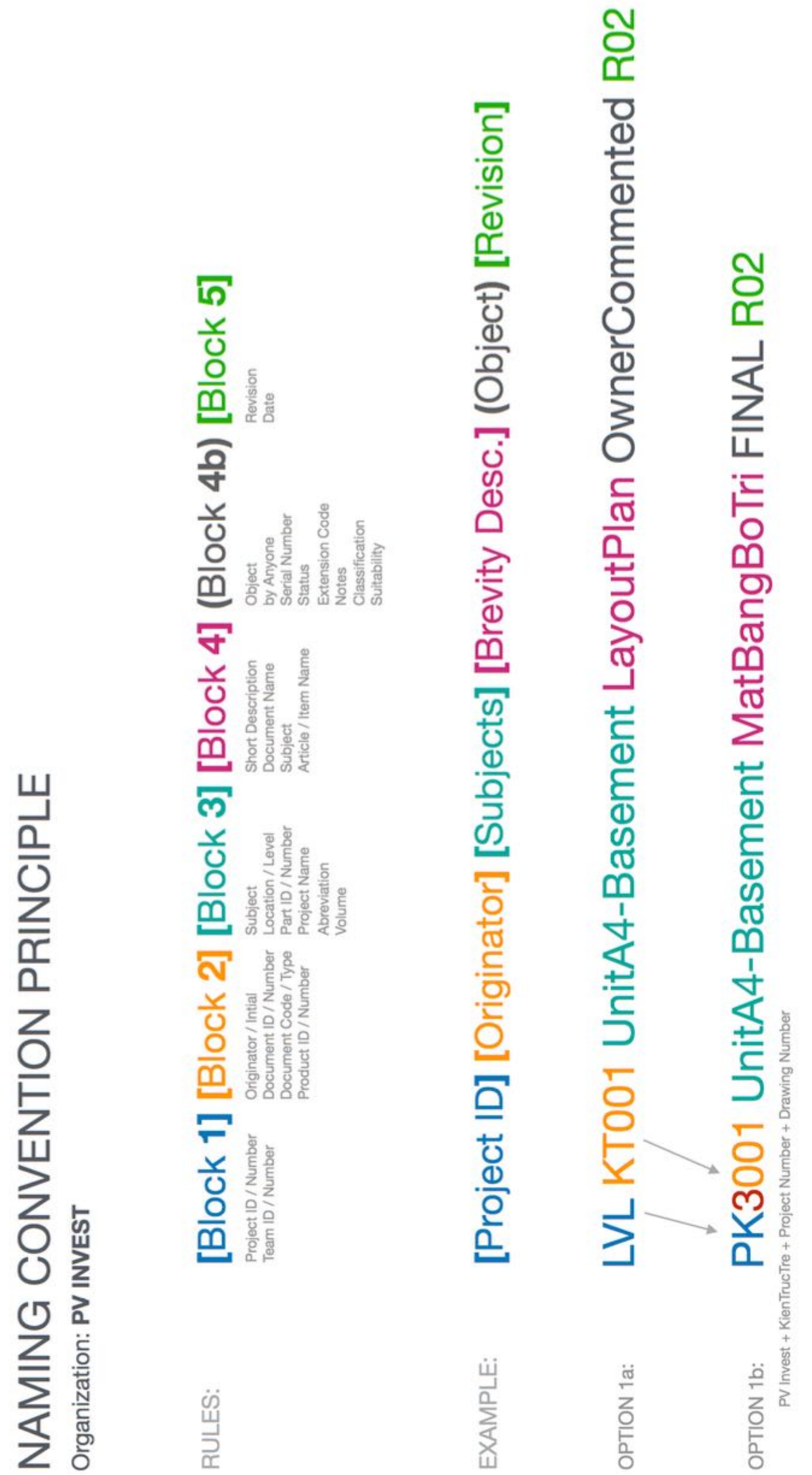


Schedule: I- - TD-03_DS-AR_CT3_2015-06-30-Render 3 Bedroom.rvt

<I->

A	B	C	D	E	F	G	H
Assembly Code	Assembly Description	Family and Type	Manufacturer	Model	Type Mark	Count	Cost
E2010100	Fixed Artwork	3BR-K01c: Material	Casta	Kệ bếp BT01	I-BT01	1	8,000,000đ
E2010100	Fixed Artwork	3BR-K01b: 3BR-K01b	Casta	Kệ bếp BT03	I-BT03	1	12,000,000đ
E2010100	Fixed Artwork	3BR-K01: 3BR-K01	Casta	Kệ bếp đảo BD03	I-BD03	1	10,000,000đ
Casta: 3							30,000,000đ
E10	Equipment	3BR-K01d: Material	Electrolux	Tủ lạnh Side by side EX02	I-EX02	1	45,000,000đ
Electrolux: 1							45,000,000đ
E2020200	Furniture & Accessories	Haworth_Bay-Table-Re	Haworth	Haworth_Bay-Table-Rectangle	I-BA01	1	20,000,000đ
Haworth: 1							20,000,000đ
E2020200	Furniture & Accessories	3BR-01-006 Bed Cabin	IKEA	Bed Table 01	I-TB01	4	12,000,000đ
E2020200	Furniture & Accessories	Chair-Breuer: Chair-Bre	IKEA	Breuer 01	I-GA01	6	18,000,000đ
E2020200	Furniture & Accessories	Table-Coffee Mies: 40"	IKEA	Coffe Table	I-BC01	1	5,000,000đ
E2020200	Furniture & Accessories	LF_B01 Bed: LF_B01 B	IKEA	MALM Bed frame, high, w 4 storage boxes	I-G01	2	32,000,000đ
