INSTITUTIONAL DRIVERS AND PERFORMANCE IMPACTS OF BIM IMPLEMENTATION IN CONSTRUCTION PROJECTS: AN EMPIRICAL STUDY IN CHINA

CAO DONGPING

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Institutional Drivers and Performance Impacts of BIM Implementation in Construction Projects: An Empirical Study in China

CAO Dongping

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CERTIFICATE OF ORIGINALITY

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_____________________(Signed)

Name of student: CAO Dongping

Student No: 1290____

ABSTRACT

As a fundamentally new way of creating, sharing and utilising project lifecycle information, building information modelling (BIM) has been increasingly regarded as one of the most promising technologies to address the performance problems in traditional design and construction processes. Despite its great potential, the advancement of BIM worldwide is still in a relatively infant stage, with a relatively high percentage of construction projects still sitting on the sidelines of BIM implementation, and many others which have already been involved in BIM use having not yet gained the expected benefits from BIM implementation. Drawing on institutional theory and resource dependence theory, this study aims to identify how institutional isomorphic pressures drive the implementation of BIM in construction projects, and how BIM implementation activities in turn impact the performances of involved project participants. To achieve these aims, project-based data from the Chinese mainland were collected and analysed to sequentially investigate: (1) the characteristics of BIM implementation; (2) the impacts of institutional isomorphic pressures on BIM implementation; (3) the motivations of project participants to implement BIM under the impacts of isomorphic pressures; and (4) the impacts of BIM implementation on the performances of involved project participants.

Using a set of quantitative data analysis methods including partial least squares modelling, bootstrapping mediation test and ordinary least squares regression, the empirical analysis led to several key findings: (1) Project BIM implementation practices, in terms of both the extent of BIM implementation across different application areas and client/owner support for BIM implementation, are associated with project characteristic factors including project type and project size. (2) With regard to the impacts of the three types of institutional isomorphic pressures, coercive and mimetic pressures both significantly influence the extent of project-level BIM implementation, and client/owner support plays a crucial but varied mediating role in the influences of different isomorphic pressures. (3) Considering the impacts of institutional isomorphic pressures, the motivations of project participants to implement BIM in construction projects could be classified into four broad categories: image motives, reactive motives, project-based economic motives, and cross-project economic motives; while image motives and cross-project economic motives are currently the strongest reasons for designers and general contractors to implement BIM in construction projects, different motivations do not necessarily preclude each other and could be differently impacted by organisational BIM capability as well as other contextual factors. (4) BIM-enabled interorganisational collaboration capabilities as a whole significantly mediate the relationships between the extent of project BIM implementation and BIM-enabled performance gains for both designers and general contractors; however, designers and general contractors do not benefit equivalently from project BIM implementation, with BIM-enabled task efficiency improvement for designers being much less substantial than that for general contractors, and the benefits for designers being primarily limited to the enhancement of task effectiveness.

Through illustrating the associations between institutional isomorphic pressures and BIM implementation activities in construction projects, the findings not only validate the applicability of the institutional theory perspective in a new context, but also provide insights into how different types of institutional forces can be better manipulated to facilitate the diffusion of BIM in the construction industry. Through providing evidence that the motivations of project participants to implement BIM under the impacts of institutional environments are distinctly multi-dimensional and dynamic, the findings could also help to partly reconcile the discordant findings on innovation implementation reasons in extant construction innovation literature. The findings also contribute to a deepened understanding of the performance impacts of project BIM implementation activities through using a resource dependence theory perspective to articulate the important roles of BIM-enabled interorganisational collaboration capabilities in determining the performance gains from BIM implementation, and through characterising the non-equivalence between the BIM-enabled performance gains for designers and general contractors.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

1.1 Research Background

1.1.1 BIM as a Solution to the Performance Problems in Construction Projects

Construction projects worldwide have long been plagued by a variety of performance problems such as design deficiency, cost overruns, schedule slippages and poor construction quality. According to Lopez and Love's (2012) investigation of 139 construction projects in Australia, for example, the average direct and indirect costs caused by design errors could account for 6.85% and 7.36% of project contract value, respectively. With respect to cost overruns, US Department of Transportation's investigation of rail transit projects in the USA shows that the actual costs of the studied projects were 61% higher than the initial project budgets on average (Pickrell, 1990). Similar project performance problems have also been widely reported in many other countries such as China (Zhang et al., 2008), Saudi Arabia (Assaf and Al-Hejji, 2006), the UK (Olawale and Sun, 2010) and Zambia (Kaliba et al., 2009). While inherently associated with some industry characteristics such as the one-of-a-kind nature of construction projects, the presence of these performance problems could also be attributed to the relatively conservative culture of the construction industry in implementing innovative technologies to streamline traditional design and construction processes (Reichstein et al., 2005; Smyth, 2010).

As a fundamentally new way of creating, sharing and utilising project lifecycle information, building information modelling (BIM) has been increasingly regarded as a promising technology to address the performance problems in construction projects in the past decade (Eastman et al., 2011; Froese, 2010; Li et al., 2009). Accompanied by its distinct capability of parametrically modelling and integratively managing project information, BIM can be used in a variety of areas such as clash detection, sustainability analysis, cost estimation, construction scheduling and offsite fabrication throughout the project life cycle (CICRP, 2011; Ding et al., 2014; Eastman et al., 2011; Hartmann et al., 2008; Park et al., 2011). As such, it is widely claimed that BIM, if implemented appropriately, could facilitate a more integrated design and construction process and generate substantial benefits in terms of, for instance, fewer design coordination errors, more energy-efficient design solutions, faster cost estimations, reduced production cycle time, lower construction cost, and higher design and construction productivity (Bryde et al., 2013; Eastman et al., 2011; Gao and Fischer, 2008). Because of the potential benefits of BIM, governments (or their affiliated organisations) in several countries, such as China, Singapore, South Korea, the UK and the US, have established related plans to advocate and facilitate the implementation of BIM in the construction industry (Cheng and Lu, 2015).

1.1.2 Varied and Generally Low Diffusion Rates of BIM Worldwide

Despite its great potential benefits, BIM's actual diffusion rate worldwide has been much lower than expected since its initial inception in the mid 1970s (Aibinu and Venkatesh, 2014; CCIA, 2013; Jensen and Jóhannesson, 2013; Samuelson and Björk, 2014). While industry reports reveal that the number of industry practitioners involved in BIM use has clearly increased in some pioneering countries (e.g., South

Korea and the US) in recent years (Bernstein et al., 2012; Lee et al., 2012; NBS, 2016), the facts remain that the use of BIM worldwide still falls considerably short of its potential, and the vast majority of construction projects in many countries are still sitting on the sidelines of BIM adoption and implementation.

According to Jensen and Jóhannesson's (2013) investigation in Iceland, for example, although computerisation in the Icelandic construction industry has generally reached a very high level, the advancement of BIM in the industry is still "*surprisingly low*" (Jensen and Jóhannesson, 2013, p.103), with industry organisations' utilisation rate of BIM in no application area reaching 10 percent. The National Building Specification (NBS)'s 2015 BIM Report in the UK similarly shows that the advancement of BIM in the British construction industry is still in a relatively infant stage, with 67% of the survey respondents agreeing that "*the industry is not clear enough on what BIM is*" (NBS, 2015, p.14). With respect to the development of BIM in China, which is currently undertaking one of the largest volumes of construction in the world, the adoption rate of BIM is also distinctly low, with 85.05% of construction enterprises being reported to have not been involved in any BIM-based project up to 2012 (CCIA, 2013). Considering the evidently low adoption rates of BIM in the industry, researchers have contended or empirically validated that BIM has been diffusing more slowly than its predecessor 2D CAD (two-dimensional computer-aided design) technology (Taylor and Bernstein, 2009), and other technologies including EDM (Electronic Document Management) and EDI (Electronic Data Interchange) (Samuelson and Björk, 2014).

1.1.3 Varied Performance Outcomes of BIM Implementation

Apart from the relatively slow diffusion of BIM worldwide, another evident characteristic of current BIM use is related to the varied performance outcomes of BIM implementations in different project contexts. Based on case studies of three BIM-based and three pre-BIM construction projects in the USA, Giel and Issa (2013) find that the calculated returns on the investment (ROI) of BIM varied greatly from 16% to 1654% (Table 1.1). Azhar's (2011) case studies of ten other projects in the USA suggest an even greater uncertainty of BIM value, with the identified ROI of BIM use in the studied projects varying from 140% to 39900%.

Similarly varied but negative performance outcomes of BIM use have been further revealed by some industry reports, in which it is indicated that a relatively high percentage of practitioners involved in BIM use have not yet gained the expected benefits from the implementation practices. According to the SmartMarket survey on the Chinese mainland in 2015, for example, only 40% and 45% of the surveyed designers and contractors report positive ROI from their BIM implementation practices (Bernstein, 2015). Similar surveys in North America and South Korea in 2012 also show that only 62% and 59% of the respondents perceive positive ROI (Bernstein et al., 2012; Lee et al., 2012). Through case studies or questionnaire surveys, as shown in Table 1.1, Barlish and Sullivan (2012) and Suermann and Issa (2009) further reveal that BIM implementation could even be negatively associated with some performance indicators, such as project schedule and labour productivity. Such reported variations in the performance outcomes of

BIM implementation, together with the evident low diffusion rate of BIM in the construction industry worldwide, not only raise the concerns of specifying the key antecedents that affect the diffusion of BIM in the industry, but also prompt the need to explore the underlying mechanisms of how BIM implementation activities concretely impact project design and construction performances.

Table 1.1 Variations in the performance outcomes of BIM implementation

Category	Performance Outcome	Research Method	Source
Returns on investment (ROI)	Only 40% and 45% of the surveyed designers and contractors report positive ROI	Questionnaire survey in China in 2015	Bernstein (2015)
	Only 62% of the respondents report positive ROI	Questionnaire survey in North America in 2012	Bernstein et al. (2012)
	Only 59% of the respondents report positive ROI	Questionnaire survey in the Korea in 2012	Lee et al. (2012)
	ROI vary from 16% to 1654% in different projects	Case studies of six projects in the USA	Giel and Issa (2013)
	ROI vary from 140% to 39900%	Case studies of ten BIM-assisted projects in the USA	Azhar (2011)
Impact on the number of RFIs	Requests for information (RFIs) decrease 50% for one case, but increase 50% for another case	Case studies of related construction projects for a semiconductor manufacturer	Barlish and Sullivan (2012)
Impact on schedule	16.8% of the respondents indicate that schedule is inhibited by BIM implementation	Questionnaire survey of industry professionals working with or interested in working with BIM	Suermann and Issa (2009)
Impact on productivity	24.6% of the respondents indicate that productivity is inhibited by BIM implementation	Questionnaire survey of industry professionals working with or interested in working with BIM	Suermann and Issa (2009)

1.2 Knowledge Gaps and Research Objectives

1.2.1 Knowledge Gaps

Because of the great potential of BIM for addressing project performance problems in the construction industry, there has been increasing research interest in BIM in the past decade. As will be illustrated in detail in Chapter 2, however, extant research on BIM has been primarily focused on technical issues, including exploring potential areas in which BIM could be beneficially implemented (Eastman et al., 2009; Golparvar-Fard et al., 2011; Motawa and Almarshad, 2013; Wang et al., 2013, 2014) and enhancing the interoperability among different BIM applications (Eastman et al., 2010; Jeong et al., 2009). In view of the relatively low diffusion rate of BIM worldwide, as well as the possible gap between technical feasibility and practical implementation, some researchers have begun to empirically examine how BIM is practically used in the industry and to identify factors influencing the adoption and implementation practices. To date, however, much of this research has focused on identifying industry professionals' perceived barriers to the diffusion of BIM in the industry (Eadie et al., 2013; Gerrard et al., 2010; Gu and London, 2010; Howard and Björk, 2008), or on using theories such as the technology acceptance model to examine how technology attributes and individual characteristics influence practitioners' personal intentions to accept BIM (Lee et al., 2015; Son et al., 2015). While project is the basic unit of design/construction activities and in most cases the decision on BIM implementation is made at the project level (CICRP, 2011), scant scholarly attention has been devoted to investigating how related BIM implementation decisions are made in specific construction projects and why the extent of BIM implementation in different projects varies. With regard to the performance impacts of BIM implementation activities, much of the extant research has focused on reporting descriptive statistics of the project benefits gained from

BIM implementation activities in specific project contexts (Barlish and Sullivan, 2012; Bryde et al., 2013; Giel and Issa, 2013), and there has been a lack of rigorous understanding regarding how the resultant project benefits of BIM implementation are influenced by related implementation characteristics and why the performance impacts of BIM implementations in different project contexts vary substantially.

While extant research on other construction innovations could provide important insights into why and how BIM is implemented in construction projects, the generalisation of the relevant research findings would be limited by the differences in technology characteristics. As a radically innovative technology to parametrically represent and integratively manage project lifecycle information, BIM possesses several distinct characteristics such as multiple implementation areas, interorganisational implementation process, and relatively high investment costs (Eastman et al., 2011). These characteristics may complicate BIM implementation activities, and result in the particularities of how project BIM implementation activities are driven by relevant factors and how BIM implementation activities in turn impact the performances of project participants. In fact, due to the differences among different innovations, extant empirical studies on the drivers and impacts of innovation implementation activities in the construction industry have already generated relatively discordant findings. With regard specifically to the drivers of the implementation of construction innovations, while some studies (e.g., Toole, 1998) reveal that innovation implementation decisions are often accompanied by gathering information from external entities, a stream of other research (e.g., Kale and Arditi, 2005; Esmaeili and Hallowell, 2012) suggests that innovation implementations are primarily driven by imitative motivations but less influenced by external requirements or suggestions, and still another (e.g., Nikas et al., 2007) controversially indicates that innovation usage has no significant association with environmental contextual factors, including the practices of peer organisations, but is proactively driven by internal economic reasons. With regard to the performance impacts of the implementation of construction innovations, while some empirical studies (e.g., Thomas et al., 2004) suggest that the use of information technology can result in substantial construction cost savings for owners/clients and contractors, other similar studies (Kang et al., 2008; O'Connor and Yang, 2004) suggest that the impact of information technology use on project cost performance is relatively weak. Given such discordance, it would be relatively difficult to generalise extant research findings on other construction innovations to develop a rigorous understanding of how BIM implementation activities are driven by relevant factors and how the implementation activities in turn impact the performances of project participants.

1.2.2 Research Objectives

Drawing on institutional theory and resource dependence theory, this study aims to extend our understanding of how environmental contextual factors drive the implementation of BIM in construction projects, and how BIM implementation activities in turn impact the performances of involved project participants. Since institutional theory suggests that organisational activities are primarily shaped by three types of isomorphic pressures (i.e., coercive, mimetic and normative pressures) in institutional environments (DiMaggio and Powell, 1983), this study focuses on investigating the impacts of three types of isomorphic pressures while examining how environmental contextual factors drive BIM implementation activities. According to resource dependence theory (Pfeffer and Salancik, 1978), organisations are rarely self-sufficient in terms of strategically important resources and therefore need to appropriately manage their dependence on other organisations to acquire required resources and ensure organisational viability. This study posits that BIM is an important boundary spanning tool for project participants to facilitate interorganisational collaboration to manage interdependence, and therefore focuses on identifying how project BIM implementation impacts the performances of project participants from an interorganisational collaboration perspective. In order to better identify how institutional isomorphic pressures drive the implementation of BIM in construction projects and how BIM implementation activities in turn impact the performances of involved project participants, it is necessary to first develop an understanding regarding the characteristics of BIM implementation practices of project participants in different application areas. Following the above research logic, the specific research objectives of the present study are set as follows.

(1) To illustrate the basic characteristics of BIM implementation practices in construction projects in terms of application areas and project participants' roles;

(2) To identify the impacts of institutional isomorphic pressures (including coercive pressures, mimetic pressures and normative pressures) on BIM implementation activities in construction projects;

(3) To identify and contextualise the organisational motivations for BIM implementation in construction projects through taking into account the impacts of institutional isomorphic pressures; and

(4) To characterise how BIM implementation activities impact the performances of project participants from an interorganisational collaboration perspective.

1.2.3 Research Approach

In order to achieve the research objectives, this study not only draws upon institutional theory and resource dependence theory to develop theoretical arguments, but also uses empirical survey data to quantitatively test or extend related arguments. The empirical survey data used in this study was all collected from BIM-based construction projects in a specific national context of the Chinese mainland. In recent years, local governments in some developed regions on the Chinese mainland, such as Guangdong and Shanghai, have begun to take official measures to require or advocate the implementation of BIM in certain types of construction projects (especially large scale public projects). These pioneering BIM-related official measures for certain types of projects in certain regions, together with the unbalanced development of the construction markets across different regions, could facilitate the collection of project-based data from construction projects with different institutional environments and BIM implementation characteristics on the Chinese mainland and, therefore, enable a quantitative analysis of how BIM implementation characteristics are associated with external institutional pressures and project participants' performances.

1.3 Definition of Key Terms

The analysis in the present study involves a variety of terms, such as building information modelling (BIM), BIM implementation, and institutional isomorphic pressures. This section focuses on defining or specifying the terms "BIM" and "BIM implementation" which are to be used throughout the thesis. With regard to other terms such as institutional isomorphic pressures (including coercive, mimetic and normative pressures) which are to be used in specific chapters, definitions or specifications will be provided in relevant chapters where appropriate.

1.3.1 Building Information Modelling (BIM)

The concept of BIM can be traced back to the working prototype "building description systems" proposed by Chuck Eastman in the mid 1970s (Eastman, 1975). As an evolution of the terms "building product model" and "building information model" (Eastman et al., 2008; van Nederveen and Tolman, 1992), the term "building information modelling (BIM)" was first proposed by Jerry Laiserin in around 2002 (Eastman et al., 2008). With the accelerated diffusion of the concept in the construction industry around the world since then, a number of researchers and institutions have attempted to define the concept from different perspectives. Some of the typical definitions are listed in Table 1.2. Comparison of the listed definitions reveals that there are two main different streams of definitions: (1) defining BIM as a technology or approach (Eastman et al., 2011; Singh et al., 2011b); and (2) defining BIM as the activity of the development and use of object-oriented building information models (AGC, 2006; GSA, 2007; NIBS, 2007).

Table 1.2 Definitions of BIM in extant literature

Researcher(s) or institution(s)	Definition	Literature source
Chuck Eastman and his colleagues in the USA and Israel	A modelling technology and associated set of processes to produce, communicate, and analyse building models. Building models are characterized by: (1) Building components that are represented with digital representations (objects) that carry computable graphic and data attributes that identify them to software applications, as well as parametric rules that allow them to be manipulated in an intelligent fashion; (2) Components that include data that describe how they behave, as needed for analyses and work processes, for example, takeoff, specification, and energy analysis; (3) Consistent and nonredundant data such that changes to component data are represented in all views of the component and the assemblies of which it is a part; and (4) Coordinated data such that all views of a model are represented in a coordinated way.	Eastman et al. (2011)
Vishal Singh, Ning Gu and Xiangyu Wang, Australia	An advanced approach to object-oriented CAD, which extends the capability of traditional CAD approach by defining and applying intelligent relationships between the elements in the building model. BIM models include both geometric and non-geometric data such as object attributes and specifications. The built-in intelligence allows automated extraction of 2D drawings, documentation and other building information directly from the BIM model. This built-in intelligence also provides constraints that can reduce modelling errors and prevent technical flaws in the design, based on the rules encoded in the software.	Singh et al. (2011b)
Associated General Contractors of America (AGC); General Services Administration (GSA), the USA	The development and use of a computer software model to simulate the construction and operation of a facility. The resulting model is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions and improve the process of delivering the facility.	AGC (2006); GSA (2007)
National Institute of Building Sciences (NIBS), the USA	The act of creating an electronic model of a facility for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes.	NIBS (2007)

It is noteworthy that although institutions such as AGC (2006), GSA (2007) and NIBS (2007) define BIM itself as an activity rather than a technology, they still frequently use the expressions "use BIM" and "implement BIM" to represent the activity of model development and use, and use expressions such as “BIM as a facility lifecycle management tool” (NIBS, 2007, p.20), “BIM is a tool” (AGC, 2006, p.30) and “this new technology” (GSA, 2007, p.6) to represent BIM itself. Therefore, this stream of literature still essentially regards BIM as a technology. Although not explicitly defining the term BIM, a variety of other literature also generally regards BIM as a technology or approach, and uses expressions such as “use of BIM” and “implementation of BIM” to describe BIM-related activities (Barlish and Sullivan, 2012; Becerik-Gerber et al., 2012; Eadie et al., 2013; McCuen et al., 2012; Love et al., 2014; Lu et al., 2014; Volk et al., 2014; Wang et al., 2015c).

While using the term BIM, this thesis follows the widely accepted definition by Eastman et al. (2011) to regard BIM as “*a model[l]ing technology and associated set of processes to produce, communicate, and analy[se] building models*” (Eastman et al., 2011, p.16). A produced, communicated and analysed building model, which is termed building information model or BIM model, is characterised by the following three properties (Eastman et al., 2011; Singh et al., 2011b; AGC, 2006; GSA, 2007): (1) building components in the model are represented with digital objects that not only carry computable graphic and data attributes, but also include parametric rules allowing them to be intelligently manipulated; (2) building components in the model not only include geometric data, but also include behaviour-related data such as cost and schedule which is related to the their design, construction and operation activities throughout the building lifecycle; and (3) all types of data in the model are consistent, coordinated and non-redundant.