IKEA: 13							67,000,000đ
E2010100	Fixed Artwork	Fabic Curtain2: Type 1	Màn Việt	Màn 2 lớp voan + màn cotton màu ghi	I-MA01	6	12,000,000đ
Màn Việt: 6							12,000,000đ
E2020200	Furniture & Accessories	LF_B02 Bed: LF_B02 B	Mộc Việt	Giường 2 tầng G02	I-G02	1	8,000,000đ
E2020200	Furniture & Accessories	3BR-01-J01: 3BR-01-J0	Mộc Việt	Tủ quần áo + Bàn trang điểm TA01	I-TA01	1	10,000,000đ
E2010100	Fixed Artwork	3BR-Pa1 Partition: 3BR-	Mộc Việt	Vách trang trí bọc vải V02	I-V02	1	6,000,000đ
E2010100	Fixed Artwork	3BR-Pa3 Partition: 3BR-	Mộc Việt	Vách trang trí dán Venner V01	I-V01	1	10,000,000đ
E2010100	Fixed Artwork	3BR-Pa2 Partition: 3BR-	Mộc Việt	Vách trang trí dán Venner V03	I-V03	1	6,000,000đ
Mộc Việt: 5							40,000,000đ
E2010100	Fixed Artwork	3BR-J04: 3BR-J04	Nhà Xinh	Kệ giày dép TG01	I-TG01	1	5,000,000đ
E2020200	Furniture & Accessories	3BR-01-002 TV Cabinet	Nhà Xinh	Kệ Tivi TV01	I-TV01	1	6,000,000đ
E2020200	Furniture & Accessories	3BR-01-007 TV Cabinet	Nhà Xinh	Kệ Tivi TV02	I-TV02	1	4,000,000đ
E2010100	Fixed Artwork	3BR-J02: 3BR-J02	Nhà Xinh	Tủ âm tường TA04	I-TA04	1	6,000,000đ
Nhà Xinh: 4							21,000,000đ
Grand total: 33							235,000,000đ

Appendix 18 Full page of Figure 8.2



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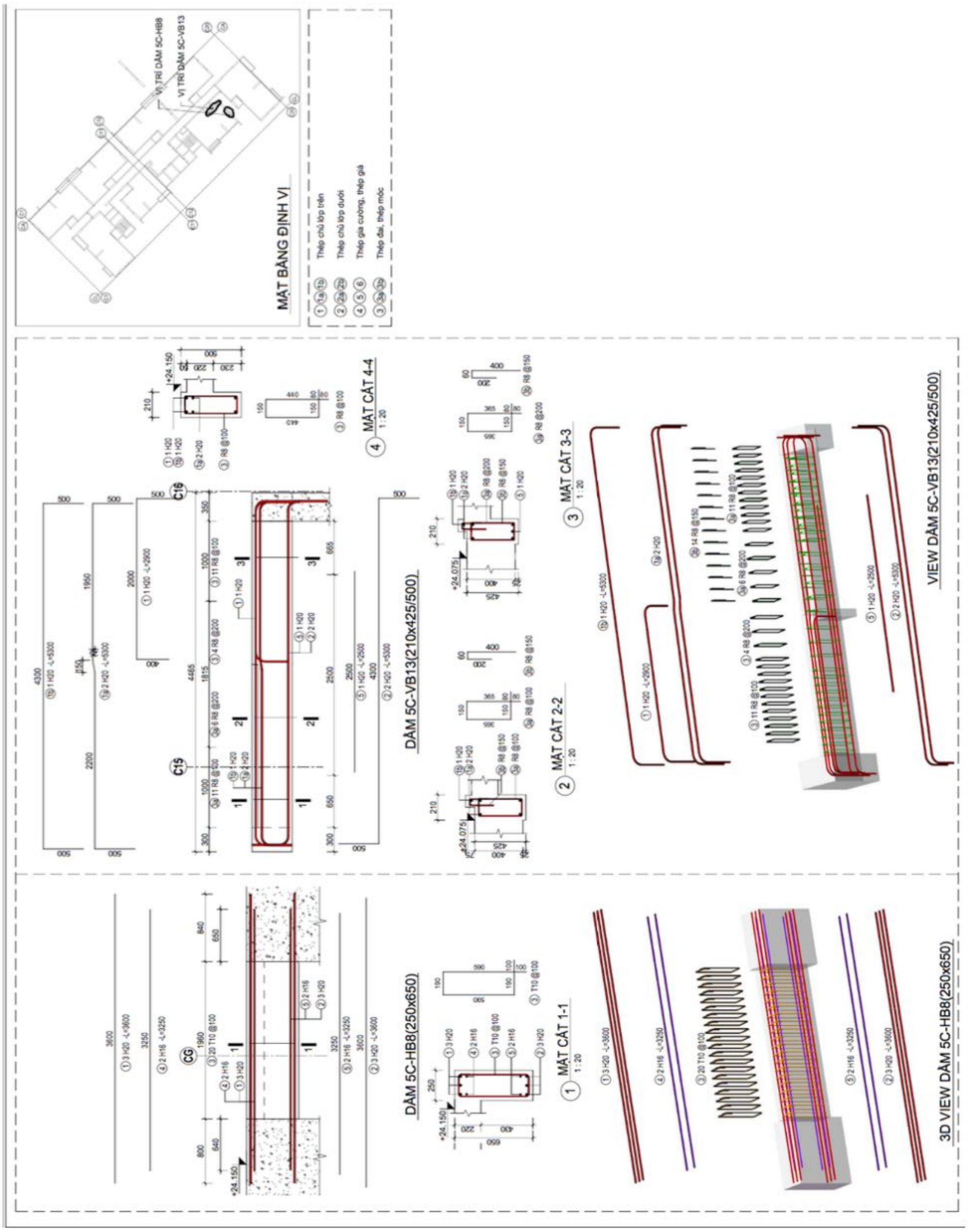