1.3.2 BIM Implementation

Rather than examining the adoption intentions of project participants on whether or not to adopt BIM in their participated projects, this study focuses on examining how BIM is actually implemented in construction projects during the post-adoption stage and how the variations in BIM implementation are associated with external institutional pressures and project performances. In this thesis, BIM implementation refers to *the development and use of BIM models to support the design, construction and operation of built facilities*. While BIM as a technology of an integrated nature could be implemented in the design, construction and operation stages throughout a facility lifecycle, the implementation of BIM still involves a variety of technology and process problems, and the in-depth implementation of BIM in practice is still principally limited to design and construction stages worldwide (Becerik-Gerber et al., 2012; Eadie et al., 2013; Jensen and Jóhannesson, 2013). In view of the feasibility of data collection as well as the appropriateness of the research scope, the analysis of BIM implementation activities in this study is also limited to those in project design and construction stages. The primarily examined aspects of the activities include the areas where BIM is concretely implemented, and the roles of project participants in the implementation process. As quantitative research, this study specifically uses the quantitative variable “extent of BIM implementation” to measure the overall status of BIM implementation across different areas in a project, and the quantitative variable “client/owner support” to measure the level of clients/owners’ overall support for project BIM implementation.

1.4 Organisation of the Thesis

The remainder of this thesis is organised as follows. Chapter 2 reviews the relevant literature on BIM as well as other construction innovations, and provides an overview of the two theoretical perspectives that underpin the analysis of the present study: institutional theory and resource dependence theory. Chapter 3 illustrates the research design of the present study, not only outlining how the perspectives of institutional theory and resource dependence theory are juxtaposed to establish the research framework, but also presenting the primary data collection and analysis methods adopted to empirically test the research framework. Corresponding to the four research objectives, Chapters 4 to 7 are sequentially devoted to empirically examining: the practice characteristics of BIM implementation in construction projects; the impacts of institutional isomorphic pressures on BIM implementation in construction projects; the motivations for BIM implementation in construction projects under the impacts of institutional isomorphic pressures; and the impacts of BIM implementation on the performances of involved project participants. Chapter 8 summarises the major findings, discusses the primary theoretical contributions, and outlines the directions for future research.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

With the aim of reviewing the literature that lays the foundation for the present study, this chapter is organised as follows. Section 2.2 provides an overview of extant BIM research and identifies the major research trends, and Section 2.3 specifically reviews the research on the drivers and performance impacts of BIM implementation. As research on other innovations in the construction industry, such as 2D CAD technologies, could also provide insights into the analysis of BIM technology, Section 2.4 further examines related studies on the drivers and performance impacts of the implementation of other construction innovations. Section 2.5 then provides an overview of the two theories that underpin the analysis of the present study: institutional theory and resource dependence theory. The major findings of these reviews are subsequently summarised in Section 2.6.

2.2 Overview of BIM-Related Research

2.2.1 Review Method

The two-stage literature review method proposed by Tsai and Wen (2005) and Ke et al. (2009) were deployed to investigate BIM-related research outputs in first-tier construction journals from 2004 to 2015. In the first stage, a comprehensive literature search based on the "title/abstract/keyword" search method was conducted through the Elsevier scientific search engine *Scopus*. The search keywords included *building information model*, *building information modelling*, *building product model*, *virtual design and construction*, and *construction virtual prototyping*. Papers with these specific terms included in the title, abstract, or keyword were considered to be possible publications in the area of BIM. As this study is only interested in analysing academic publications, the search was further limited to identifying the document type of *article* or *review*. The search result at this stage indicated that a total of 1052 BIM-related papers had been published during the time period 2004-2015.[❶] A further analysis of the search result revealed the obvious diversity of the publication sources of the 1052 papers, with a total of 78 journals having published more than 3 papers possibly related to BIM during 2004-2015. As different journals generally have different publication interests and the selection of the publication journals may have a substantial impact on the identified research topics, this study focuses on investigating the research papers published in first-tier academic journals in the area of construction engineering and management. Seven top-ranked construction journals identified by Chau (1997), therefore, were included for further analysis: *Automation in Construction (AIC)*, *Construction Management and Economics (CME)*, *Engineering, Construction and Architectural Management (ECAM)*, *Journal of Construction Engineering and Management (JCEM)*, *Journal of Management in Engineering (JME)*, *International Journal of Project Management (IJPM)*, and *Building Research and Information (BRI)*. In order to improve the publication coverage and thus the validity of the content analysis, *Journal of Computing in Civil Engineering (JCCE)*, another academic journal that had published frequently cited

❶ This is the search result on 7th March 2016. The number of the searched papers may vary due to the change of the indexed journals in Scopus.

BIM-related papers, was also added to the journal list. As a result, a total of eight journals were selected for further investigation during the second stage.

In the second stage, a more focused search within the eight target journals was conducted similarly with the help of the *Scopus* search engine. As the search at this stage was confined to the construction journals, a more comprehensive set of search keywords including *BIM*, *building information model**, *building product model*, *virtual design and construction*, *virtual prototyping*, *nD model**, *three-dimensional model**, *four-dimensional model** and *five-dimensional model**, was entered into the "title/abstract/keyword" field to carry out the search process. Similar to the first stage, the search at this stage was also limited to identifying the document type of *article* or *review* during the period 2004-2015. This resulted in a list of 321 papers probably related to BIM. After the removal of papers under the categories of *book review*, *comment, discussions/closures, editorial* and *letter to editor*, and those that include the BIM-related terms in the title, abstract or keyword but focused on BIM irrelevant research topics, a total of 296 BIM-related papers were identified. The analyses on the research topics and research trends of BIM in the following subsection are principally based on these 296 identified papers.

2.2.2 Research Topics and Trends

Table 2.1 illustrates the distribution of the 296 identified papers published in the eight target journals during the period from 2004 to 2015. It is evident that research interests in BIM-related topics have been growing consistently during the studied period, especially since 2009, with the total number of published papers exhibiting prominent new peaks at 63 in 2014 and 68 in 2015. As shown in Table 2.1, such an obvious growing trend is also revealed by the distribution of the 1052 papers from all sources identified in the first stage. Among the eight selected target journals, AIC published 182, about 61.49%, of all the BIM-related papers, followed by 41 papers published in JCCE, and 35 papers published in JCEM. The total number of the papers published in these three journals accounts for approximately 87.16% of all the 296 identified papers, indicating these three journals are the major sources of BIM-related academic publications in the past twelve years.

Table 2.1 BIM-related papers published from 2004 to 2015

Source journal	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
AIC	0	4	3	4	4	6	13	16	11	33	41	47	182
JCCE	1	2	2	0	1	8	3	2	4	4	5	9	41
JCEM	2	2	0	2	3	1	3	2	3	8	7	2	35
JME	0	0	0	0	0	1	1	0	1	0	8	2	13
CME	0	0	0	1	1	1	0	2	0	2	2	3	12
ECAM	0	0	0	0	0	1	0	1	1	1	0	4	8
IJPM	0	0	0	0	0	0	0	1	0	1	0	1	3
BRI	0	0	0	0	0	1	0	0	1	0	0	0	2
Eight journals	3	8	5	7	9	19	20	24	21	49	63	68	296
All sources	9	16	31	43	36	64	67	81	100	133	237	235	1052

Note: The top 16 BIM-related research institutions which are ranked based on their numbers of published papers on BIM are as follows: the Hong Kong Polytechnic University (21), Georgia Institute of Technology (20), Technion - Israel Institute of Technology (15), Curtin University (14), Tsinghua University (11), Loughborough University (9), Yonsei University (9), Kyung Hee University (8), University of Salford (8), Queensland University of Technology (8), Stanford University (8), University Michigan Ann Arbor (8), Carnegie Mellon University (8), Chung-Ang University (7), the University of British Columbia (6), and Columbia University (6).

A comprehensive review of the 296 identified papers shows that the research interests of these papers can be categorised into six distinct themes: modelling method development, application area exploration, interoperability issues, organisational and process issues, practice assessment, and research and educational issues. The conceptual framework of these themes is depicted in Figure 2.1.

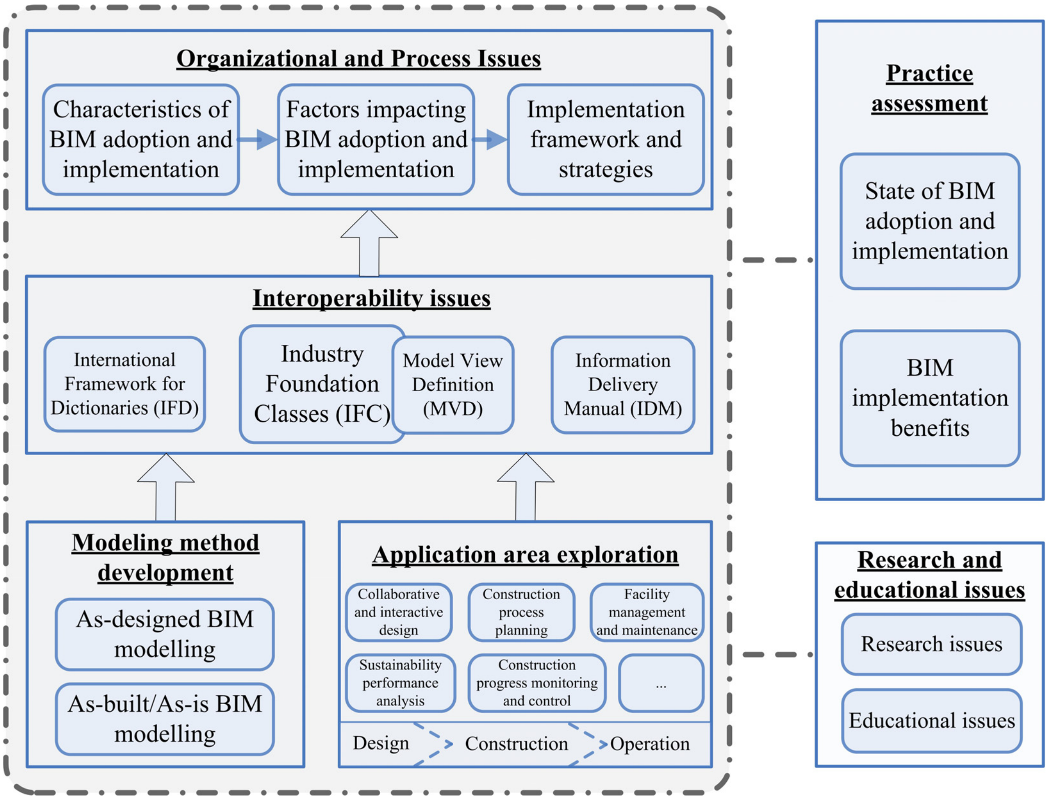

Figure 2.1 Thematic framework of BIM-related research

(1) Modelling method development. Research within this theme mainly focuses on investigating how to develop object-based parametric modelling methods or tools to better represent the geometric and functional properties of facility components[❶]. As BIM models are created either to express design intentions (as-designed condition) or to depict how the facility is actually built (as-built condition) or

❶ While a BIM model could incorporate a variety of product and process information of a facility, only the papers focusing on examining the parametric modelling of the geometric and functional properties of building components are categorised in this research theme. Papers related to the modelling of building process information and the simulation of specific facility building or operation performances (such as cost and energy performances) are more about the functional application of BIM product models and are thus categorised into the theme of application area identification.

currently exists (as-is condition), related research on modelling method development also falls naturally into two main streams: as-designed BIM modelling and as-built/as-is BIM modelling❷. Extant research on the development of as-designed BIM modelling methods involves a variety of issues such as developing the ontology to characterize component similarity (e.g., Staub-French and Nepal, 2007), exploring new hybrid sheet metal processing techniques to fabricate double-curved metal panels (e.g., Lee and Kim, 2012), developing related query languages for building information models to facilitate spatial analysis of buildings (e.g., Borrmann et al., 2009), proposing the notation and description methods for building object behaviour (BOB) (e.g., Lee et al., 2006), and presenting fuzzy logic-based extensions of semantic building information models (e.g., Gómez-Romero et al., 2015). With regard to as-built BIM modelling, as current practices of modelling as-built conditions largely employ a manual process which is relatively subjective and time-consuming (Tang et al., 2010), there is an increasing interest in developing methods to automatically or semi-automatically generate object-based information models based on the image data or point clouds collected through photography or laser scanning technologies (Anil et al., 2013; Dimitrov and Golparvar-Fard, 2015; Hinks et al., 2009; Styliadis, 2008; Wang et al., 2015a; Xiong et al., 2013).

(2) Application area exploration. The parametric modelling of facility components is only the first step in the integrated use of BIM, and the potential of

❷ For the sake of brevity, the term "as-built" will be used to refer to "as-built/as-is" throughout the remainder of this thesis.

BIM will not be fully realised unless the semantically rich models are effectively integrated with the daily design, construction, and operation activities throughout a facility lifecycle. As a result, the largest stream of extant research on BIM is related to the exploration and validation of how BIM could be beneficially used in potential areas to enable more efficient and effective facility lifecycle management. Examples of these application areas include, but are not limited to, model-based collaborative and interactive design (Lee and Ha, 2013; Rekapalli and Martinez, 2009; Shen et al., 2013; Yan et al., 2011), automated code validation (Choi et al., 2014; Eastman et al., 2009; Martins and Monteiro, 2013; Melzner et al., 2013; Solihin and Eastman, 2015; Tan et al., 2010), sustainability performance analysis (Ham and Golparvar-Fard, 2015; Kim and Anderson, 2013; Wong et al., 2013; Wu and Chang, 2013), construction process planning (Boton et al., 2013; Huang et al., 2007; Li et al., 2012; Sacks et al., 2009; Wang et al., 2015b), construction progress monitoring and control (Akula et al., 2013; Cho et al., 2012; Elbeltagi et al., 2011; Golparvar-Fard et al., 2011; Han and Golparvar-Fard, 2015), safety management (Guo et al., 2013; Kim et al., 2006; Park and Kim, 2013; Zhang et al., 2015), quality management (Bosché et al., 2014; Chen and Luo, 2015; Kim et al., 2015; Kwon et al., 2014), and facility management and maintenance (Becerik-Gerber et al., 2012; Larsen et al., 2011; Lee and Akin, 2011; Motawa and Almarshad, 2013; Wetzel et al., 2015).

(3) Interoperability issues. In order to achieve the integrated use of BIM across different application areas and thus to better leverage the benefits of semantically rich building information models, it is of vital importance to address related issues of interoperability, which refers to "*the ability to pass data between applications and for multiple applications to jointly contribute to the work at hand*" (Eastman et al., 2011, p.100). The most important effort to achieve interoperability at present is the Industry Foundation Class (IFC), a schema developed to define a comprehensive and extensible set of existent building information representations to facilitate data exchange between AEC software applications (Eastman et al., 2011). Although a necessary condition for the exchange of facility lifecycle data, IFC alone is not capable of achieving full interoperability between different BIM software, but needs to be complemented by a set of other data standardisation efforts such as Model View Definitions (MDV), which defines "*a subset of the IFC schema [...] that is needed to satisfy one or many [task-related] exchange requirements of the AEC industry*" from the perspective of software specialists (buildingSMART, 2014); Information Delivery Manual (IDM), which provides an integrated reference for the task-related process and data required BIM implementation in the language of professional participants; and International Framework for Dictionaries (IFD), which is a library of terminology and ontologies to identify the type of exchanged information. Extant research interests of the identified articles in BIM interoperability issues include defining specific procedures for developing IDM (Eastman et al., 2010), presenting MVD for specific facility building or operation processes (East et al., 2013), benchmark testing of data exchanges between different modelling tools and expert software applications (Jeong et al., 2009), and presenting content-based compression algorithms for optimizing IFC files (Sun et al., 2015).

(4) Organisational and process issues. BIM use does not only mean the technological deployment of BIM software applications, but also involves a variety of organisational and process issues such as the redistribution of project participants' risks and responsibilities. Papers within this research theme typically explore the following three interrelated issues: investigating characteristics of BIM adoption and implementation (e.g., Davies and Harty, 2013; Linderoth, 2010; Moum, 2010; Shibeika and Harty, 2015; Taylor and Bernstein, 2009), identifying factors impacting BIM adoption intentions (e.g., Ding et al., 2015; Lee et al., 2015; Son et al., 2015) or BIM implementation results (e.g., Mahalingam et al. 2015; Sebastian, 2011; Taylor, 2007; Won et al., 2013), and proposing BIM implementation framework and strategies (e.g., Arayici et al., 2011; Chen et al., 2015; Isikdag and Underwood, 2010; Li et al., 2008; Porwal and Hewage, 2013; Wu and Issa, 2014).

(5) Practice assessment. While the above four research themes mainly focus on examining how BIM could or should be used throughout a facility lifecycle, the possible gap between industry practices and theoretical implementation prototypes/frameworks has also aroused increasing interest in empirically investigating how BIM is actually used in industry practices. Research within this research theme can be categorised into two relatively independent streams: examining the state of BIM adoption or implementation practices in specific contexts (e.g., Eadie et al., 2013; Hanna et al., 2013; Jensen and Jóhannesson, 2013), and identifying or assessing the benefits from BIM implementation activities (e.g., Barlish and Sullivan, 2012; Bryde et al., 2013; Poirier et al., 2015).

(6) Research and educational issues. Despite the decades of development of BIM in the industry since the technology prototype was first proposed in the mid-1970s, lack of expertise, unawareness of BIM benefits and cultural resistance to change remain critical factors hindering the adoption and implementation of BIM throughout a facility lifecycle (Eadie et al., 2013). Stimulated by the need to align academic or professional education with industry requirements, researchers have begun to explore how to develop the curriculum system for BIM education (e.g., Sacks and Pikas, 2013; Pikas et al., 2013). Given the distinct increase of BIM publications in academia but the still widespread BIM implementation problems in practice, in recent years some researchers have also begun to critically review extant BIM research and suggest future research directions (e.g., Wong and Zhou, 2015).

The distribution of these research themes during the period from 2004 to 2015 is shown in Table 2.2. An apparent observation is that the majority of extant BIM-related papers are focusing on examining technical and interoperability issues, with 70.27% of the identified articles being categorised within the themes of application area exploration, modelling method development, and interoperability issues. Another obvious observation is that non-technical issues, especially practice assessment, have emerged as distinct research themes only in recent years and were seldom investigated in early BIM-related papers. The increasing research interest in these non-technical issues of BIM in recent academic publications, however, seems to suggest that BIM is rather a complex innovation, and further research should not be confined to examining the technical feasibility issues alone.

Table 2.2 Major research themes of BIM-related papers

Theme	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total	Percent
MMD	0	1	1	2	1	4	2	1	4	3	2	6	27	9.12%
AAE	2	5	3	3	4	8	5	13	12	29	37	35	156	52.70%
IYI	0	0	1	0	1	3	5	2	1	3	3	6	25	8.45%
OPI	0	1	0	1	1	3	7	7	2	5	13	12	52	17.57%
PEA	1	0	0	1	2	0	1	0	2	7	7	7	28	9.46%
REI	0	1	0	0	0	1	0	1	0	2	1	2	8	2.70%

Note: MMD = modelling method development; AAE = application area exploration; IYI = interoperability issues; OPI = organisational and process issues; PEA = practice assessment; REI = research and educational issues.

2.3 Research on Drivers and Performance Impacts of BIM Implementation

Some of the BIM-related papers within the themes of "organisational and process issues" and "practice assessment" have directly or indirectly examined the drivers and performance impacts of BIM adoption or implementation. This section focuses on reviewing these related papers, as well as those not in the eight target journals, to provide a foundation for the analyses of the current study.

2.3.1 Research on Drivers of BIM Implementation

Because of the great potential but still limited use of BIM in the construction industry, several studies have been conducted to investigate the factors impacting the adoption or implementation of BIM. According to their analysis levels on BIM usage, this stream of studies can be segregated into two different sub-streams: research on factors impacting individual acceptance of BIM, and research on factors impacting organisational use of BIM.

Much of the extant research on factors impacting individual acceptance of BIM has primarily focused on employing theories like technology acceptance model (TAM) (Davis, 1989) to examine how technology attributes and personal characteristics impact industry practitioners' individual intentions to use BIM technology. Drawing on the technological acceptance model, for example, Lee et al. (2015) established a model to explain how antecedents such as technology quality and personal competence impact industry practitioners' individual intention to accept BIM, and deployed the questionnaire survey data collected from 114 workers in construction organisations (including contractors and design enterprises) in South Korea to empirically validate the model. Similarly drawing on the technological acceptance model, Son et al. (2015) also deployed questionnaire survey data collected in South Korea to empirically examine how architects' behavioural intention to use BIM is impacted by antecedents such as technology compatibility and individual computer self-efficacy. Although the specific antecedent factors employed in extant research to empirically explain practitioners' individual intention to use BIM have generally been different, the empirical analysis results have been consistent in underlining the mediating roles of perceived ease of use and perceived usefulness in the relationships between antecedent factors and BIM adoption intention (Lee et al., 2015; Son et al., 2015; Xu et al., 2014).

Much of the extant research on factors impacting organisational use of BIM has primarily focused on empirically identifying the barriers to BIM implementation. Using questionnaire survey data collected from 92 practitioners in the UK construction industry, for example, Eadie et al. (2013) descriptively analysed the perceived reasons for not using BIM in construction projects. The top-ranked reasons by the surveyed practitioners include lack of BIM expertise, lack of client demand, cultural resistance and high investment costs. Ku and Taiebat (2011) conducted a similar survey in the USA, and the major BIM implementation barriers perceived by the surveyed 31 constructors include lack of skilled personnel, high investment costs, reluctance of other project participants, lack of collaborative work processes and modelling standards, lack of data interoperability, and lack of legal/contractual agreements. Table 2.3 provides a profile of the primary BIM implementation barriers identified or proposed in the extant literature. It is evident that the implementation of BIM could be impeded by a variety of factors, including not only technical problems but also cultural and organisational issues.

Table 2.3 Barriers to BIM implementation

Code	Barriers	Source
B01	High investment costs	Aibinu and Venkatesh (2014), Eadie et al. (2013), Khosrowshahi and Arayici (2012), Ku and Taiebat (2011), Young et al. (2008)
B02	BIM software is difficult to use	Bynum et al. (2013), Howard and Björk (2008), Lee et al. (2012)
B03	Functions of BIM software do not meet practical requirements	Gerrard et al. (2010), Jensen and Jóhannesson (2013), Lee et al. (2012)
B04	Lack of data interoperability among BIM software	Howard and Björk (2008), Jensen and Jóhannesson (2013), Ku and Taiebat (2011)
B05	Lack of technical personnel familiar with BIM software	Eadie et al. (2013), Ku and Taiebat (2011), Mäki and Kerosuo (2015), Gerrard et al. (2010), Rogers et al. (2015)
B06	Lack of management personnel familiar with BIM implementation process	Eadie et al. (2013), Eastman et al. (2011), Gerrard et al. (2010), Mäki and Kerosuo (2015), Young et al. (2008)
B07	Lack of knowledge about the value of BIM	Eastman et al. (2011), Gerrard et al. (2010), Gu and London (2010)

B08	Cultural resistance to change of traditional process	Eadie et al. (2013), Eastman et al. (2011), Khosrowshahi and Arayici (2012)
B09	Traditional project risk/reward allocation methods do not meet BIM implementation requirements	Eastman et al. (2011), Gerrard et al. (2010), Gu and London (2010), Khosrowshahi and Arayici (2012), Taylor et al. (2007)
B10	Traditional project design/construction processes do not meet BIM implementation requirements	Eastman et al. (2011), Dossick and Neff (2010), Ku and Taiebat (2011), Taylor et al. (2007)
B11	Lack of industry standards and guidelines to support project-level BIM implementation	Eastman et al. (2011), Ku and Taiebat (2011)

By comparison, little empirical research has been conducted to specifically investigate the drivers of BIM implementation in construction projects and, therefore, provide a theoretically rigorous understanding of why BIM is differently implemented in different projects given the widespread implementation barriers. As an example of this stream of research, Gerrard et al. (2010) used a questionnaire survey in the Australian construction industry to assess the development of BIM in the industry and identify the perceived drivers of BIM implementation by industry practitioners. The three top ranked drivers by the 34 surveyed practitioners are: requirements from clients/owners, benefits gained in pilot projects, and competitive pressures. Aibinu and Venkatesh (2014) also conducted a BIM survey in the Australian construction industry, and the three most frequently cited BIM implementation drivers by the surveyed cost consultants are the quality information within BIM models, case studies to demonstrate the benefits of BIM and cost benefit analysis. Although not directly examining the drivers of BIM implementation, some studies in the themes of application area exploration and BIM practice assessment could also provide insights into the reasons why BIM is implemented in construction projects. In demonstrating the technical feasibility of implementing BIM in related areas (Melzner et al., 2013; Golparvar-Fard et al., 2011) or measuring the project benefits gained from BIM implementation activities (Giel and Issa, 2013; Francom and El Asmar, 2015; Poirier et al., 2015), an important underlying presumption of these studies is that the technical advantages of BIM are the key factors driving the implementation of BIM in construction projects. However, while Tornatzky and Fleischer's (1990) technology-organisation-environment framework and Rogers's (1995) innovation diffusion model as widely accepted theoretical perspectives in other industries both suggest that technology use is not only impacted by technological factors but also environmental factors, little empirical evidence has been provided to help understand whether, and if so, how the BIM implementation activities in specific construction projects are impacted by external environments.

2.3.2 Research on Performance Impacts of BIM Implementation

As illustrated in Section 2.2, the performance impacts of BIM implementation has attracted increasing research interest in recent years. Generally speaking, extant research in this area not only includes the qualitative identification of the primary indicators of BIM implementation benefits, but also the quantitative assessment of the extent to which relevant benefits have been gained in specific projects. As a notable example of the qualitative research in this area, Bryde et al. (2013) conducted a content analysis on the secondary data for 35 construction projects and found that cost reduction/control is the most frequently reported BIM implementation benefit for the analysed projects. Love et al. (2013) developed a framework for asset owners to realise BIM implementation benefits, and the incorporated benefits include a variety of indicators such as reduction in cost/schedule, productivity improvement, quality improvement, and reduction in change orders. With regard to the quantitative research in this area, Barlish and Sullivan (2012) conducted cases studies on both BIM-based and non-BIM-based projects to empirically assess the BIM-enabled performance gains such as the reduction in RFIs, reduction in change orders, and duration improvements. Using cases studies on specific projects in the USA, Giel and Issa (2013) similarly assessed the performance gains of fewer RFIs, reduced change orders and reduced schedule overruns. Based on the assessment, Giel and Issa (2013) further calculated the returns on the investment (ROI) in BIM technology, and found that the values of the comprehensive indicator varied greatly from 16 to 1654% in the studied projects. Using data collected from 35 completed construction projects in the USA, Francom and El Asmar (2015) recently examined the impact of BIM implementation on project quality and change performance, and validated that the use of BIM is associated with fewer design changes and decreased defect costs. Employing an action-research approach, Poirier et al. (2015) specifically examined the impact of BIM implementation on the labour productivity of a small mechanical contractor in a large commercial project in Canada, and illustrated that the use of BIM could result in an increase in productivity ranging from 75% to 240%.

These studies collectively suggest that BIM implementation activities have the potential to impact project performance in a variety of aspects, including not only advancing the effectiveness of project tasks (i.e., improving design and construction quality, reducing change orders) but also improving the efficiency of design and construction activities (i.e., improving productivity, reducing schedule overruns). However, further comparisons of the assessed indicators of BIM-enabled performance gains, including both specific indicators such as reduced RFIs and comprehensive indicators such as ROI, also suggest that the performance impacts of BIM implementation varied substantially in the studied projects (Barlish and Sullivan, 2012; Giel and Issa, 2013). These variations may be not only related to the assessment inaccuracies due to the distinct intangibility of the BIM implementation benefits for involved project participants, but may also be largely attributed to the differences in the BIM implementation characteristics and contexts among the studied construction projects (Francom and El Asmar, 2015).

In view of the probable associations between BIM-enabled performance gains and BIM implementation characteristics or contexts, some researchers have begun to empirically identify the critical characteristic or contextual factors facilitating the success of BIM implementation. Using empirical data collected form 26 design and construction organisations, for example, Taylor (2007) has identified a set of antecedents that enable the successful implementation of 3D CAD technologies in design and construction networks. The top ranked antecedent factors include: redistributing work among participating organisations, increasing collaboration between participating organisations, developing partnerships between participating organisations, and developing standards for interaction. Based on a questionnaire survey of 52 industry professionals, Won et al. (2013) have similarly identified a list of success factors for BIM implementation, including the willingness to share information among project participants, effective collaboration among project participants, organisational structure to support BIM, continuous investment, etc. These studies consistently highlight the importance of interorganisational collaboration in enabling successful BIM implementation, and could provide valuable insights into why the implementation of BIM in many projects has not resulted in expected performance gains. Generally speaking, however, the extant literature in this area has primarily focused on using descriptive analysis methods to rank the perceived importance of related success factors for BIM implementation (Taylor, 2007; Won et al., 2013). With regard to the identification of the underlying mechanism of how relevant factors interact with each other to collectively impact the performance outcomes of BIM implementation in construction projects, relevant empirical investigations are still in a formative stage.

2.4 Research on Drivers and Performance Impacts of the Implementation of Other Construction Innovations

Due to the similarities between BIM and other construction innovations in their implementation characteristics and contexts, the extant literature on the drivers and performance impacts of the implementation of other construction innovations could also provide insights into the analysis of BIM technology in the present study.

2.4.1 Research on Drivers of the Implementation of Other Construction Innovations

Given that the construction industry has long been criticised for being reluctant to implement innovative technologies to improve its relatively poor production performances (Egan 1998; Koskela and Vrijhoef 2001; Lim et al., 2010), there has been a rich stream of studies to identify the factors that could drive the adoption and implementation of innovations in construction organisations (Arora et al., 2014; Bossink, 2004; Gann and Salter, 2000; Mitropoulos and Tatum, 2000). Based on a literature review as well as an interview survey in the Dutch construction industry, for example, Bossink (2004) has identified four categories of factors driving the use of construction innovations: environmental pressure, technological capability, knowledge exchange, and boundary spanning. Based on case studies on the use of CAD and electronic data interchange technologies in construction organisations, Mitropoulos and Tatum (2000) have similarly identified four primary forces that drive the implementation of innovations: competitive advantage, process problems, technological opportunity, and institutional requirements. Although categorising the drivers of the implementation of construction innovations from different perspectives, these studies are consistent in proposing that innovation implementation activities could not only be impacted by technological and organisational factors, but may also be driven by environmental factors (e.g., the factor of environmental pressure proposed by Bossink (2004), and the factor of institutional requirements proposed by Mitropoulos and Tatum (2000)).

While Bossink (2004) and Mitropoulos and Tatum (2000) both propose the potential impacts of environmental factors on the implementation of construction innovations, empirical studies on different construction innovations have generated discordant findings regarding how environmental contextual factors exert their specific influences. Specifically, while some studies (e.g., Toole, 1998) reveal that innovation implementation decisions are often accompanied by gathering information from external entities such as trade partners and industry professionals, a stream of other research (e.g., Kale and Arditi, 2005; Esmaeili and Hallowell, 2012) suggests that innovation implementations are primarily driven by imitative motivations but less influenced by external requirements or suggestions, and still another (e.g., Nikas et al., 2007) controversially indicates that innovation usage has no significant association with environmental factors including the practices of peer organisations, but is proactively driven by internal economic reasons such as seeking communication improvement and achieving cost reduction. Given such discordance, it will be relatively difficult to generalise extant research findings on other construction innovations to develop a rigorous understanding of how BIM implementation activities could be driven by factors in external environments.

2.4.2 Research on Performance Impacts of the Implementation of Other Construction Innovations

Assessing the performance impacts of the implementation of construction innovations, especially of those emerging information technologies, has been an important research topic in the construction engineering and management literature in the past decade (El-Mashaleh et al., 2006; Kang et al., 2008, 2013; Love and Irani, 2004; O'Connor and Yang, 2004; Thomas et al., 2004; Yang et al., 2012). Although relevant studies have generally found positive outcomes of implementing construction innovations, their reported relationships between innovation implementation and specific performance measures are relatively inconsistent. With regard to project cost performance, for example, Thomas et al.'s (2004) statistical analysis of 297 construction projects in the USA indicates that the use of information technology could result in substantial construction cost savings for owners/clients and contractors, whereas similar studies by Kang et al. (2008) and O'Connor and Yang (2004) in the same national context both suggest that the impact of information technology use on project cost performance is relatively weak. With regard to project safety performance, while Thomas et al.'s (2004) empirical analysis reveals a positive impact of information technology use on safety performance, El-Mashaleh et al.'s (2006) empirical analysis of other datasets reveals that there is no such an impact.

In view of these inconsistent findings in extant studies, some recent research does not persist in assessing whether innovation implementation activities contribute to the improvement of specific performance measures, but attempts to further explore the underlying mechanism of how the implementation of innovative technologies impacts relevant performance measures and thus to provide further explanations for the inconsistent findings. Utilising project-based data in the Construction Industry Institute (CII) Benchmarking and Metrics database in the USA, for example, Kang et al. (2013) empirically examined both the direct and indirect impacts of 3D CAD use on project performance. The results show that there is no direct relationship between 3D CAD use and the performance indicator of project cost growth, and that the use of 3D CAD only indirectly impacts project cost performance through enabling the use of best practices such as front end planning and change management. Yang et al. (2012) similarly established a model to examine both the direct and indirect impacts of information technology use on project performance, and used questionnaire survey data from 115 construction project in Taiwan to validate the model. The results also show that the direct impact of information technology use on project performance is not statistically significant, and that the impact is fully mediated by the adoption of knowledge management practice. Through characterising the difference between the direct and indirect impacts of innovation implementation on project performance, this stream of research could provide valuable insights into the analysis of the performance impacts of BIM implementation in the present study.

2.5 Theoretical Foundations

Apart from the related research on BIM and other construction innovations, the following two theories can also provide the foundations for the analyses within this thesis: institutional theory, and resource dependence theory.

2.5.1 Institutional Theory

Institutional theory, which has been advanced primarily through the seminal works of Meyer and Rowan (1977) and DiMaggio and Powell (1983), is a theory examining the processes by which structures such as rules and norms become established as guidelines for social behaviour (Scott, 2001). In contrast to transaction cost economics which posits that organisational decision making is based on an efficiency-seeking logic to rationally minimise the total production and transaction costs (Williamson, 1985), institutional theory emphasizes the critical role of external institutional environments in driving organisations to make structural and behavioural changes with the aim of gaining social legitimacy (DiMaggio and Powell, 1983; Meyer and Rowan, 1977; Scott, 2001). One of the most widely accepted tenets of institutional theory is the concept of institutional isomorphism, which refers to the tendency for organisations to follow socially accepted norms and behaviours in order to be structurally congruent with their specific institutional environments (DiMaggio and Powell, 1983).

It is argued that institutional isomorphic pressures can originate from both formal rules (regulations, mandates) and informal constraints (norms, conventions, beliefs), and how organisations respond to these pressures will determine their institutional legitimacy (Deephouse, 1996; Scott, 2001; Suchman, 1995). According to DiMaggio and Powell (1983), there are three basic types of isomorphic pressures shaping organisational behaviours: coercive, mimetic, and normative. Coercive pressures by definition are "formal and informal pressures exerted on organisations by other organisations upon which they are dependent" (DiMaggio and Powell 1983, p.150). It is suggested that such pressures can be derived from a variety of sources such as regulatory agencies, legislative bodies, and resource-dominant organisations (Bhakoo and Choi 2013; Liang et al., 2007; Teo et al., 2003). Mimetic pressures are those that drive organisations to imitate the successful conduct of other structurally equivalent organisations, and normative pressures refer to the pressures that mainly stem from values and norms of professionals regarding how work should be conducted (DiMaggio and Powell 1983). Compared with coercive pressures, mimetic and normative pressures generally influence organisational attitudes and behaviours in a much less compelling manner.

Through viewing organisations as open systems subject to the influence of particular environments, institutional theory has provided powerful explanations for several behavioural and structural changes in organisations (Bhakoo and Choi 2013; Hertwig, 2012; Hsu et al., 2012; Liang et al., 2007; Liu et al., 2010; Sodero et al., 2013; Teo et al., 2003). These changes not only involve different industrial contexts such as the automotive industry (Hertwig, 2012), the healthcare industry (Bhakoo and Choi, 2013) and the high-technology industries (Sodero et al., 2013), but also involve a variety of national contexts such as such as China (Liang et al., 2007; Liu et al., 2010), Germany (Hertwig, 2012), Singapore (Teo et al., 2003), South Korea (Hsu et al., 2012), the UK (Ashworth et al., 2009) and the USA (Bhakoo and Choi, 2013). The present study proposes that the institutional approach could also provide significant insights regarding the relationships between project-level BIM implementation activities and external institutional environments and, therefore, help to develop a theoretically rigorous framework for examining the environmental drivers of BIM implementation in construction projects.

2.5.2 Resource Dependence Theory

Building on the early works in social exchange theory (e.g., Emerson, 1962; Thibaut and Kelley, 1959), resource dependence theory has become popular as a result of its full exposition by Pfeffer and Salancik (1978). The basic assumptions of resource dependence theory are that few organisations are internally self-sufficient with respect to strategically important resources, and that this lack of self-sufficiency will create potential dependence on other related organisations as well as introduce uncertainty into organisational decision making processes (Heide, 1994; Pfeffer and Salancik, 1978). Given these underlying assumptions, resource dependence theory proposes that organisations need to manage dependence and reduce uncertainty by purposely structuring their exchange relationships with other organisations by means of establishing formal and semiformal interorganisational links (Heide, 1994; Pfeffer, 1982; Pfeffer and Salancik, 1978; Ulrich and Barney, 1984).

Since the seminal work of Pfeffer and Salancik (1978), resource dependence theory has become one of the most influential theories in organisational studies (Davis and Cobb, 2010; Hillman et al., 2009). The theoretical perspective has been applied to explain a variety of issues related to interorganisational relationships such as the governance of interorganisational information systems (Chatterjee and Ravichandran, 2013), the impact of supply chain relationships on organisational lean practices (Chavez et al., 2015), the role of ISO 9000 in managing interorganisational relationships (Singh et al., 2011a), the impact of interorganisational co-development competency on e-service innovation (Tsou and Chen, 2012), and the impact of buyer-supplier collaboration quality on new product development performance (Yan and Dooley, 2014). Considering the resource exchange requirements for participants in construction projects (Winch, 2010) and the integrated nature of BIM technology (Eastman et al., 2011), the present study proposes that resource dependence theory could also shed light on the understanding of the value of BIM in project design and construction processes and, therefore, provide a useful theoretical lens to explain how BIM implementation activities impact the performances of project participants.

2.6 Summary of Review Findings

To sum up, the reviews in this chapter have lead to the following primary findings.

(1) While the majority of extant studies on BIM have focused primarily on technical issues, including exploring potential areas in which BIM could be beneficially implemented and enhancing the interoperability among different BIM applications, the non-technical issues related to BIM adoption and implementation, including the empirical assessment of BIM implementation practices in specific contexts, have attracted increasing research interest in recent years.

(2) With regard to the investigation of the antecedent factors impacting BIM implementation, much of the extant research has focused on identifying industry professionals' perceived barriers for construction organisations to implement BIM, or examining how technology attributes and individual characteristics influence practitioners' personal intentions to accept BIM. By comparison, little empirical research has been conducted to specifically investigate the drivers of BIM implementation in construction projects and, therefore, providing a rigorous understanding of why BIM is differently implemented in different projects given the widespread implementation barriers in the industry. While the extant literature has already noticed the potential impacts of environmental contextual factors on the implementation of construction innovations, relevant empirical studies on different

construction innovations have generated discordant findings regarding how environmental factors exert their specific influences. As such, it will be relatively difficult to generalise extant research findings on other construction innovations to develop a theoretically rigorous understanding of how BIM implementation activities could be driven by environmental factors.

(3) With regard to the investigation of the performance impacts of BIM implementation, much of the extant research has focused on reporting descriptive statistics of the project benefits gained from BIM implementation activities in specific project contexts. While this stream of research has valuably illustrated the uncertainty of the performance impacts of BIM implementation, scant scholarly attention has been further devoted to characterising how the resultant project benefits of BIM implementation are influenced by related implementation characteristics, and thereby explaining why the performance impacts of BIM implementations in different project contexts vary substantially. Through characterising the difference between the direct and indirect impacts of innovation implementation on project performance, some recent investigations on other construction innovations could provide valuable insights into the analysis of the performance impacts of BIM implementation in the present study.

(4) As two theoretical perspectives that have been widely applied in organisational studies, institutional theory and resource dependence theory could provide theoretical bases for the analyses within the present study. Through viewing organisations as open systems subject to the influence of isomorphic pressures in

institutional environments, specifically, institutional theory could provide significant insights regarding the relationships between project-level BIM implementation activities and external institutional environments, and thereby help to develop a theoretically rigorous framework for examining the environmental drivers of BIM implementation in construction projects. Through characterising the resource dependence among organisations and the importance of interorganisational relationship in managing resource interdependence, resource dependence theory could shed light on the understanding of the value of BIM in project design and construction processes, and thereby provide a useful theoretical lens to explain how BIM implementation activities impact the performances of project participants.

CHAPTER 3 RESEARCH DESIGN

3.1 Introduction

In achieving the established research objectives, this study is designed principally based on a positivist epistemology. In contrast to the interpretive epistemology which rejects the possibility of an objective account of events and advocates researchers to understand phenomena through accessing the meanings that participants assign to them, positivist as a research epistemology asserts the existence of a priori fixed relationships within phenomena that could be structurally identified and tested through hypothetico-deductive logic (Orlikowski and Baroudi, 1991). In the spirit of this assertion, positivist studies are generally characterised by the formulation of hypotheses or causal relationships among variables, the use of quantitative measures, the deployment of large-scale sample surveys or controlled laboratory experiments, and the presentation of objective and value-free interpretation from researchers (Chen and Hirschheim, 2004; Creswell, 2013; Klein and Myers, 1999; Lee, 1991; Orlikowski and Baroudi, 1991).

Similar to many other positivist studies which rely on existing theories to increase the predictive understanding of a priori fixed relationships,[❶] this study also draws upon relevant theoretical perspectives to advance the body of knowledge

❶ It is noteworthy that although many positivist researchers rely on existing theories to test a priori fixed relationships, positivist research does not naturally relate to theory testing but instead also includes the theory-irrelevant studies which only descriptively present straightforward and objective accounts of events (Dubé and Paré, 2003; Orlikowski and Baroudi, 1991).

regarding the implementation of BIM in construction projects. As institutional theory and resource dependence theory are both drawn upon in this study, a natural question related to research design is whether the two theoretical perspectives are compatible and provide complementary insights into the analysis of the present study. As such, this chapter will first illustrate how the two theoretical perspectives are juxtaposed to establish an integrated research framework. Consistent with positivist epistemology, this study adopts quantitative data collection and analysis methods to empirically test the established research framework. As important elements of research design, the adopted data collection and analysis methods will also be briefly illustrated in the remainder of this chapter.

3.2 Research Framework

3.2.1 Juxtaposition of Perspectives of Institutional Theory and Resource Dependence Theory

As the two fundamental theoretical perspectives used to establish the research framework, institutional theory and resource dependence theory share several common or similar assumptions. Specifically, both perspectives view organisations as open systems and assume that organisational activities are constrained by other organisations in external environments (DiMaggio and Powell 1983; Pfeffer and Salancik, 1978). Based on this common assumption, the two theoretical perspectives both suggest that organisations must appropriately respond to external expectations and demands to ensure organisational viability and prosperity, although institutional theory places more emphasis on the purpose of seeking social legitimacy underlying the response (DiMaggio and Powell, 1983) while resource dependence theory primarily underlines the purpose of achieving a stable or predicable inflow of needed resources (Pfeffer and Salancik, 1978). Due to these commonalities or similarities, researchers have long claimed the feasibility and appropriateness of juxtaposing the two perspectives to provide a more comprehensive understanding regarding organisational activities (Hillman et al., 2009; Oliver, 1991).