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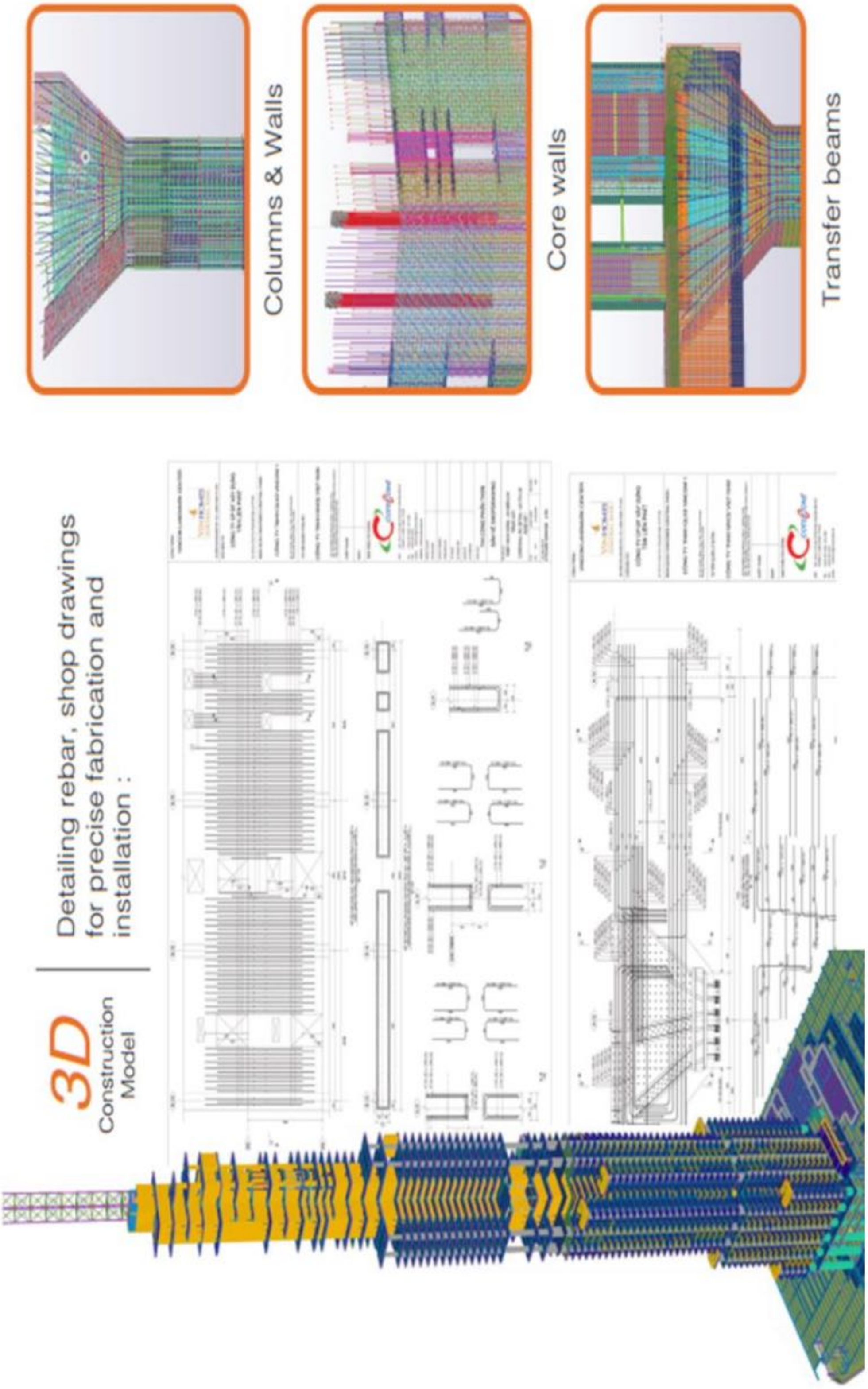

Appendix 21 Full page of Figure 9.2