The juxtaposition of the two theoretical perspectives is particularly appropriate for the analysis of the present study due to the complex relationships among project participants and external organisations which could not be sufficiently explained by either perspective alone. For a participating organisation in a construction project, its related organisations not only include other project participants with which it directly cooperates to execute design and construction activities, but also the actors outside the project who may indirectly and socially impact its project activities. As a theoretical perspective primarily delineating the relationship between organisations and their task environments, resource dependence theory could provide significant insights into the resource interdependence among project participants and the value of BIM in managing their interdependence, but shed limited light on why and how project participants respond to their institutional environments. As a theoretical perspective primarily delineating the relationship between organisations and their institutional environments, however, institutional theory could provide significant insights into why and how project participants respond to institutional isomorphic pressures exerted by organisations outside the project, but shed little light on the relationship among different participants within the project. As such, this study juxtaposes these compatible perspectives which are both rooted in the open systems paradigm, specifically employing resource dependence theory to understand the relationship among project participants and thus explain how BIM implementation activities impact their performances, and employing institutional theory to understand the relationship between project participants and external institutional environments and thus explain how institutional pressures drive BIM implementation activities of project participants.

3.2.2 Framework for Investigating Institutional Drivers and Performance Impacts of BIM Implementation in Construction Projects

Through juxtaposing institutional theory and resource dependence theory, this study develops the research framework shown in Figure 3.1. With regard specifically to the environmental drivers of BIM implementation, this study draws on institutional theory and focuses on investigating how three types of institutional isomorphic pressures (i.e., coercive, mimetic and normative pressures) impact BIM implementation activities in construction projects. With regard to the performance impacts of BIM implementation, this study uses resource dependence theory as a lens to understand BIM as a boundary spanning tool for project participants to manage interorganisational dependence and, therefore, focuses on investigating how BIM-enabled interorganisational collaboration capabilities mediate the relationship between BIM implementation activities and BIM-enabled performance gains for project participants. In order to further explain the relationship between BIM implementation process and project non-technical context, this study also incorporates project incentive mechanisms as a contextual factor and examines its impacts on BIM implementation activities and BIM-enabled interorganisational collaboration capabilities. With regard to the characterisation of BIM implementation activities, this study focuses on examining how BIM is implemented in different application areas and what are the roles of different project participants in implementing BIM. In illustrating the two aspects of characteristics, this study also quantitatively analyses how BIM implementation activities are associated with project characteristics including project size, type and nature. In order to further reveal the underlying logic of BIM implementation and thus to deepen the understanding of the relationship between BIM implementation activities and institutional environments, this study also specifically investigates the underlying motivations for project participants to implement BIM in construction projects.

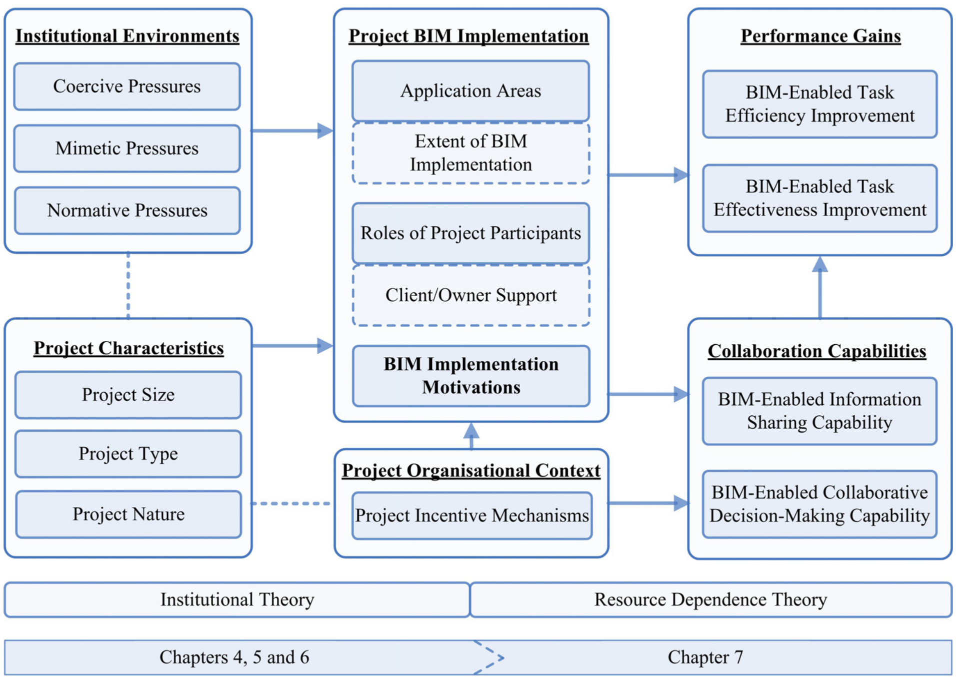

Figure 3.1 Research framework

Based on the framework, subsequent chapters of this thesis will theoretically and empirically analyse the specified relationships in more detail and consequently fulfil the four research objectives proposed in Chapter 1. Corresponding to the first research objective, Chapter 4 will focus on examining the characteristics of BIM implementation activities in construction projects and investigating how the activities are associated with project characteristics. Relating to the second research objective, Chapter 5 will specifically analyse how three types of institutional isomorphic pressures (i.e., coercive, mimetic and normative pressures) impact BIM implementation activities in construction projects. Based on the analysis in Chapter 5 and taking into account the impacts of institutional isomorphic pressures on BIM implementation, Chapter 6 aims to fulfil the third research objective through identifying and contextualising the motivations of designers and general contractors to implement BIM in construction projects. Relating to the fourth research objective, Chapter 7 will focus on investigating the relationships among BIM implementation activities, BIM-enabled interorganisational collaboration capabilities and BIM-enabled performance gains, and thus provide explanations of how BIM implementation activities impact the performances of project participants.

3.3 Research Methods

Consistent with the quantitative research paradigm of positivist studies (Chen and Hirschheim, 2004; Creswell, 2013; Orlikowski and Baroudi, 1991), this study quantitatively examines the research framework through collecting large empirical datasets and using rigorous data analysis techniques. As shown in Figure 3.2, the research process for the four research objectives are all comprised of three primary steps: model development and questionnaire design, data collection, and data analysis and result discussion. This section aims to provide an overview of the primary data collection and analysis methods employed throughout the research process. More details of why and how these methods are concretely employed will be further illustrated in the remaining chapters where appropriate.

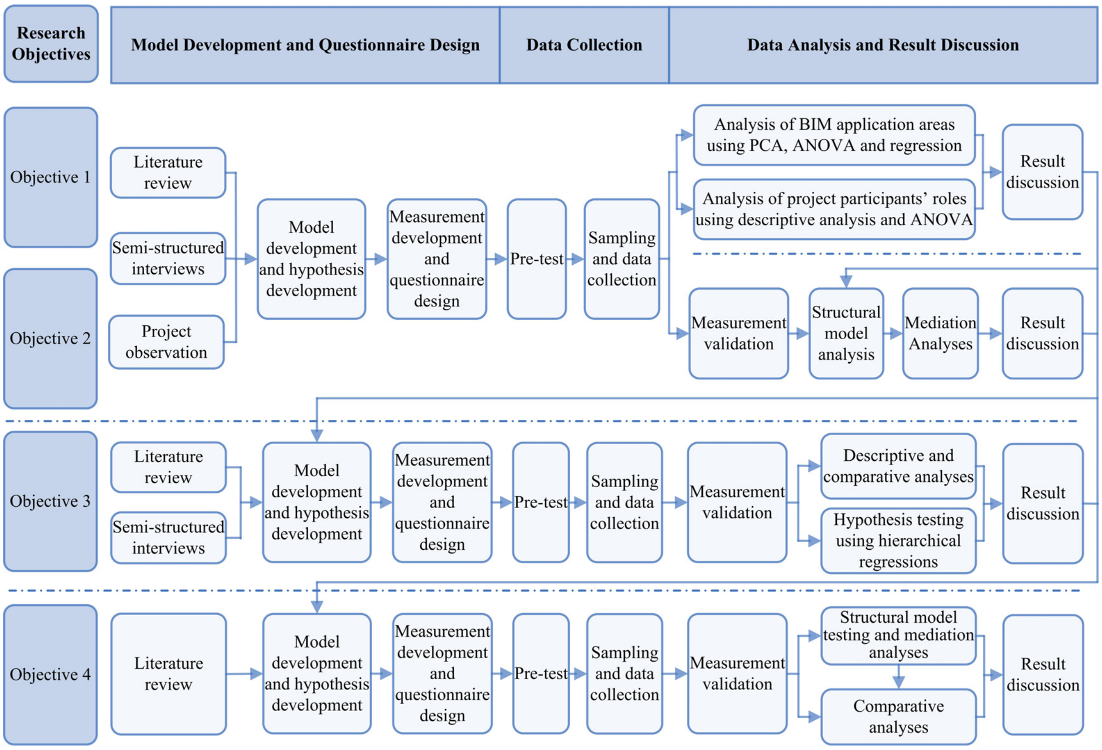

Figure 3.2 Flow of the research process

3.3.1 Data Collection Methods

Due to its intrinsic advantages of allowing replicability and collecting structured information, the questionnaire survey has been a commonly used method of collecting large scale data in positivist studies (Chen and Hirschheim, 2004; Creswell, 2013; Orlikowski and Baroudi, 1991). In order to realise structured comparisons of different BIM-based projects and statistical analysis of the examined relationships, this study also used the questionnaire survey as the primary data collection method. As shown in Figure 3.3, a total of three questionnaire surveys were conducted in this study. The first survey was conducted for analysing the practice characteristics of BIM implementation (Chapter 4) and the impacts of isomorphic pressures on BIM implementation (Chapter 5), the second was for analysing the motivations for BIM implementation (Chapter 6), and the third was for analysing the performance impacts of BIM implementation (Chapter 7).

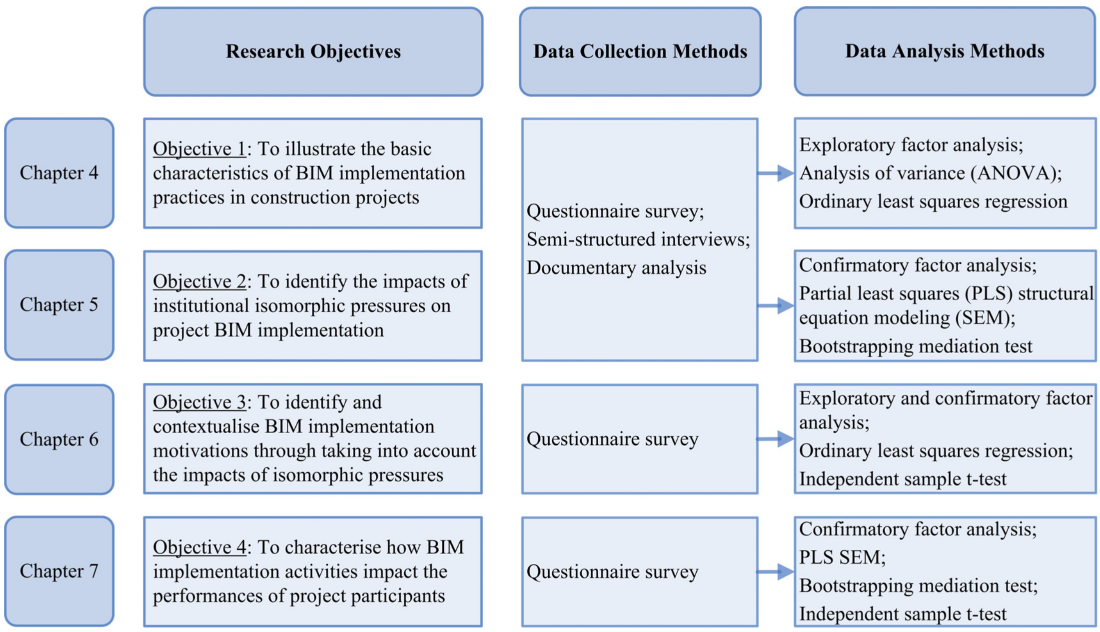

Figure 3.3 Data collection and analysis methods

The measurement items in the survey questionnaires were generally developed based on information gleaned from the literature as well as semi-structured interviews or direct project observations. Before being formally administered to targeted project respondents for large-scale surveys, as indicated in Figure 3.2, the questionnaires for different analyses were all pre-tested to identify ambiguous expressions and preliminarily test the validity of related constructs. For the first questionnaire survey, two other data collection methods (semi-structured interviews and documentary analysis) were also employed to gain additional project BIM implementation information and interpretations of the questionnaire responses.

3.3.2 Data Analysis Methods

Data analysis in this study includes both the assessment of the measurement validity of variables and the analysis of the relationships among measured variables. Measurement validity was assessed only for the variables operationalised as multi-item constructs, whether through exploratory factor analysis (EFA) or confirmatory factor analysis (CFA) methods.[❶] Validity indicators assessed using factor analysis methods are primarily composed of internal consistency, convergent validity and discriminant validity. Specifically, internal consistency reflects the homogeneity of the measurement items and is generally assessed through the estimate of composite reliability or Cronbach's Alpha (Fornell and Larcker, 1981; Hair et al., 2010); convergent validity measures the extent to which the items underlying a particular construct actually refer to the same conceptual variable (Zhu et al., 2006); and discriminant validity assesses the degree to which different constructs diverge from one another (Fornell and Larcker, 1981; Zhu et al., 2006).

With regard to the analysis of the relationships among measured variables, as shown in Figure 3.3, the primarily used analysis methods include partial least squares (PLS) SEM, bootstrapping mediation test, ordinary least squares (OLS)

❶ In the cases of the relationships among variables were analysed using the technique of structural equation modelling (SEM) (Chapters 5 and 7), the measurement validity was assessed generally using the CFA method within the SEM technique.

regression (including both simple linear and hierarchical regressions), and analysis of variance (ANOVA). Specifically, PLS-SEM was used to analyse the relationships in complex models which include mediating variables between dependent variables and independent variables (Barclay et al., 1995). Mediation effects of the mediating variables were not only indirectly tested based on causal steps analysis of the PLS results (Baron and Kenny, 1986), but also directly tested using the bootstrapping approach due to its distinct capabilities of yielding strong statistical power and examining the collective effects of multiple mediating variables (MacKinnon et al., 2002; Preacher and Hayes, 2004, 2008). For the simple models involving no mediating variables, the relationships between relevant variables were generally analysed using OLS regression (Cohen et al., 2003). ANOVA was primarily used to compare the means of relevant variables across different kinds of construction projects. Apart from the above data analysis methods, some other methods such as independent sample t-test and χ^2 test were also used, where appropriate, to analyse the associations between relevant variables.

3.4 Chapter Summary

This chapter has briefly illustrated the research framework of the present study, as well as the primary data collection and analysis methods used to empirically examine the framework. In order to provide a more comprehensive understanding regarding the external drivers and performance impacts of BIM implementation activities in construction projects, this study juxtaposes the compatible perspectives of institutional theory and resource dependence theory to establish the research framework. Consistent with the quantitative research paradigm of positivist studies, this study quantitatively examines the framework through collecting large-scale survey data from BIM-based construction projects. The primary methods used to analyse the collected data include partial least squares SEM, bootstrapping mediation test, ordinary least squares regression, and analysis of variance.

CHAPTER 4 PRACTICE CHARACTERISTICS OF BIM IMPLLEMENTATION IN CONSTRUCTION PROJECTS

4.1 Introduction

In order to better investigate the institutional drivers and performance impacts of BIM implementation, it is necessary to first establish an understanding of how BIM has been practically implemented in project design and construction activities. As illustrated in Chapter 2, the large majority of extant studies on BIM have focused primarily on technical issues with the purposes of validating or improving the technical feasibility of related BIM prototypes. In view of the possible gap between technical feasibility and practical implementation, there is an increasing research effort to examine empirically how BIM has been implemented in construction projects. To date, however, most of these investigations have been conducted in the form of case studies of individual construction projects, and in particular those in North America and Europe which are at the forefront of BIM deployment in the industry (Davies and Harty, 2013; Khanzode et al., 2008; Manning and Messner, 2008; Trebbe et al., 2015). Through examining the detailed processes of BIM use in specific projects, these case studies are valuable in providing professionals with an in-depth understanding of concrete BIM implementation practices in specific project contexts. However, activities in a single project can only characterise one aspect of industry practices but could not be easily generalised (Yin, 2009). As examples of BIM implementation practices in the industry accumulate, there is a strong need for further research to statistically synthesise the anecdotal evidence from different project contexts, and thus provide a more generalised understanding of how BIM has been implemented across the construction industry (Becerik-Gerber and Rice, 2010; Du et al., 2014; Hanna et al., 2013; Taylor and Bernsein, 2009).

Based on an investigation of 106 BIM-based projects commencing in the period from 2007 to 2013, this chapter aims to illustrate the characteristics of BIM implementation practices in Chinese mainland construction projects from the following aspects: (1) areas where BIM is implemented in design and construction stages; and (2) the roles of project participants. In illustrating the two aspects of characteristics, this chapter will quantitatively analyse how the extent of BIM implementation across different application areas and client/owner support for BIM implementation are associated with project characteristics. The remainder of this chapter proceeds as follows. The next section describes the measurements and data used for analysis. The results of the analyses are presented in Section 4.3, while Section 4.4 discusses the findings. Section 4.5 summarises this chapter.

4.2 Measurements and Data

4.2.1 Measurement Development

With its intrinsic advantage of allowing replicability and thus enabling structured comparisons across different projects, a questionnaire survey was used as the main method of collecting project-based data. Following the suggestions of Eisenhardt (1989), a mix of other data collection methods, including semi-structured interviews and document analysis, was also used in order to better design the survey instrument and to gain more detailed information relating to the surveyed projects. As the starting point, an exploratory investigation was carried out to gain a preliminary understanding of current BIM implementation practices in China. This includes semi-structured interviews with 17 industry professionals from 10 organisations that have pioneered BIM use[❶], the author's three-month ethnographic observation of an industrial project in Shanghai, and short observations and document analysis of several other projects. Based on information gleaned from these interviews and observations as well as related literature, a draft of the survey questionnaire was developed to collect project-based data on BIM-related practices. The questionnaire was then sent to 23 respondents to conduct a pre-test in October 2012, with the aim of assessing the appropriateness of the questionnaire scope, identifying ambiguous expressions and testing the validity of related constructs. Based on the feedback, the questionnaire was further revised and subsequently distributed to targeted construction projects. The questionnaire associated with the analysis in this chapter was structured into two parts (see Appendix A). The first part concentrates on general information of the surveyed project. The second part evaluates the extent to which BIM was implemented in different application areas in the surveyed project, as well as the roles of the key project participants in project BIM implementation.

The questionnaire items used to measure BIM application areas and participant roles were developed based on information collected from the literature and industry practice. The classification of BIM application areas was based principally on a

❶ These organisations, which are all located in Shanghai, include one project owner, four design companies, three general contractors, one consultant and one software vendor.

comprehensive review of the frameworks provided by Eastman et al. (2011), CICRP (2011), Hartmann et al. (2008) and Gao and Fischer (2008) as well as the results of preliminary interviews and project observations. After further revisions based on the pre-test feedback, a total of 13 BIM application areas in design and construction stages were finally incorporated into the questionnaire (see Table 4.1). As the list of application areas is not exhaustive, two open-ended items (one for the design stage and the other for the construction stage) were also included in the questionnaire for respondents to indicate other areas in which BIM had been implemented in their projects. The extent of BIM implementation in each application area was measured on a three-point scale of "0" (not used), "1" (some use) and "2" (extensive use). To avoid misleading respondents into providing information with which they were not familiar, an alternative “not clear” option was also provided for each area item.

Table 4.1 BIM application areas in design and construction stages

Stage	Application area	Description	References
Design Stage	A1 (Site analysis)	Analysing project site location	Azhar et al. (2011); CICRP (2011); Isikdag et al. (2008)
	A2 (Analysing design options)	Exploring and comparing design options based on 3D models	CICRP (2011); Eastman et al. (2011); Gao and Fischer (2008); Hartmann et al. (2008); Schade et al. (2011)
	A3 (3D presentation)	Three-dimensional (3D) presentation of complex structures to non-professionals	Eastman et al. (2011); Gao and Fischer (2008); Hartmann et al. (2008)
	A4 (Design coordination)	Coordinating design of architectural, structural, and MEP systems	CICRP (2011); Eastman et al. (2011); Gao and Fischer (2008); Hartmann et al. (2008)
	A5 (Cost estimation)	Project cost estimating during design stage	Cheung et al. (2011); CICRP (2011); Eastman et al. (2011); Hartmann et al. (2008); Ma et al. (2013)
	A6 (Energy simulation)	Analysing building’s energy distribution and consumption	Bynum et al. (2013); CICRP (2011); Eastman et al. (2011); Schlueter and Thesseling (2009)
	A7 (Other performance simulations)	Analysing building’s other performances such as lighting, acoustics, ventilation and air flows, and pedestrian circulation	Azhar et al. (2011); Bynum et al. (2013); CICRP (2011); Eastman et al. (2011); Rueppel and Stuebbe (2008)

Construction Stage	A8 (Clash detection)	Checking conflicts among building systems prior to construction	CICRP (2011); Eastman et al. (2011); Gao and Fischer (2008); Hartmann et al. (2008)
	A9 (Construction system design)	Designing and analysing the construction of complex building systems in order to increase planning	CICRP (2011); Eastman et al. (2011); Gao and Fischer (2008); Hartmann et al. (2008); Li et al. (2012)
	A10 (Schedule simulation)	Simulating master schedules and construction sequences	CICRP (2011); Eastman et al. (2011); Gao and Fischer (2008); Hartmann et al. (2008)
	A11 (Quantity takeoff)	Quantity takeoff and cost estimation during construction stage	Eastman et al. (2011); Gao and Fischer (2008); Hartmann et al. (2008); Monteiro and Martins (2013)
	A12 (Site resource management)	Integration with schedules and onsite information to manage the storage and procurement processes of project materials and equipments	Chin et al. (2008); Eastman et al. (2011); Gao and Fischer (2008); Hartmann et al. (2008)
	A13 (Offsite fabrication)	Generating digitized information to facilitate greater use of prefabricated components	CICRP (2011); Eastman et al. (2011); Gao and Fischer (2008); Larsen et al. (2011); Li et al. (2011)

The roles of the key project participants (including the client/owner, designer, general contractor, subcontractors and consultants) were further examined within the questionnaire. As suggested by Gao and Fischer (2008), the roles were classified into three categories of: "leading" (i.e., coordinating the whole process of creating, reviewing and utilising BIM models), "participating" (i.e., involved in but not leading the BIM implementation process) and "not involved". The respondents were also asked to identify whether the majority of BIM costs in the surveyed projects were passed on to clients/owners. Due to the client/owner's special influence in project activities, the level of client/owner support (COS) for BIM implementation in each surveyed project was further examined through measurement items adapted from the measures of leadership involvement validated by Zhu et al. (2010). These items, as to be discussed in more detail in Chapter 5, specifically reflect client/owner support from the aspects of investing BIM-related resources, championing BIM implementation and driving project participants to implement BIM collaboratively.

4.2.2 Sampling and Data Collection

Only Chinese mainland construction projects involving BIM implementation were included in the sampling frame of this study. Since the implementation of BIM has been relatively rare in China, a completely random sampling method could not be used to elicit cases from a specific project database. Instead, a wide variety of BIM-based construction projects and appropriate project respondents were identified by several methods, including searching through related industry publications, interviewing pioneering corporations in BIM implementation, requesting information from industry associations, and contacting professionals participating in three BIM industry seminars held by Tongji University between 2009 and 2011. Targeted project respondents were identified as those most-informed senior and professional individuals directly involved project BIM implementation. A snowball sampling technique was also utilised to increase the sample size, with the initially contacted respondents being asked to share related information concerning knowledgeable participants of other BIM-based projects (Salganik and Heckathorn, 2004). A diversified set of BIM-based projects with different geographic locations and project characteristics was selected to improve the representativeness of the sample and thus provide the best possible view of industry practice.

Responses were collected by a variety of means including e-mail, personal visits and an online survey system (www.sojump.com). To those survey recipients expected to return their questionnaires through e-mail or online survey system, reminder emails or telephone calls were sent three weeks after the first contact. After an almost 14-month investigation from November 2012 to January 2014, a total of 137 responses from 125 BIM-based construction projects were obtained. After completing the questionnaires, some respondents were also contacted to allow further interpretation of their answers and to provide more details of the surveyed projects. Whenever possible, respondents were also requested to share possible project documents including BIM implementation plans, animations of BIM models and any other materials that could help to understand the BIM implementation practices involved in the surveyed projects. The completed questionnaires were then carefully scrutinised and coded based on follow-up contacts and supplementary documents. For projects with more than one response, the Interclass Correlation Coefficient (ICC) was calculated in order to assess inter-rater agreement (Boyer and Verma, 2000). This showed most of the items involved in the study to have ICC values larger than the criteria of 0.6, indicating acceptable inter-rater agreement. In cases where there was a difference among the collected responses, the corresponding respondents were further contacted to clarify the rationale underlying their answers and the response considered to contain the most reliable answers was selected for each project case. After the further omission of responses due to either incomplete information concerning key variables or due to projects being still in the early design stage, 106 project cases were ultimately included in the analysis. The demographics of these 106 projects are shown in Table 4.2.

Table 4.2 Demographic information of samples for analysis of practice characteristics

Variable	Category	N	%	Variable	Category	N	%
Project size	Below ¥50 million	12	11.32	Year[a]	2007	1	0.94
	¥50-200 million	24	22.64		2008	8	7.55
	¥200-1000 million	32	30.19		2009	11	10.38
	Above ¥1000 million	38	35.85		2010	14	13.21
Project type	Residential	14	13.21		2011	20	18.87
	Commercial	38	35.85		2012	35	33.02
	Cultural	19	17.92		2013	17	16.04
	Sporting	4	3.77	Location	North China	17	16.04
	Hospital	4	3.77		Northeast China	4	3.77
	Transportation	11	10.38		East China	51	48.11
	Industrial	14	13.21		South Central China	22	20.75
	Others	2	1.89		Southwest China	6	5.66
Project nature	Public	50	47.17		Northwest China	6	5.66
	Private	56	52.83				

[a] Year for the commencement of construction activities.

These projects are diverse in terms of project size, project type and project nature, and the commencing years of their construction activities vary from 2007 to 2013. Largely due to the non-balanced development of BIM in different regions in China, a vast majority (84.91%) of the sample projects are located in the regions of East China, South Central China and North China. Among the 106 project-specific responses, 47.17% were collected through e-mail, with the remaining 37.74% and 15.09% collected by personal visits and the online survey system respectively. ANOVA and χ^2 tests were conducted to compare the answers from the three types of responses, and the results suggest that there were no significant differences as a whole. The respondents are from a mix of project participants, with 13.21% from clients/owners, 34.91% from designers, 32.08% from general contractors (including EPC/DB contractors), 15.09% from consultants and 4.72% from subcontractors. Most respondents are senior and professional individuals knowledgeable of BIM implementation, with 29.25% being project managers or chief project engineers, 17.92% BIM managers, 24.53% BIM engineers, and the remaining 28.30% being other types of engineers also directly involved in project BIM implementation.

The use of single-source and self-reported data for the study may raise concerns about the problems of common method bias in the answers (Podsakoff et al., 2003). Before answering the questions, as a procedural control method, the respondents were guaranteed that all their answers would be kept confidential. This procedure could help to reduce the possible response bias resulting from consistency motif and social desirability. As a statistical control technique, Harman's one-factor test was also conducted on the measurement items to detect the presence of common method bias (Podsakoff and Organ 1986). The test showed that no single dominant factor emerged and the largest factor only accounted for 23.95 percent of the total variances in the items, suggesting that common method bias is unlikely to be a substantial contaminant of the results (Podsakoff and Organ 1986).

4.3 Data Analyses and Results

4.3.1 Analysis of BIM Application Areas

The state of the surveyed projects' BIM implementation practices in different application areas is illustrated in Figure 4.1, showing that there are varying degrees of frequency. The most frequently implemented areas are clash detection in the construction stage (83.96%) and 3D presentation in the design stage (76.42%). These are followed by construction system design (75.47%), design coordination (66.04%) and design option analysis (63.21%). Site analysis and site resource management are the two least-frequent application areas. Only a small minority of the surveyed projects attempted to implement other non-listed areas in the design (5.66%) and construction (3.77%) stages. These areas include checking the design against building codes, controlling construction safety, and checking construction quality based on laser scanning technologies. Examination of the results indicates that BIM implementation in 31.13% of the surveyed projects was restricted to a single project stage, with 11.32% and 19.81% of projects limiting BIM implementation within the design and construction stages respectively.

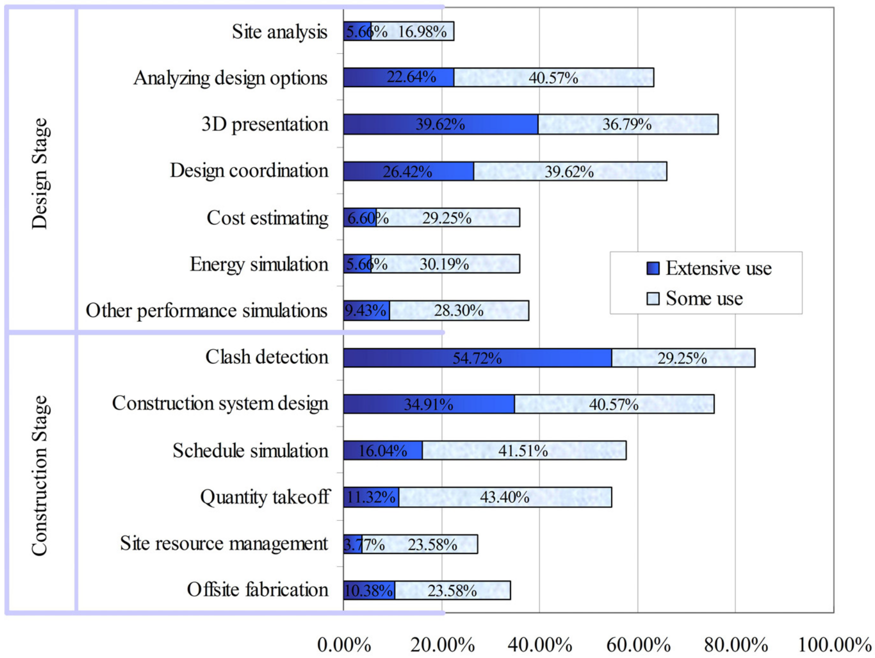

Figure 4.1 BIM implementation practices in different application areas

From Figure 4.1, it is evident that the depth of BIM implementation in most application areas is still relatively limited. Except in 3D presentation and clash detection, the implementation of BIM in all other areas is identified as “some use” more often than “extensive use”. Figure 4.2 further compares BIM implementation practices in different areas according to the frequency of extensive use. The result shows that the implementation of BIM in different areas generally follows a trajectory from model-based visualisation to model-based analysis and model-based management. The result also shows that, while the majority of the surveyed projects have attempted to implement BIM across several application areas, in-depth BIM implementation in most projects is limited principally in the areas of visualization.

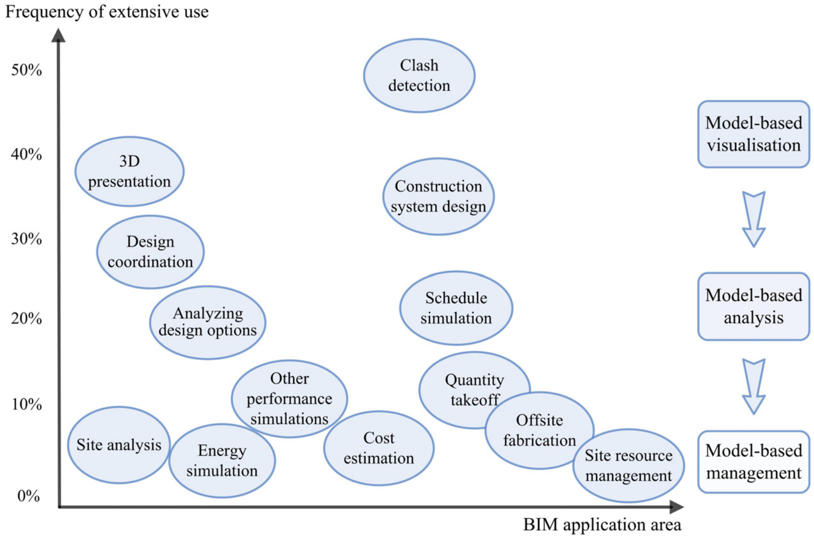

Figure 4.2 Paradigm of BIM implementation in design and construction stages

In order to improve the comprehensiveness of the implementation measurement and following Zhu et al. (2006) and Madapusi and D'Souza (2012), a principal component analysis (PCA) based factor analysis was performed to aggregate the BIM usage in the 13 application areas into one summated factor, and the factor was then used to measure the extent of BIM implementation as a whole in each project. A test for internal consistency of the summated factor, which is termed "*extent of BIM implementation*", yielded a satisfactory Cronbach's Alpha of 0.805. ANOVA tests were then performed to identify how the extent of BIM implementation are associated with project characteristic factors including project size, project type and project nature, and the results of these tests are presented in Table 4.3.

Table 4.3 Results of ANOVA tests for extent of BIM implementation by project characteristics

Variable	Category	N	Mean	SD		SS[a]	F-value	p-value
Project size	Below ¥50 million	12	-0.40	0.78	Between groups	5.37	1.83	0.146
	¥50-200 million	24	-0.11	0.83	Within groups	99.63		
	¥200-1000 million	32	-0.10	0.96	Total	105.00		
	Above ¥1000 million	38	0.28	1.14				
	Total	106	0.00	1.00				
Project type	Residential	14	-0.52	0.90	Between groups	4.32	4.46	0.037
	Non-residential	92	0.08	1.00	Within groups	100.68		
	Total	106	0.00	1.00	Total	105.00		
Project nature	Public	50	0.06	1.02	Between groups	0.31	0.31	0.582
	Private	56	-0.05	0.99	Within groups	104.69		
	Total	106	0.00	1.00	Total	105.00		

[a] SS = sum of squares.

As shown in Table 4.3, project type is found to be significantly associated with the dependent variable, suggesting that the extent of BIM implementation in non-residential projects are generally higher than that in residential projects. The association between project nature and the extent of BIM implementation, however, is not found to be significant. Follow-up contact and further examination of the data indicate that, even though public projects generally possess more resources to invest in innovative technologies, in many public projects BIM is still implemented primarily as a visualization tool, especially in stadium and exhibition hall projects due to their specific needs to represent complex designs to the public and non-professional clients/owners. Although the ANOVA test result on the association between the extent of BIM implementation and project size is not significant either, the result of ordinary least squares (OLS) regression[❶] reveals that the positive

❶ The four categories of project size (below ¥50 million, between ¥50 and ¥200 million, between ¥200 and ¥1000 million, above ¥1000 million) were valued as “1”, “2”, “3” and “4” respectively.

association between the two variables are statistically significant ($F = 4.852$，$p = 0.030$). This result suggests that project size is also a project characteristic factor significantly associated with BIM implementation practice.

4.3.2 Analysis of Roles of Project Participants in BIM Implementation

The roles of key project participants in the implementation of BIM are profiled in Table 4.4. It is evident that the most frequently involved participants in the implementation of BIM in the surveyed projects are general contractors (83.02%), followed by designers (76.42%). In nearly half (40.57%) of the projects, designers are identified as the leading participants in creating, reviewing and using BIM models. It is significant to note that BIM consultants are also involved in implementing BIM in approximately one third of the surveyed projects, mostly acting as BIM converters of the traditional 2D project documentation produced by designers. This result is unsurprising as BIM is still a relatively new solution for many industry practitioners in China, and a number of BIM consulting entities have emerged in recent years, either from traditional construction management consultants or newly established by pioneering BIM professionals.

Table 4.4 Roles of project participants in BIM implementation

Participant	Roles		
	Leading	Participating	Not involved
Client/owner	21 (19.81%)	55 (51.89%)	30 (28.30%)
Designer	43 (40.57)	38 (35.85%)	25 (23.58%)
General contractor	30 (28.30%)	58 (54.72%)	18 (16.98%)
Subcontractors	3 (2.83%)	49 (46.23%)	54 (50.94%)
BIM consultant	9 (8.49%)	25 (23.58%)	72 (67.92%)

Note: Values outside parentheses are project frequencies and values inside represent percentages (totals may not add to 100.00% due to rounding).

While there are increasing project participants involved in BIM implementation, it seems that few project teams work collaboratively to share a BIM model throughout the project lifecycle. In most cases, each participant builds their own BIM model to suit the specific needs of their own disciplines, and as a result, several respondents indicated mistrust and collaboration issues among participants in their projects. A general contractor in one of the leading skyscraper projects in Shanghai involving BIM implementation also commented:

(The designers) do not trust our (BIM) models, neither do we trust theirs … The BIM models provided by the designers are quite inconsistent with their later provided (2D) shop drawings. Frankly speaking, (our own BIM) model is almost rebuilt by ourselves. We have only referred to the axes and elevations in their models.

Respondents in around half of the surveyed projects (50.94%) revealed that the majority of BIM costs in their projects have been passed on to the clients/owners. Some of the respondents, however, further indicated that while some project clients/owners allow the inclusion of BIM costs in bidding prices, such costs are often suppressed to extraordinarily low levels, which can be an important cause of problems later encountered in BIM implementation practices in their projects. To further understand the client/owner's roles in BIM implementation, the respondents were also asked to rate their perceptions of the clients/owners' overall support for BIM implementation, which was measured in three dimensions of investing BIM-related resources, championing BIM implementation and driving project participants to implement BIM collaboratively. One-way ANOVA tests were then performed to assess the mean differences of COS across different kinds of projects. As shown in Table 4.5, there is a general trend for clients/owners to provide more support for BIM implementation with larger, non-residential and public projects.

Table 4.5 Results of ANOVA test for client/owner support for BIM implementation by project characteristics

Variable	Category	N[a]	Mean	SD		SS[b]	F-value	p-value
Project size	Below ¥50 million	11	3.12	0.95	Between groups	22.89	4.27	0.007
	¥50-200 million	21	4.17	1.29	Within groups	157.27		
	¥200-1000 million	30	3.88	1.48	Total	180.16		
	Above ¥1000 million	30	4.70	1.34				
	Total	92	4.12	1.41				
Project type	Residential	11	3.30	1.38	Between groups	8.40	4.40	0.039
	Non-residential	81	4.23	1.38	Within groups	171.76		
	Total	92	4.12	1.41	Total	180.16		
Project nature	Public	43	4.46	1.42	Between groups	9.02	4.74	0.032
	Private	49	3.83	1.34	Within groups	171.14		
	Total	92	4.12	1.41	Total	180.16		

[a] To mitigate response bias, 14 responses from project client/owners were excluded.

[b] SS = sum of squares.

Table 4.5 shows that the mean score of COS in the surveyed projects is 4.12 (SD = 1.41), which is quite neutral for a seven-point Likert scale. This result suggests that while considering clients/owners' behaviours in the aspects of championing BIM implementation as well as driving project teams to collaboratively implement BIM, their overall support for BIM implementation is still relatively lacking. This is also corroborated by follow-up contact, in which several respondents indicated that after the adoption of BIM, related contract clauses and responsibility allocation have not actually changed in their projects. One contractor in an exhibition hall project described that the only obvious change in their project may be the addition of a new department to build BIM models. It seems that such limited process and organisational change may be not only due to clients/owners' lack of knowledge on the effectiveness ways of BIM implementation, but also from the resistance to change, as the client/owner in a large-scale public project in Shanghai commented:

We have no intentions to change related project participants' responsibilities just because of the implementation of BIM … we do not want to change the behaviours of the majority (of the project participants), because such a change may influence the progress of our project to some extent.

4.4 Discussions of Findings

The major research objective of this chapter is to provide an overview of the characteristics of BIM implementation practices in Chinese mainland construction projects. Compared with early practices (specifically in those projects built for the 2008 Beijing Olympic Games around 2004) in which BIM was predominantly implemented to visualise complex facility shapes during the architectural design stage, a distinct characteristic of BIM implementation practices in the surveyed projects of the present study is that BIM use has been frequently extended to application areas within the construction stage, and general contractors have surpassed designers as the participants most frequently involved in BIM implementation.[❶] Such a change seems to be relatively inspiring as some recent investigations, such as Eadie et al. (2013)'s survey in the UK and the SmartMarket

❶ A recent industry report published by Dodge Data & Analytics suggests that the BIM implementation rate in contractors has surpassed that in designers in Chinese mainland (Bernstein, 2015), thus partly corroborating the empirical findings in this chapter.

surveys both in Western Europe (Bernstein et al., 2010) and in South Korea (Lee et al., 2012), show that in some developed countries contractors are still significantly less frequently involved in BIM implementation than designers, and many project BIM implementation practices are still limited to the design stage. Such a change also seems to be similar with what has happened in North America, where BIM has been increasingly implemented during the construction stage (Becerik-Gerber et al., 2012) and the BIM adoption rate among contractors is reported to have surpassed that of designers (Bernstein et al., 2012). There are several reasons for this change on the Chinese mainland. As it is required to submit 2D project documentation for regulatory approvals but it is still difficult for BIM software applications to automatically generate 2D shop drawings in accordance with industry specifications in China, BIM implementation is often regarded as extra work by the designers with fixed fee contracts.[❶] As for contractors within the highly fierce competition environment of the construction market, however, they often have internal incentives to actively embrace innovative technologies such as BIM to effectively manage construction activities or to win more construction contracts. As a result, several large-sized contractors, such as the China State Construction Engineering Corporation (CSCEC) and the Shanghai Construction Group (SCG), have already established corporation-wide mechanisms of staff training and project awards to facilitate the diffusion of BIM in their subsidiaries.

❶ The analysis in Chapter 7 will further illustrate that the BIM-enabled task efficiency improvement of general contractors is more substantial than that of designers.

Despite these clear developments, the advancement of BIM in China remains considerably lower than that of pioneering countries (Bernstein et al., 2012; Lee et al., 2012; NBS, 2015). It is evident in the surveyed projects that the in-depth implementation of BIM to date is still limited principally to the areas of visualization, with the aim of visually conceptualising the form of complex facilities or virtually detecting the conflicts of building systems. This corresponds with a number of previous investigations in which BIM was also identified to be most frequently implemented as a visualization tool in many other countries (Gerrard et al., 2010; Kreider et al., 2010; McCuen et al., 2012). This can be attributed partly to the continued persistence of data interoperability problems among various BIM applications that require relatively specific and different building information models, and to the tedium involved in importing information from previously created 3D models to related performance analysis applications that are customised to industry specifications on the Chinese mainland. Also, the traditional modular view of BIM application areas has resulted in many projects only trialling the implementation of BIM in some application areas, with the purposes of exploring suitable BIM implementation process, training professional staff, and guiding the use of BIM in future projects. While illustrating BIM is generally implemented as a visualisation tool, the empirical analysis further reveals the integrated implementation of BIM across different areas has been especially scarce in residential and small-sized projects. The results suggest that there is still a potential for greater benefits to be obtained by a more systemic and comprehensive implementation of BIM in a wider variety of application areas over the project lifecycle in the Chinese construction industry.

While collaboration problems related to project BIM implementation have been reported in many countries (Dossick and Neff, 2010; Miettinen and Paavola, 2014; Gu and London, 2010; Papadonikolaki et al., 2015), such problems caused by the use of traditional project delivery systems seem to be particularly severe in China at present. According to Becerik-Gerber and Rice (2010)'s survey in the US construction industry in 2009, the majority of BIM-based construction projects were being delivered through relatively collaborative methods such as integrated project delivery (IPD) and design-build (DB) to better leverage BIM benefits, and only 32.7% were being delivered through the traditional design-bid-build (DBB) system. Limited by a number of regulations on the project execution processes and related bidding mechanisms in the Chinese construction industry, however, design and construction services in most Chinese mainland construction projects are procured separately through the traditional DBB method. Such a situation has not changed markedly with the advent of BIM in the industry. Of the 106 surveyed BIM-based projects in the present study, a vast majority (88.7%) are still using the traditional DBB delivery method. The separated project delivery process, together with the lack of project incentive mechanisms, has critically impeded project participants to form an integrated team to collaboratively implement BIM throughout the project lifecycle. As a result, nearly one third of the surveyed projects implement BIM only in a single project stage. Even for those projects that include multi-disciplinary BIM use, few project teams work collaboratively to share BIM models and, in many cases, the model development process is largely isolated from the daily design and construction processes. As a result, the models are often outdated and underutilised.

Clients/owners, who could potentially become both primary beneficiaries and important drivers of BIM implementation in construction projects, were also found to be an important participant in extant BIM implementation practices. While Becerik-Gerber and Rice (2010)'s investigation in the USA in 2009 reported that most designers and contractors were still absorbing a large share of tangible BIM-related costs, the evidence in this chapter seems to be relatively favourable, with the majority of BIM costs in around half of the surveyed projects having been covered by the client/owner. Despite clients/owners increasingly assuming the responsibility for BIM costs, however, the results in this chapter also indicate that clients/owners' overall support for BIM implementation have been lacking to some extent. In residential building projects and smaller-sized projects, such support appears to be even more limited. A noteworthy observation is that the perceived client/owner support in public projects is higher than that in private projects, but the related difference in the extent of BIM implementation is not found to be statistically significant. It seems that, in many public projects, client/owner support for BIM implementation is still primarily related to visualization needs, but neglects the potential of BIM in the areas of model-based analysis and management. A number of public clients/owners around the world, such as the General Services Administration (GSA) in the United States and the Senate Properties in Finland, have already been aware of the core benefits of BIM and mandated BIM implementation in their projects. This is clearly an important area with great potential for public project clients/owners in China to improve in the future.

4.5 Chapter Summary

Based on an investigation of 106 BIM-based construction projects commencing in the period from 2007 to 2013, this chapter has illustrated the characteristics of BIM implementation practices in Chinese mainland construction projects from the following two aspects: how BIM is implemented in different application areas, and what are the roles of different project participants in BIM implementation. The results reveal that the implementation of BIM across different application areas generally follows a trajectory from model-based visualisation to model-based analysis and model-based management, and that in the surveyed projects the in-depth implementation of BIM has been principally limited to the areas related to visualisation. With regard to the roles of project participants, the results suggest that general contractors have surpassed designers as the participants most frequently involved in the BIM implementation activities in the surveyed projects, and that the overall support for BIM implementation by clients/owners is limited, despite their increasing absorption of BIM related costs. The results also provide evidence that BIM implementation practices, in terms of both the extent of BIM implementation across different application areas and client/owner support for BIM implementation, are significantly associated with project characteristic factors including project type and project size. In the *Discussions of Findings* section, this chapter has also compared BIM implementation practices on the Chinese mainland with those in other regions and discussed related implications.

CHAPTER 5 IMPACTS OF INSTITUTIONAL ISOMORPHIC PRESSURES ON BIM IMPLEMENTATION IN CONSTRUCTION PROJECTS

5.1 Introduction

Because of the great potential but still limited use of BIM in the industry, several studies have been conducted to identify antecedent factors impacting the adoption and implementation of BIM. As illustrated in Chapter 2, much of this research has focused on identifying industry professionals' perceived barriers to the diffusion of BIM in the industry (Eadie et al., 2013; Gerrard et al., 2010; Gu and London, 2010; Howard and Björk, 2008), or on using theories such as the technology acceptance model to examine how technology attributes and individual characteristics influence practitioners' personal intentions to accept BIM (Ding et al., 2015; Lee et al., 2015; Son et al., 2015). While project is the basic unit of design/construction activities and in most cases the decision on BIM implementation is made at the project level (CICRP, 2011), scant scholarly attention has been devoted to investigating how related BIM implementation decisions are made in specific construction projects and why the extent of BIM implementation in different kinds of projects varies.

Prior research on other innovations in the construction industry suggests that innovation implementation activities are not necessarily driven by efficiency needs to proactively address internal process problems, but may also be influenced by pressures from external environments (Bossink, 2004; Ng et al., 2001). Studies on innovations in other industries further suggest that how organisations respond to external pressures is dependent on innovation characteristics and industry attributes (Bhakoo and Choi, 2013; Chwelos et al., 2001; Tsai et al., 2013). BIM is a relatively complex and influential innovation (Eastman et al., 2011; Smith and Tardif, 2009), and its ROI are reported to be at highly varying levels (Bernstein et al., 2012; Lee et al., 2012). These characteristics, together with related attributes of the construction industry, may complicate the relationship between BIM implementations and external pressures. To date, however, little empirical evidence has been provided to help understand whether, and if so, how different types of external pressures relate to the extent of BIM implementation in construction projects.

Drawing on institutional theory (DiMaggio and Powell, 1983), this chapter aims to develop and empirically test a parsimonious model to explain how three types of institutional isomorphic pressures (i.e., coercive, mimetic and normative pressures) drive the implementation of BIM in construction projects in China. As it is claimed that project clients/owners (Winch, 2015) could play a critical role advocating for other construction innovations (Ling, 2007) as well as BIM solutions (Eastman et al., 2011), the construct of client/owner support is also incorporated within the model to examine how such a factor mediates the influences of isomorphic pressures on the extent of project BIM implementations. The remainder of this chapter is organised as follows. Section 5.2 develops the theoretical model and proposes the research hypotheses. Section 5.3 outlines the data and measurements used to test the model and hypotheses. Section 5.4 presents the data analysis results. This is followed by the discussions of the findings in Section 5.5. Section 5.6 summarises this chapter.

5.2 Theoretical Model and Research Hypotheses

5.2.1 Institutional Perspectives on BIM Implementation

In contrast to transaction cost economics, which posits that organisational decision making is based on an efficiency-seeking logic to rationally minimise the total production and transaction costs (Williamson, 1985), institutional theory emphasizes the critical role of the institutional environment in driving organisations to make structural and behavioural changes with the aim of gaining social legitimacy (DiMaggio and Powell, 1983; Meyer and Rowan, 1977; Scott, 2001). Through viewing organisations as *open systems* subject to the influence of particular environments, institutional theory has provided powerful explanations for several organisational changes and innovation diffusions in some other industries (Bhakoo and Choi, 2013; Hertwig, 2012; Hsu et al., 2012; Liang et al., 2007; Liu et al., 2010; Sodero et al., 2013; Teo et al., 2003). This study posits that the institutional approach could also provide significant insights regarding how complex BIM solutions are implemented in the backward construction industry.

BIM is a complex innovation whose successful technological implementation needs to be accompanied by complementary process and organisational changes (Dossick and Neff, 2010; Miettinen and Paavola, 2014; Mahalingam et al., 2015). If used appropriately, BIM can facilitate a more integrated design and construction process and thus generate a variety of project benefits. It seems, however, that many of these benefits are relatively intangible or not easily realisable at present (Barlish and Sullivan, 2012; Giel and Issa, 2013). As a consequence, a relatively high percentage of the practitioners involved in BIM use have not yet perceived the positive value of BIM (Bernstein et al., 2012; Lee et al., 2012).

The relative uncertainty of BIM benefits, together with many other implementation barriers (Eadie et al., 2013; Gu and London, 2010; Howard and Björk, 2008), may increase the difficulties for practitioners to make rational BIM implementation decisions purely driven by internal efficiency needs. As a consequence, project decision makers, including clients/owners, may also look toward the BIM implementation practices of similar projects and the guidance of industry professionals and be impacted by external isomorphic pressures. This may be even more the case in those countries where the diffusion of BIM is still in an initial stage and most industry practitioners still lack relevant knowledge on BIM. Taking into account these possible influences, the theoretical model of isomorphic pressures for BIM implementation is depicted in Figure 5.1.

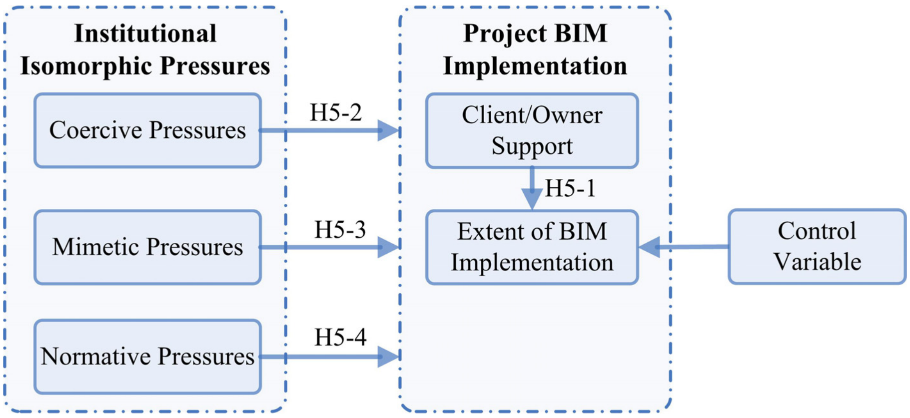

Figure 5.1 Theoretical model of isomorphic pressures for BIM implementation

5.2.2 Role of Client/Owner Support

Construction projects are typically operated through the production-to-order system and, therefore, clients/owners can exert profound influences on project design and construction activities. Prior empirical investigations on other innovations in the construction industry have illustrated that clients/owners' attitudes towards innovations could largely determine the direction and extent of innovation implementation in their projects, and that the implementation of innovations would become rather difficult without the support of clients/owners (Hedgren and Stehn, 2014; Ling et al., 2007; Manley, 2006; Nam and Tatum, 1997). However, some empirical evidences also reveal that in many cases clients/owners, whether due to their limited technical competence or out of their intentions to avoid risk of change, have not played expected roles to stimulate or support the implementation of innovative solutions (Ivory, 2005; Taylor and Levitt, 2007).

Whether the implementation of BIM is driven by internal efficiency needs or by external institutional pressures, project clients/owners are the primary beneficiaries (Eadie et al., 2013; Lee et al., 2012). In order to gain BIM benefits, competent and supportive clients/owners can facilitate the implementation of BIM in their projects through different ways. (1) Investing BIM-related resources. While generating benefits, BIM implementation also entails cost-intensive investments in related expertise, equipments and software. As construction and design service providers generally compete with each other under price-based competitive mechanisms with relatively low profit margins, the high investment cost of BIM-related resources may greatly impede their implementation behaviours without clients/owners covering or sharing related costs (Eadie et al., 2013). (2) Championing BIM implementation. Like many other innovations, BIM is accompanied with implementation risks and its utilisation may sometimes conflict with traditional project goals. The championing behaviours of project clients/owners, such as contractually requiring BIM use or indirectly convincing others of BIM benefits, can considerably justify the legitimacy of BIM use and thus lead to a greater extent of project BIM implementation. (3) Supporting process and organisational change to drive project participants to implement BIM collaboratively. BIM implementation does not only mean technological change, but also requires the redesign of project processes as well as the redistribution of collaborating participants' risks and responsibilities. As the extent of BIM implementation moves from the initial modelling stage towards the integration stage, such process and organisational change for inter-organisational collaboration will become more obvious and thus require stronger support from project clients/owners (Succar, 2009). These insights lead to the first hypothesis.

H5-1. The level of client/owner support is positively associated with the extent of BIM implementation in a construction project.

5.2.3 Role of Coercive Pressures

Coercive pressures by definition are "formal and informal pressures exerted on organisations by other organisations upon which they are dependent" (DiMaggio and Powell, 1983, p.150). Within the context of project-level BIM implementation examined in this chapter, coercive pressures could primarily stem from regulatory agencies and industry associations (often partly affiliated with the government). Due to the potential benefits of BIM, governments (or their affiliated organisations) in several countries have established plans for the mandatory use of BIM in public projects. In recent years local governments in some developed regions in China, such as Guangdong and Shanghai, have also established official BIM promotion committees or publicly advocated the implementation of BIM in large government-funded projects. Moreover, in emerging economies such as China that are undergoing the transition from centrally planned system to market-based mechanisms, government agencies and affiliated associations still frequently interfere with daily design and construction activities (Xu et al., 2005), for example, promoting the utilisation of innovative technologies in certain highly influential projects (e.g., the World Expo 2010 projects, and city landmark skyscrapers) to establish "showcase projects" or even "image projects". These authoritative activities, whether in the form of public regulation or project-specific requirement, may significantly influence the BIM implementation behaviours of both project clients/owners and other stakeholders, and thus result in a greater extent of project BIM use. Therefore the following set of hypotheses is proposed.

H5-2a. The levels of coercive pressures are positively associated with the level of client/owner support for BIM implementation in a construction project.

H5-2b. The levels of coercive pressures are positively associated with the extent of BIM implementation in a construction project.

5.2.4 Role of Mimetic Pressures

Mimetic pressures are those that drive organisations to imitate the successful conduct of other structurally equivalent organisations (DiMaggio and Powell, 1983). The primary source of mimetic pressures is uncertainty. When innovative solutions are poorly understood, organisational goals are ambiguous, or the environment creates uncertainty, organisations tend to benchmark their behaviours against that of peer organisations and to mimic those that appear legitimate and progressive (DiMaggio and Powell, 1983). Compared with many other innovations, BIM implementation practices generally involve more complex process and organisational change in construction projects, and most practitioners have been struggling on how to address related issues according to their specific project characteristics (Bynum et al., 2013; Eadie et al., 2013; Eastman et al., 2011). Moreover, BIM entails relatively high investment cost and its value is influenced by a number of factors such as project type, building shape, construction constraints, participant attributes and external support (Bryde et al., 2013; Giel and Issa, 2013). These characteristics may significantly increase the uncertainties of BIM implementation and, therefore, cause project decision makers to be more easily influenced by the conduct of peer projects with similar project characteristics and institutional environments. Both project clients/owners and other participants can be subject to such influence. As the primary risk bearers of construction projects, project clients/owners generally possess incentives to mimic the successful practices in peer projects, in order to better hedge against the associated risks that have already been partly borne by the first movers, and also not to lag behind their peers and thus lose legitimacy. For other project participants including designers and general contractors, the reputation and recognition acquired through mimicry would further help them to sustain their competitiveness in future projects. These mimicking behaviours will then lead to higher extent of BIM implementation in their own projects. Therefore the next set of hypotheses is suggested.

H5-3a. The levels of mimetic pressures are positively associated with the level of client/owner support for BIM use in a construction project.

H5-3b. The levels of mimetic pressures are positively associated with the extent of BIM implementation in a construction project.

5.2.5 Role of Normative Pressures

Normative pressures are primarily derived from professionalization (DiMaggio and Powell, 1983). Consistent with technology development and environment change, professional bodies within specific fields may gradually form shared norms and collective expectations regarding what constitute desirable behaviours. These norms and expectations can be diffused and strengthened within the professional fields through information exchange activities such as formal education, association participation, conference communication and professional consultation (DiMaggio and Powell, 1983; Teo et al., 2003). Being embedded within these professional fields, organisations could gradually develop their understandings of the commonly recognised values and beliefs and thus adjust their behaviours according to their specific organisational characteristics. Compared with coercive pressures, normative pressures generally influence organisational attitudes and behaviours in a much less compelling manner. Within the context of project-level BIM implementation, normative pressures may originate from a variety of sources. As quasi-government organisations, industry associations in the Chinese construction industry not only have the potential to exert coercive influences on project activities, but could also act as important vehicles for the definition and promulgation of BIM implementation norms through organising industry workshops (e.g., the "BIM Strategy Workshop" organised by the Beijing Exploration and Design Trade Association) and publicly recognizing best practices (e.g., the "Competition of BIM Implementation in Construction Projects" organised by the China Construction Industry Association). Similarly, software vendors, industry consultants and universities could also exert normative influences on industry practitioners through a variety of channels such as conference communication, specialised training and professional certification. As important decision makers on BIM implementations in construction projects, clients/owners may become a potential focal point of these normative influences. Through direct or indirect interactions with the professionals, project clients/owners could better understand the values and industry expectations regarding the BIM use in their specific projects, and thus exert more support for BIM implementation. Such client/owner support, together with the adjusted attitudes and behaviours of other project participants who could also be directly exposed to external normative influences, would result in a greater extent of project BIM implementation. These discussions lead to the final set of hypotheses.

H5-4a. The levels of normative pressures are positively associated with the level of client/owner support for BIM use in a construction project.

H5-4b. The levels of normative pressures are positively associated with the extent of BIM implementation in a construction project.

5.3 Measurements and Data

5.3.1 Measurement Development

A questionnaire survey was used as the main method to collect project-based data to test the theoretical model and research hypotheses proposed in Section 5.2. The questionnaire is the same one used for analysing practice characteristics of BIM implementation in Chapter 4 (see Appendix A). As illustrated in Subsection 4.2.1, the questionnaire was initially developed with information gleaned from semi-structured interviews, project observations and related literature, and was then sent to 23 respondents to conduct a pre-test for further revisions in October 2012. The revised questionnaire associated with the analysis in this chapter was structured into three parts. The first part concentrates on general information of the surveyed project. The second part evaluates the extent to which BIM was implemented in different application areas. In the third part, respondents are asked for their perceptions of external isomorphic pressures on and client/owner support for BIM implementation in the surveyed projects. Apart from related project characteristic variables such as project size, a total of five core variables have been measured in the questionnaire: extent of BIM implementation (EB), client/owner support (COS), coercive pressures (CP), mimetic pressures (MP) and normative pressures (NP).

In order to improve the comprehensiveness of the implementation measurement, as described previously in Chapter 4, the variable of EB was measured by an aggregated index on BIM usage in 13 application areas in design and construction stages (see Table 4.1). Different from EB, the variables of COS, CP, MP and NP were all operationalised as reflective constructs with seven-point scale items ("1" = strongly disagree; "7" = strongly agree), and their detailed measurement items are shown in Table 5.1. As illustrated in Subsection 4.2.1, the three measurement items of COS were developed based on the measures of leadership involvement previously validated by Zhu et al. (2010), and were reworded to suit the context of BIM implementation in construction projects. These items also relate to the three aspects of client/owner influences discussed in Subsection 5.2.2. The items of CP were adapted from Liang et al. (2007) and capture the two dimensions of authoritative influences by regulatory agencies and industry associations. The construct of MP was operationalised in terms of the perceived success of BIM implementation by peer projects, with three items measuring the extent to which peer BIM-based projects had benefitted greatly, had gained good reputations, and had been perceived favourably by others in the industry. Similar items had previously been validated by Liang et al. (2007), Son and Benbasat (2007) and Teo et al. (2003) in other research contexts. The construct of NP was operationalised to reflect how different professional bodies shaped the norms of BIM implementation in the industry. Based on the previous discussions, four items were used to measure the normative influences of software vendors, consultants, universities and industry associations, respectively. As larger projects generally have more slack resources that may allow them to implement BIM more easily than smaller projects, project size, measured by investment value, was employed as a control variable to check for other potential influences on BIM implementation. Due to the skewness in the size distribution for the surveyed projects, natural logarithms of the investment values (1 = Below ¥50 million; 2 = Between ¥50 and ¥200 million; 3 = Between ¥200 and ¥1000 million; 4 = Above ¥1000 million) were used in the data analysis process.

Table 5.1 Measurement items for constructs in analysis of isomorphic pressures

Construct	Code	Items	Mean	SD
Client/Owner support (COS)	COS1	Client/owner invested substantial resources in BIM use in the project	4.15	1.44
	COS2	Client/owner regarded BIM use as a priority of project activities	4.10	1.51
	COS3	Client/owner put much effort in driving project participants to collaboratively use BIM	4.12	1.49
Coercive pressures (CP)	CP1	The government required our project to use BIM	3.00	1.50
	CP2	Industry associations required our project to use BIM	2.95	1.48
Mimetic pressures (MP)	MP1	Peer projects that had implemented BIM had benefitted greatly	4.61	1.38
	MP2	Peer projects that had implemented BIM had gained good reputations in the industry	4.65	1.32
	MP3	Peer projects that had implemented BIM were perceived favourably by others in the industry	4.63	1.31
Normative pressures (NP)	NP1	Software vendors strongly advocated the use of BIM in our types of projects	4.57	1.67
	NP2	Industry consultants strongly advocated the use of BIM in our types of projects	4.49	1.65
	NP3	Universities strongly advocated the use of BIM in our types of projects	3.98	1.62
	NP4	Industry associations strongly propagated the value of BIM in our types of projects	4.45	1.59

Note: Measurement items of extent of BIM implementation are shown in Table 4.1.

5.3.2 Sampling and Data Collection

The survey data used for analysis in this chapter is the same with that used for analysing practice characteristics of BIM implementation in Chapter 4. After an investigation from November 2012 to January 2014, as illustrated in more details in

Subsection 4.2.2, a total of 106 usable project-based responses were collected by a variety of means including e-mail, personal visits and an online survey system (www.sojump.com). As client/owner support is examined in this chapter, in order to mitigate the response bias, 14 responses from project clients/owners were further excluded. As a result, a total of 92 project cases were ultimately included in the analysis in this chapter. The demographics of these projects are shown in Table 5.2.

Table 5.2 Demographic information of samples for analysis of isomorphic pressures

Variable	Category	N[a]	%	Variable	Category	N	%
Project size	Below ¥50 million	11	11.96	Year[b]	2007	1	1.09
	¥50-200 million	21	22.83		2008	7	7.61
	¥200-1000 million	30	32.61		2009	8	8.70
	Above ¥1000 million	30	32.61		2010	13	14.13
Project type	Residential	11	11.96		2011	17	18.48
	Commercial	35	38.04		2012	31	33.70
	Cultural	18	19.57		2013	15	16.30
	Sporting	4	4.35	Location	North China	16	17.39
	Hospital	3	3.26		Northeast China	4	4.35
	Transportation	9	9.78		East China	41	44.57
	Industrial	10	10.87		South Central China	21	22.83
	Others	2	2.17		Southwest China	4	4.35
Project nature	Public	43	46.74		Northwest China	6	6.52
	Private	49	53.26				

[a] To mitigate response bias, 14 responses from project clients/owners were excluded.

[b] Year for the commencement of construction activities.

These projects are diverse in terms of project size, project type, project nature and project location, and the commencing years of their construction activities vary from 2007 to 2013. This diversity could help to enlarge the difference in the isomorphic pressures for BIM implementation among the surveyed projects and, therefore, help to better examine the relationships between isomorphic pressures and BIM implementation activities. Among the 92 project-specific responses, 51.09% were collected through e-mail, with the remaining 34.78% and 14.13% collected by personal visits and the online survey system respectively. Analysis of variance (ANOVA) and χ^2 tests were conducted to compare the answers from the three types of responses, and the results suggest that there were no significant differences as a whole. The respondents are from a mix of project participants, with 40.22% from designers, 36.96% from general contractors (including EPC/DB contractors), 17.39% from consultants and 5.43% from subcontractors. Most respondents are senior and professional individuals who are knowledgeable of BIM implementation in their projects, with 28.26% being project managers or chief project engineers, 18.48% BIM managers, 26.09% BIM engineers, and the remaining 27.17% being other types of engineers also directly involved in the implementation of BIM. In order to formally examine whether the responses were impacted by the project participating type of the respondents, a series of ANOVA tests were also conducted to compare the differences in the mean values of the constructs with perceptual measures, and no statistically significant difference was found for any construct among the respondents from designers, general contractors, consultants and subcontractors (p-values of the ANOVA tests for EB, COS, CP, MP and NP are 0.966, 0.564, 0.836, 0.087 and 0.130 respectively).

In order to statistically assess the potential problems of common method bias caused by the use of single-source and self-reported data (Podsakoff et al., 2003), Harman's one-factor test was conducted on the five variables of EB, COS, CP, MP and NP (Podsakoff and Organ, 1986). The test showed that no single dominant factor emerged and the largest factor only accounted for 27.05 percent of the total variances in the measurement items, suggesting that common method bias is unlikely to be a substantial contaminant of the results (Podsakoff and Organ, 1986).

5.4 Data Analyses and Results

Partial least squares (PLS), a component-based structural equation modelling (SEM) technique, was used to validate the measurements and test the hypothesised research model. *SmartPLS 2.0 M3* was employed as the PLS analysis program. Similar to covariance-based SEM techniques such as LISREL, PLS allows for simultaneous estimation of multiple dependent variables and thus is well suited for the assessment of mediation effects (Hair et al., 2011). Moreover, as the sample size is relatively small in this chapter, and an aggregated factor score based on PCA analysis is employed to gauge the extent of project-level BIM implementation, PLS's abilities to analyse small sample size data[❶] and research models with single-item constructs make it particularly appropriate as the analysis technique (Hair et al., 2012).

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❶ There is an ongoing debate among scholars over the minimum sample size requirements for using SEM techniques. While some scholars contend that the sample size for using covariance-based SEM techniques like LISREL should not be lower than 100 (Hair et al., 2010) or five times the number of parameters to be estimated (Bagozzi and Edwards 1998), many others suggest that PLS as a component-based SEM technique has an advantage over other SEM techniques in processing smaller sample size data (Barclay et al., 1995; Chin, 1998; Chin and Newsted, 1999; Hair et al., 2011, 2012). According to Ringle et al.'s (2012) review of the empirical studies published in *MIS Quarterly* from 1992 to 2011, there are 65 studies using the PLS technique and 36.92% of these 65 studies explicitly state that their reasons for choosing PLS are related to their small sample sizes. Goodhue et al.'s (2012) review of the 90 PLS-based studies published in *Information Systems Research*, *Journal of Management Information Systems*, *MIS Quarterly* from 2006 to 2010 also reveals that at least 35% of the studies have emphasised the special ability of PLS to process small sample size data, and that 13 of these studies (14.44%) have sample sizes smaller than 80.

5.4.1 Measurement Model Assessment

The validity of the measurements was assessed in terms of internal consistency, convergent validity and discriminant validity. Internal consistency was assessed through the estimate of composite reliability. As reported in Table 5.3, the composite reliability values of the examined constructs all exceed the recommended criterion of 0.70 (Fornell and Larcker, 1981). Following the study of Zhu et al. (2006) on other technologies, extent of BIM implementation was measured as a summated factor based on PCA analysis and, therefore, its reliability and validity measures were not calculated in the PLS-based model validation process. Instead, the internal consistency of the summated factor was further tested in SPSS Statistics 21.0 and a satisfactory Cronbach's Alpha of 0.818 (N = 92) was yielded. Convergent validity measures the extent to which the items underlying a particular construct actually refer to the same conceptual variable. The first evidence of convergent validity is provided by the values of average variance extracted (AVE). As shown in

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A commonly cited minimum sample size rule for using the PLS technique is the "*10 times rule*", which suggests that the sample size should be at least ten times the largest number of structural paths directed at a particular latent construct in the structural model (Barclay et al., 1995; Chin and Newsted, 1999; Goodhue et al., 2012; Hair et al., 2011, 2012). Some literature has also cited Falk and Miller (1992) to justify using a "*5 times rule*" as a weaker rule of thumb. With regard to the structural model analysed in this chapter, the latent construct with the largest number of directed structural paths is the variable of the extent of BIM implementation (number of paths = 5), and the sample size (N = 92) satisfactorily meets the requirement of the "*10 times rule*". In order to further validate the model estimation results based on the PLS technique, however, a series of ordinary least squares (OLS) regressions were also performed in the program of SPSS Statistics 21.0 to estimate the hypothesised relationships within this chapter. The parameter estimates of OLS regressions, as illustrated in details in Appendix D, are substantially similar to the results based on the PLS technique, and the hypothesis testing results using the two different analysis techniques are essentially identical.

Table 5.3, each AVE is above the threshold of 0.5, indicating that at least 50 percent of the variance in the items can be accounted for by their respective construct. Further evidence of convergent validity is obtained by estimating the factor loadings of the measurement items. The standardised factor loadings of the items on their respective constructs, as shown in Table 5.4, are all above the threshold of 0.7 and are significant, and there exists no cross-loading problem (Hulland, 1999). Discriminant validity assesses the degree to which different constructs diverge from one another. It is shown that the square roots of the AVE (values on the diagonal of the correlation matrix in Table 5.3) are all greater than the absolute value of inter-construct correlations (off-diagonal values), suggesting that the constructs possess satisfactory discriminant validity (Fornell and Larcker, 1981).

Table 5.3 Measurement validity for constructs in analysis of isomorphic pressures

Construct	Mean	SD	CR	AVE	Correlation matrix[b]				
					COS	CP	MP	NP	EB
Client/Owner support (COS)	4.12	1.41	0.97	0.90	**0.95**				
Coercive pressures (CP)	2.97	1.46	0.98	0.96	0.42	**0.98**			
Mimetic pressures (MP)	4.63	1.18	0.92	0.79	0.40	0.48	**0.89**		
Normative pressures (NP)	4.37	1.41	0.88	0.66	0.11	0.16	0.11	**0.81**	
Extent of BIM implementation (EB)[a]	NA	NA	NA	NA	0.46	0.42	0.43	0.14	NA

Note: SD = standard deviation; CR = composite reliability; AVE = average variance extracted.
[a] Values are calculated based on PCA analysis, related measures are not applicable for this construct.
[b] Bold values on the diagonal represent the square root of AVE.

Table 5.4 Results of CFA of constructs in analysis of isomorphic pressures

Construct	Measurement items	Factor loadings				T-value
		COS	CP	MP	NP	
Client/Owner support (COS)	COS1	**0.932**	0.405	0.307	0.049	50.240
	COS2	**0.961**	0.425	0.438	0.137	92.343
	COS3	**0.959**	0.377	0.388	0.107	71.552
Coercive pressures (CP)	CP1	0.411	**0.978**	0.466	0.206	72.752
	CP2	0.417	**0.979**	0.466	0.117	105.592

Mimetic pressures (MP)	MP1	0.473	0.467	**0.853**	0.112	17.977
	MP2	0.327	0.435	**0.941**	0.129	43.449
	MP3	0.260	0.359	**0.865**	0.057	13.777
Normative pressures (NP)	NP1	-0.003	0.124	0.022	**0.728**	3.315
	NP2	0.106	0.152	0.110	**0.973**	3.738
	NP3	0.043	0.181	-0.013	**0.802**	4.005
	NP4	0.057	0.124	0.104	**0.720**	3.286

Note: Bold values represent standardised factor loadings of the items on their respective constructs.

5.4.2 Structural Model Testing

A bootstrapping procedure with 5000 resamples was performed to compute standard errors and thus test the statistical significance of path coefficients in the hypothesised structural model. The results of the bootstrap-based PLS analyses are presented in Figure 5.2. The R^2 value of the dependent variable, extent of BIM implementation, is 0.314, suggesting that relatively substantial variances in the construct are explained by the research model. As shown in Figure 5.2, the influence of COS on the extent of BIM implementation is significant ($\beta = 0.278$, $p < 0.05$), thus Hypothesis 5-1 is supported. It is also shown that the CP-COS link ($\beta = 0.296$, $p < 0.01$) and the MP-COS link ($\beta = 0.258$, $p < 0.05$) are significant, providing evidence for Hypotheses 5-2a and 5-3a. However, the NP-COS link is not found to be significant ($\beta = 0.028$, $p > 0.05$), hence Hypothesis 5-4a is not supported. The results further indicate that while both the influences of CP and MP on COS are significant, the influence of CP is much stronger than that of MP. With regard to the relationships between isomorphic pressures and the extent of BIM implementation, only the influence of MP is found to be significant while the effect of COS is included, hence Hypothesis 5-3b is supported. As for the control variable, project size exerts no significant influence on the extent of BIM implementation while the influences of isomorphic pressures and COS are considered (β = 0.034, p > 0.05).

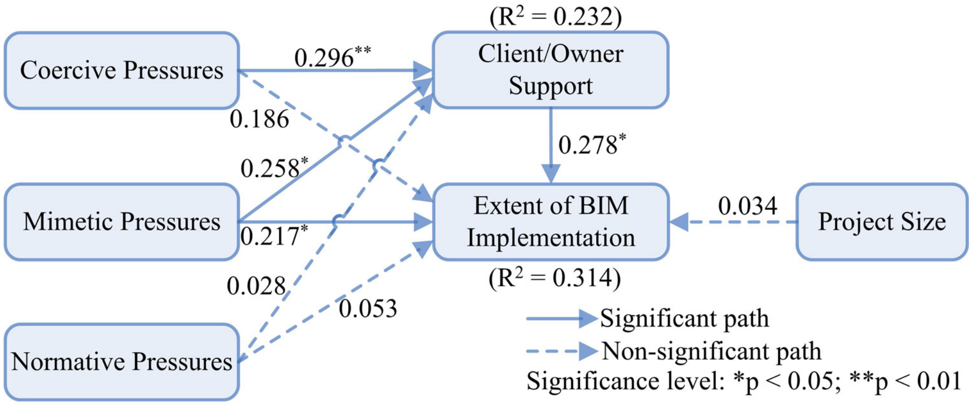

Figure 5.2 Results of PLS analyses for the model of isomorphic pressures

In order to better understand the mechanisms of how isomorphic pressures influence BIM implementation activities in construction projects, an alternative model without the intermediate construct of COS was further tested with the collected data. The results of the PLS analyses on this alternative research model are presented in Figure 5.3. The statistical significance of path coefficients was also tested using a bootstrapping procedure with 5000 resamples. While the intermediating effect of COS is excluded, as is evident in Figure 5.3, the influences of CP (β = 0.256, p < 0.05) and MP (β = 0.296, p < 0.01) on the extent of BIM implementation are both statistically significant. Combined with the results of the original full model shown in Figure 5.2, these findings suggest that although the direct effect of CP on project-level BIM implementation is not significant after controlling for the effects of client/owner support, the total effect of CP on the extent of BIM implementation is still statistically significant, hence Hypothesis 5-2b is also supported. With regard to the influence of NP, the path coefficient is still non-significant at the 5% level (β = 0.084, p > 0.05), thus Hypothesis 5-4b is not supported by the data. The hypothesis testing results are summarised in Table 5.5.

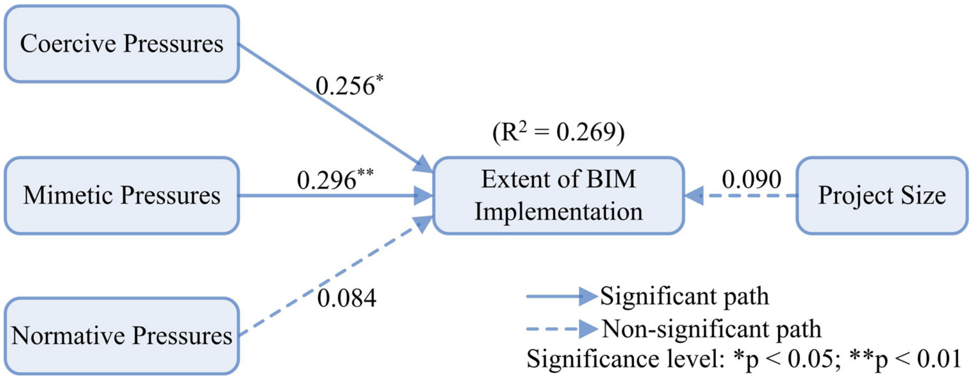

Figure 5.3 Results of PLS analyses for the alternative model of isomorphic pressures

Table 5.5 Summary of hypothesis testing results for analysis of isomorphic pressures

Dependent variable	R^2	Code	Path	Path coefficient	T-value	Significance	Result
Client/owner support (COS)	0.232	H5-2a	CP → COS	0.296	2.619	p<0.01	Supported
		H5-3a	MP → COS	0.258	2.196	p<0.05	Supported
		H5-4a	NP → COS	0.028	0.213	NS	Not supported
Extent of BIM implementation (EB)	0.314	H5-1	COS → EB	0.278	2.366	p<0.01	Supported
		H5-2b	CP → EB	0.186	1.450	NS (p<0.1)	Supported
		H5-3b	MP → EB	0.217	1.988	p<0.05	Supported
		H5-4b	NP → EB	0.053	0.335	NS	Not supported
		NA	Size [a] → EB	0.034	0.390	NS	NA

Notes: CP = coercive pressures, MP = mimetic pressures, NP = normative pressures; With regard to Hypothesis H5-2b, the relationship between CP and EB is found to be non-significant while the effect of COS is included, but the relationship become significant while the effect of COS is excluded, so H5-2b is also supported.

[a] Refers to project size measured by investment value. Due to the skewness in the size distribution for the surveyed projects, natural logarithms of the investment values were used for data analysis.

5.4.3 Mediation Analyses

The structural model testing results in Subsection 5.4.2 have initially illustrated that client/owner support plays different roles in the influences of the three types of isomorphic pressures. In order to further assess such a difference, the mediation effects of client/owner support on the relationships between isomorphic pressures and the extent of BIM implementation was further assessed using both the causal steps approach (Baron and Kenny, 1986) and the bootstrapping approach (Preacher and Hayes, 2004, 2008). Through sequentially examining related paths in the mediation model (Baron and Kenny, 1986), the causal steps approach could provide a relatively clear understanding of the relationships among the independent, mediating and dependent variables and is the most commonly used mediation analysis method (Preacher and Hayes, 2004). However, this approach is also associated with several shortcomings such as only indirectly testing the significance of mediation effects and possessing relatively low statistical power (MacKinnon et al., 2002; Preacher and Hayes, 2004, 2008; Zhao et al., 2010). As a nonparametric resampling procedure to directly test the significance of mediation effects, by contrast, the bootstrapping approach does not impose assumptions on the shape of the sampling distribution of the mediation effect statistic and has been found to have stronger statistical power than most other mediation analysis methods, especially for small sample size data (MacKinnon et al., 2004; Preacher and Hayes, 2004, 2008). With the help of the macros developed by Preacher and Hayes (2008), moreover, the bootstrapping procedure could be efficiently implemented in statistical programs such as SPSS to test mediation effects in complex models with multiple mediating or independent variables. As such, the bootstrapping approach could be used to further validate the analysis results based on the causal steps approach.

Mediation analyses based on the causal steps approach were performed in the program of *SmartPLS 2.0 M3*. Following Andrews et al. (2004), a total of four criteria were sequentially checked to assess the mediation effects. First, while not considering the effect of COS (mediating variable), as shown in Figure 5.3, the impacts of CP and MP (independent variables) on EB (dependent variable) are both significant, but the impact of NP (independent variable) is not significant. Therefore, there is no need to further examine the mediation effect of COS on the relationship between NP and EB. Second, the impact of COS (mediating variable) on EB (dependent variable) is significant. Third, the impacts of CP and MP (independent variables) on COS (mediating variable) are both significant. Fourth, after controlling for the effect of COS (mediating variable), as shown in Figure 5.2, the impact of CP on EB decreases and becomes non-significant at the 5% level, and the impact of MP on EB also decreases but is still significant at the 5% level. The results collectively suggest that COS fully mediates[❶] the relationship between CP and EB but partially mediates the relationship between MP and EB.

Mediation analyses based on the bootstrapping approach were performed using the SPSS macro developed by Preacher and Hayes (2008). The bias-corrected (BC) bootstrap confidence intervals (CIs) for the estimated mediation effects are listed in Table 5.6. It is evident that the BC 95% CIs for the mediation effects of COS on the CP-EB and MP-EB links both do not contain zero, suggesting that the two mediation

❶ The situation of full mediation is also called as complete mediation (James and Brett, 1984) or perfect mediation (Preacher and Hayes, 2004).

effects are both significant at the 5% level. However, the BC 95% CI for the mediation effect of COS on the NP-EB link is found to contain zero, suggesting that the effect is not significantly different from zero at the 5% level. These results are all consistent with those based on the causal steps approach.❷

Table 5.6 Mediation effects of client/owner support: Results based on bootstrapping approach

Mediation path			Bias-corrected 95% CI		Significance
Independent variable	Dependent variable	Mediating variable	Lower	Upper	
Coercive pressures	Extent of BIM implementation	Client/owner support	0.023	0.205	Significant
Mimetic pressures			0.004	0.241	Significant
Normative pressures			-0.037	0.091	Non-significant

Note: The number of resamples is 5000.

5.5 Discussions of Findings

The major research objective of this chapter is to identify the impacts of institutional isomorphic pressures on project-level BIM implementation activities. Overall, the results provide evidence that isomorphic pressures as a whole can significantly influence the extent of BIM implementation in construction projects, suggesting that project-level BIM implementation is a complexly socialised activity that is closely associated with external institutional environments. During such a socialised BIM implementation process, however, different types of institutional isomorphic pressures manifest themselves in relatively different ways.

Coercive pressures are found to be significant influencing factors for the extent of BIM implementation, and their influence is fully mediated by the construct of client/owner support. It is also found that the influence of coercive pressures on

❷ The results based on the bootstrapping approach do not differentiate full and partial mediations.

client/owner support is stronger than those of two other types of isomorphic pressures. These findings jointly indicate that project clients/owners, with many of them being non-professional practitioners, may be more easily impacted by external authoritative pressures than by less compelling forces such as normative suggestions. While some prior research in other industries reveals that external mandates may not significantly influence innovation implementation activities, or may only result in some ceremonial changes (Barratt and Choi, 2007), the influence of coercive pressures on BIM implementation examined in this chapter seems to be more substantial. This is probably because at present coercive pressures are principally exerted on complex public projects (as shown in Table 5.3, the overall level of perceived coercive pressures is quite low, with a mean value of 2.97), whose clients/owners are more prone to comply faithfully with the requirements of highly interconnected regulatory agencies and associations. In addition, the investment nature may also enable these public projects to invest substantially in BIM use as a response to external authoritative influences, thus leading to a greater extent of project BIM implementation.

The relationship between mimetic pressures and BIM implementation extent is also found to be statistically significant. Although not explicitly built on institutional theory, some prior studies on other construction innovations have also examined the influence of mimetic pressures on innovation implementation intentions or behaviours, and have suggested relatively conflicting results. For example, Esmaeili and Hallowell's (2012) study on administrative safety innovations in the USA and

Kale and Arditi's (2005) study on CAD technology in Turkey indicate that imitative behaviour is the primary reason for the diffusion of these innovations. Nikas et al.'s (2007) investigation on collaborative technologies in the Greek construction industry, however, suggests that technology use practices in the environment have no significant influence on organisations' technology use intention. The differences in the nature of these innovative solutions may serve as a plausible explanation for these inconsistent findings. As for complex and radical innovations like BIM, the implementation process often not only involves project process change, high investment cost and intangible benefits, but may also exert considerable social influence due to the widespread industry interest in the innovations. Compared with those on other innovations with less ROI uncertainty and social influence, implementation decisions on these innovations tend to be more easily impacted by the behaviours of peer projects. Mediation analysis results based on the causal steps approach further shows that the influence of mimetic pressures on BIM implementation is partially mediated by client/owner support. This finding suggests that other project participants such as designers and contractors could be directly exposed to mimetic pressures without the influence of project clients/owners. This probably reflects how the BIM implementations in many early projects are actually driven by architects and then by general contractors because of their professional capabilities and sensitivity to innovative technologies.

With respect to normative pressures, this study fails to provide evidence for their significant influence on the extent of BIM implementation in construction projects.

This finding is somewhat surprising because some prior research (e.g., Toole, 1998) indicates that participants in the construction industry often rely on the information provided by outside professionals to determine whether or not to implement innovative technologies. Such a non-significant influence of normative pressures on BIM implementation extent is probably not because professional communities have not yet exerted enough effort to promote the use of BIM in the industry, as the collected data also reveal that the average level of perceived normative pressures in the surveyed projects is relatively high (Table 5.3, mean = 4.37). However, it seems that most project clients/owners, with many of them being one-off participants in the construction industry, may be not easily exposed to or impacted by the normative influences of industry professionals (Figure 5.2, $\beta_{NP\text{-}COS}$ = 0.028). Without the mediation of client/owner support, there may also be ineffectiveness of the normative pressures exerted on other project participants with limited capabilities to invest substantially on innovative technologies. Such pressures, therefore, may influence organisational intention to adopt some other innovations (Toole, 1998), but could not, if not exerted appropriately, significantly impact the actual implementation level of cost-intensive technologies like BIM. This is also partly corroborated by the fact, as indicated by some respondents in this study, that designers and contractors in several projects under intense normative pressures were employing tentative use strategies to implement BIM, with the purposes of exploring proper BIM implementation process, training BIM professional staff and guiding the implementation of BIM in future projects.

5.6 Chapter Summary

From an institutional theory perspective, this chapter has developed and empirically tested a research model to explain how three different types of institutional isomorphic pressures influence the behaviours of project clients/owners and then the extent of project-level BIM implementation. The results from PLS analyses based on the data collected from 92 Chinese mainland construction projects reveal that coercive and mimetic pressures both significantly influence the extent of project-level BIM implementation. However, this study does not find support for a significant influence of normative pressures. The results further indicate that client/owner support plays a crucial but varied mediating role in the influences of these different isomorphic pressures. Overall, the results provide evidence that external isomorphic pressures as a whole can significantly drive BIM implementation activities in construction projects, suggesting that project BIM implementation should be regarded as a complexly socialised activity that is closely associated with external institutional environments. The research findings in this chapter also shed light on how different types of institutional influences could be better exercised to facilitate the diffusion of BIM in the construction industry.

CHAPTER 6 MOTIVATIONS FOR BIM IMPLEMENTATION UNDER THE IMPACTS OF INSTITUTIONAL PRESSURES

6.1 Introduction

Drawing on institutional theory, chapter 5 has empirically investigated how three types of institutional isomorphic pressures exert influences on BIM implementation activities in construction projects. Although having provided valuable insights into the association between BIM implementation activities and external institutional environments, the empirical research in Chapter 5 has primarily focused on identifying the impacts of different institutional pressures, but not comprehensively explained the fine-grained mechanisms behind project participants' complex responses to external institutional environments. As the internal preceding factors for organisational activities, organisational motivations directly determine not only the direction but also the intensity of organisational activities (Locke and Latham, 2004). A further examination of the motivations of project participants to implement BIM in construction projects, therefore, will help to reveal the underlying logic of BIM implementation and thus to deepen the understanding of the relationship between BIM implementation activities and external institutional environments.

As illustrated in Chapter 2, prior research on other innovations in the construction industry has already empirically probed the question of why construction organisations adopt and implement innovations, but related research findings regarding the motivations or reasons for adopting and implementing innovations have been relatively discordant. While some studies (e.g., Toole, 1998) reveal that innovation implementation decisions are often accompanied by gathering information from external entities such as trade partners and industry professionals, a stream of other research (e.g., Kale and Arditi, 2005; Esmaeili and Hallowell, 2012) suggests that innovation implementations are primarily driven by imitative motivations but less influenced by external requirements or suggestions, and still another (e.g., Nikas et al., 2007) controversially indicates that innovation usage has no significant association with environmental factors including the practices of peer organisations, but is proactively driven by internal economic motivations such as seeking communication improvement and achieving cost reduction. Such discordance in the research results, together with the complexity of the BIM implementation process which may be caused by the unique characteristics of BIM as a relatively complex and influential innovation, will increase the difficulty in generalising extant research findings on other construction innovations to develop a theoretically rigorous understanding of BIM implementation motivations.

Grounded in institutional theory and the innovation diffusion literature, this chapter aims to identify and categorise the motivations of designers and general contractors to implement BIM in construction projects, and investigate how different motivations are impacted by organisational BIM capability as well as other related contextual factors. The remainder of this chapter is organised as follows. The next section describes the theoretical model of BIM implementation motivations, and develops the research hypotheses on the relationships between organisational BIM capability and BIM implementation motivations. Section 6.3 outlines the data and measurements used to test the theoretical model and research hypotheses. This is followed by the presentation of the data analyses and results in Section 6.4. Section 6.5 discusses the findings and Section 6.6 summarises this chapter.

6.2 Theoretical Model and Research Hypotheses

6.2.1 Theoretical Model of BIM Implementation Motivations

Through viewing organisations as socially embedded systems subject to the impacts of external isomorphic pressures, institutional theory suggests that structural and behavioural changes in organisations are primarily triggered by the motivations of seeking social legitimacy (i.e., seeking to be socially accepted) (DiMaggio and Powell, 1983; Scott, 2001). The empirical research in Chapter 5 provides evidence that external isomorphic pressures as a whole can significantly influence the extent of BIM implementation in construction projects. Therefore, it can be inferred that social motivations probably play an important role in inducing project participants to implement BIM in construction projects. As isomorphic pressures in institutional environments include both compelling pressures (such as coercive pressures) and less compelling pressures (such as mimetic and normative pressures), the social motivations of project participants to implement BIM could reflect not only their reactive needs to comply with the formal and informal requirements from the organisations upon which they are dependent (labelled as "*reactive motives*"), but also their intrinsic desires to proactively adapt to the industry expectations and technology development trends and thus to portray a good image of technological sophistication (labeled as "*image motives*"). Due to their relatively disadvantaged positions in project principal-agent relationships, designers and general contractors' reactive motives could be induced not only by the coercive pressures from regulatory agencies outside the project, but also by the compelling influences from other project participants (such as clients/owners) strongly advocating BIM use.

While having provided important theoretical perspectives to explain the relationship between organisational activities and institutional environments, institutional theory has also been criticised for overemphasising the social logic underlying organisational activities but largely ignoring the role of economic or efficiency considerations (Martinez and Dacin, 1999; Roberts and Greenwood, 1997). As an attempt at applying institutional theory to explain the innovation diffusion process, the classic institutional diffusion model also separates social and economic motivations underlying innovation implementation activities, and claims that the two types of motivations substitute for each other rather than working in a parallel logic (Tolbert and Zucker, 1983; Westphal et al., 1997). Although such a claim has a relatively long-standing tradition, it has recently drawn critical attention. Lounsbury (2007), for example, contends that segregating economic and social logics underlying innovation diffusion process is problematic, since economic mechanisms such as performance and efficiency are "institutionally embedded" rather than "decoupled from broader institutional beliefs" (p.302). Kennedy and Fiss (2009) similarly contend that economic and social motivations may coexist with rather than substitute for each other, and suggest that "the desire to appear legitimate should only conflict with a desire to improve performance when performance improvements themselves are illegitimate" (p.899).

As a fundamentally new way of creating, sharing, and utilising project life-cycle data (Eastman et al., 2011), BIM has been institutionally advocated because it has great potential to streamline project life-cycle processes and address performance problems in the construction industry. As such, the motivations to appear socially legitimate through implementing BIM do not logically conflict with the motivations to realise economic performance improvement, and they may even reinforce each other. As a consequence, although the variety of BIM implementation barriers will increase the difficulties of gaining economic benefits from BIM and cause project participants to be more easily motivated by social reasons, the institutionalised BIM implementation process under the impacts of isomorphic pressures will probably be not completely isolated from the motivations to seek economic performance improvement. As for project-based organisations like design and construction enterprises, the improvement of economic performances is impacted not only by how they utilise technologies to enhance design and construction performances in a certain project in the short term, but also by whether they could establish cross-project learning and capability building mechanisms to utilise current project activities to enhance the performances of future projects in the long term (Brady and Davies, 2004; Gann and Salter, 2000). When organisations move into a new technology or market base, cross-project learning and capability building will become more important to the improvement of long-term economic performances

(Cao and Wang, 2014; Ruuska and Brady, 2011). As for innovative and complex technologies like BIM, therefore, the efficiency-related economic motivations (Kennedy and Fiss 2009, p.904) of designers and general contractors to implement technologies in a project should not only include the motives to improve short-term design and construction performances in the current project (labelled as "*project-based economic motives*"), but also involve the desires of conducting cross-project learning and capability building to gain long-term economic benefits in future projects (labelled as "*cross-project economic motives*").

Based on the above discussions, the motivations of designers and general contractors to implement BIM in construction projects are classified into four broad categories as shown in Figure 6.1: image motives, reactive motives, project-based economic motives, and cross-project economic motives.

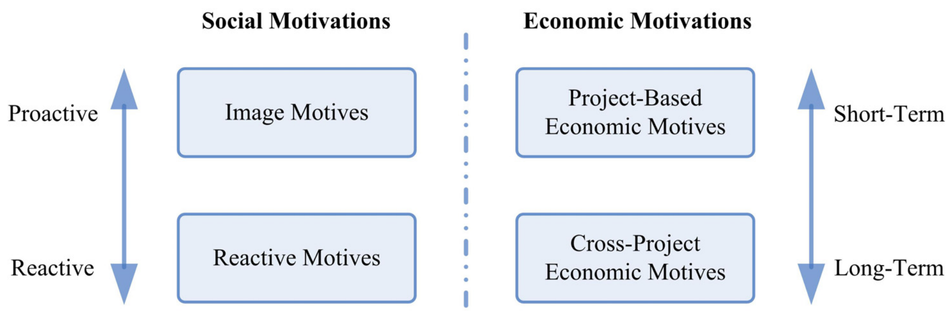

Figure 6.1 Motivations for BIM implementation in construction projects

6.2.2 Research Hypotheses on Relationships between Organisational BIM Capability and BIM Implementation Motivations

Due to the project-based nature of design and construction organisations, the motivations of designers and general contractors to implement BIM in construction projects may be impacted by both organisational and project characteristics. As an organisational contextual factor directly hinging on BIM implementation processes, BIM capability of designers and general contractors may be closely related to their motivations for implementing BIM in construction projects.

Impression management literature suggests that there are two primary tactics for an organisation to manage social image: protecting the organisation's established social image from degradation, and improving the organisation's social image based on emerging opportunities (Rosenfeld et al., 1995). As such, as long as the implementation of BIM in a certain project is in accordance with external institutional expectations on the project, participating organisations with different levels of BIM capability may both have motivations to regard the implementation of BIM in the project as an image management tactic. As for participating organisations with high BIM capability, they may need to conduct BIM implementation to exhibit their BIM capability, and thus to avoid their established image for embracing advanced technologies being contaminated. As for participating organisations with low BIM capability, they may need to conduct BIM implementation to improve or re-establish their social image for utilising the advanced BIM technology, and to narrow the image gap for technology implementation between themselves and their counterparts. Therefore, organisational BIM capability may have no significant impact on the image motives of project participants to implement BIM in construction projects. With regard to reactive motives underlying technology implementation, project participating organisations with such types of motivation are probably those coerced or unprepared users, as categorised by Iacovou et al.

(1995), which are unaware of the potential benefits of BIM or unable to realise such benefits in the current project. Therefore, project participants possessing more obvious reactive motives would be more likely to be those organisations without necessary experience or expertise on BIM technology. These considerations lead to the following set of hypotheses regarding the relationships between organisational BIM capability and the two types of social motivations:

H6-1. Project participants' BIM capability is not associated with their image motives for implementing BIM in a construction project.

H6-2. Project participants' BIM capability is negatively associated with their reactive motives for implementing BIM in a construction project.

According to the classification of construction innovations by Slaughter (1998, 2000), BIM is a typical systemic innovation (Harty, 2005). The effective implementation of this type of innovation generally requires an obvious change of traditional project processes and, therefore, also places new requirements on the technical capability of related project participants. It has recently been reported in several developed countries that lack of BIM expertise has become a prominent factor inhibiting project participants from effectively gaining economic benefits from project BIM implementation activities (Eadie et al., 2013; Mäki and Kerosuo, 2015). In a developing country like China where the advancement of BIM is still in a relatively infant stage, the inhibiting effect of expertise insufficiency should be more obvious. As a consequence, as for project participants with higher BIM capability, they would be more capable of leveraging BIM to improve short-term design and construction performances and, therefore, have stronger project-based economic motivations while implementing BIM in a construction project. As for project participants with lower BIM capability, however, it would be more difficult for them to realise the short-term economic benefits of BIM in the current BIM-based construction project. As a result, they may put more emphasis on cross-project learning and capability building to better gain BIM benefits in future projects. This leads to the following set of hypotheses regarding the relationships between organisational BIM capability and the two types of economic motivations:

H6-3. Project participants' BIM capability is positively associated with their project-based economic motives for implementing BIM in a construction project.

H6-4. Project participants' BIM capability is negatively associated with their cross-project economic motives for implementing BIM in a construction project.

6.3 Measurements and Data

6.3.1 Measurement Development

In order to empirically test the theoretical model and research hypotheses proposed in Section 6.2, a questionnaire survey was used as the method to collect data from participating organisations in BIM-based construction projects. The measurement items in the survey questionnaire were initially developed based on information gleaned from related literature as well as a semi-structured interview with four industry professionals conducted in September 2014. The four interviewed industry professionals included a project design director in an engineering and construction company in Shanghai, a vice general manager of a large construction consulting corporation in Shanghai, a project chief engineer in a construction group corporation in Shanghai, and a BIM technology director in a general contractor in Jiangsu. After the measurement items were initially developed, a pre-test involving 21 respondents from designers and general contractors was conducted via a Chinese online survey system (www.sojump.com) to identify ambiguous expressions and preliminarily test the validity of related constructs. Based on the feedback from these respondents, the expressions of some measurement items in the questionnaire were further revised. For example, the expression “economic benefits” in the motivation item “expecting that the economic benefits of BIM use will outweigh its costs in the project” was adjusted to “direct economic benefits”.

The revised questionnaire associated with the analysis in this chapter was structured into two parts (see Appendix B). The first part obtains general information such as project size and project type of the surveyed project, as well as ownership type of the surveyed project participating organisation in which the respondent was employed. The second part focuses on evaluating motivations of the surveyed project participating organisation (i.e., the designer or general contractor in which the respondent was employed) to implement BIM in the surveyed project, and BIM capability of the surveyed participating organisation at the time of implementing BIM in the surveyed project. Apart from related project and organisational characteristic variables such as project size and organisational ownership type, a total of five core variables have been measured in the questionnaire: image motives (IMM), reactive motives (REM), project-based economic motives (PEM), cross-project economic motives (CEM) and BIM capability (BCA). These five variables were all operationalised as reflective constructs, and their detailed measurement items are shown in Table 6.1.

Table 6.1 Measurement items for BIM implementation motivations and BIM capability

Construct	Code	Items	Mean	SD
Image motives (IMM)	IMM1	To maintain a good image for using advanced technologies	5.75	1.19
	IMM2	Not to lag behind industry counterparts in using BIM	5.88	1.17
Reactive motives (REM)	REM1	Needing to comply with BIM use requirements from governments or other project participants	4.19	1.55
	REM2	Having to promise to use BIM to improve our competitiveness in project bidding	4.79	1.50
	REM3	Having to participate in using BIM as many other participants are using BIM in the project	4.12	1.55
Project-based economic motives (PEM)	PEM1	Using BIM as a tool to solve related design and construction problems in the project	5.66	1.03
	PEM2	Using BIM as a tool to improve cost and schedule performances in the project	5.48	1.19
	PEM3	Expecting that the direct economic benefits of BIM use will outweigh its costs in the project	5.45	1.24
Cross-project economic motives (CEM)	CEM1	To become more familiar with BIM implementation process through using BIM in the current project	5.72	0.89
	CEM2	To foster BIM expertise of our team members through using BIM in the current project	5.73	0.99
	CEM3	To better guide the implementation of BIM in future projects through using BIM in the current project	5.87	0.93
BIM capability (BCA)	BCA1	Our team is/was experienced in implementing BIM	4.03	1.59
	BCA2	Our team is/was capable to solve the possible technical problems in BIM implementation	4.14	1.44
	BCA3	Our team has/had the knowledge necessary for implementing BIM in such types of projects	4.31	1.44

The two measurement items of IMM were adapted from Arevalo et al. (2013) and reworded to suit the context of BIM implementation in construction projects. The operationalisation of REM was partly based on Gavronski et al.'s (2008) work on the construct of "reactive motivations" in the context of ISO 14001 certification.

According to the information gleaned from the interviews and the pre-test, a total of three items were ultimately adopted to measure REM, namely needing to comply with BIM use requirements from governments or other project participants, having to promise to use BIM to improve competitiveness in project bidding, and having to participate in using BIM as many other participants are using BIM in the project. The development of the measurement items of PEM was based on Grewal et al.'s (2001) similar study on the organisational use of other types of information technology, but the detailed measurement items were largely modified to fit the context of BIM implementation in construction projects. A total of three items were ultimately used to reflect PEM for BIM implementation from different aspects including solving process problems, improving project performances and gaining instant positive ROI. The operationalisation of CEM was largely based on the information gleaned from the interviews with four industry professionals. The measurement items ultimately adopted include learning the BIM implementation process, fostering team members' BIM expertise and guiding the implementation of BIM in future projects. Similar to the measurement of organisational motivations by other studies such as Brønn and Vidaver-Cohen (2009), Evangelos et al. (2011) and Grewal et al. (2001), the items of the four motivation constructs were all rated by asking respondents to evaluate each motivation item as the reason for project BIM implementation on a seven-point Likert scale ranging from "1" (strongly disagree) to "7" (strongly agree). The items of BCA were adapted from the measures of "IT capability" developed by Grewal et al. (2001), and reworded to suite the context of

BIM implementation in construction projects. These items were also rated on a seven-point Likert scale anchored with “strongly disagree” to “strongly agree”.

In order to isolate the variation in the four motivation constructs (i.e., IMM, REM, PEM, CEM) caused by organisational and project context, four control variables were included in the hierarchical OLS regression analyses on the relationship between BIM capability and BIM implementation motivations. As the first control variable, organisational ownership type was operationalised as a dummy variable reflecting whether the surveyed project participating organisation was state-owned or not (0 = yes; 1 = no). With regard to other control variables, project size was measured by investment value of the surveyed project (1 = Below ¥50 million; 2 = Between ¥50 and ¥200 million; 3 = Between ¥200 and ¥1000 million; 4 = Above ¥1000 million), project type was measured as a dummy variable indicating whether the surveyed project is residential type or not (0 = residential; 1 = non-residential), and project nature was also operationalised as a dummy variable distinguishing public projects and private projects (0 = public; 1 = private).

6.3.2 Sampling and Data Collection

Only those well-informed senior and professional individuals directly involved in project BIM implementation activities on the Chinese mainland were considered as targeted respondents for the survey. As indicated in Section 4.2, the use of BIM has been relatively rare in China and, therefore, a completely random sampling method could not be used to elicit BIM-based projects and related project respondents from a specific project database. Instead, respondents for diversified kinds of BIM-based construction projects in different regions were identified through a mix of methods, including searching through related industry publications, interviewing pioneering corporations in BIM utilisation, requesting information from industry associations, and contacting professionals participating in four BIM industry seminars held by Tongji University between 2009 and 2014.

After being contacted through personal visits or network-based communications, respondents were asked to answer the survey questions based on their most recent BIM-based project which had already been accomplished or had already entered into the post-design construction stage. All of the questions on BIM implementation motivations and BIM capability were designed to collect information from the specific project participating organisation employing the respondent in the selected project. It was expected that asking the respondents to select their most recently involved project would not only enable them to have a clearer recollection of the project BIM implementation process, but also help to reduce the possible response bias as many respondents might otherwise tend to select their most successful BIM-based project. As an attempt to mitigate the impact of confidentiality issues on the response rate, the respondents were not asked to report the name of the selected project as they were in the survey on practice characteristics of BIM implementation. In order to minimise the possible overlap between the surveyed projects and thus improve the representativeness of the sample, it was attempted to distribute the questionnaire to diversified respondents which come from different organisations and participate in different projects in different regions on the Chinese mainland.

Responses were collected from project designers and general contractors by means of personal visits and an online survey system from April to May 2015. Through the method of personal visits, about 75 respondents were contacted and 59 responses were collected; about 620 other respondents were invited through network-based channels such as emails and WeChat platform to participate in the online survey (www.sojump.com), and a total of 179 responses were collected. After the further omission of responses with incomplete information, a total of 188 valid responses were ultimately included in the analysis. Among the 188 valid responses, 81 were from project designers and 107 were from general contractors. Demographic characteristics of the surveyed projects and related participating organisations corresponding to the responses are shown in Table 6.2.

Table 6.2 Demographic information of samples for analysis of BIM implementation motivations

Project demographics				Organisational demographics			
Variable	Category	N	%	Variable	Category	N	%
Project size	Below ¥50 million	42	22.34	Location[a]	North China	20	10.64
	¥50-200 million	59	31.38		Northeast China	5	2.66
	¥200-1000 million	61	32.45		East China	106	56.38
	Above ¥1000 million	26	13.83		South Central China	33	17.55
Project type	Residential	40	21.28		Southwest China	11	5.85
	Commercial	72	38.30		Northwest China	13	6.91
	Cultural	10	5.32	Participating type	Designer	81	43.09
	Sporting	5	2.66		General contractor	107	56.91
	Hospital	11	5.85	Ownership type	State-owned	90	47.87
	Transportation	16	8.51		Privately-owned	93	49.47
	Industrial	16	8.51		Foreign-owned	5	2.66
	Others	18	9.57				
Project nature	Public	106	56.38				
	Private	82	43.62				

[a] Location of the respondent at the time of the survey, it might be different from the location of the project participating organisation in which the respondent was employed.

Among the 188 valid responses, 56 (29.79%) were collected through personal visits and 132 (70.21%) were collected by the online survey system. A series of χ^2 tests were conducted to compare the responses collected through the two different methods, and no statistically significant association between data collection method and sample characteristics was found (p-values for the analyses on organisational ownership type, project size, project type and project nature are 0.889, 0.798, 0.556 and 0.271 respectively). Most respondents are senior and professional individuals with knowledge of the BIM implementation processes of their organisations in the surveyed projects, with 18.62% being project managers or chief project engineers, 14.89% BIM managers, 40.43% BIM engineers, and the remaining 26.06% being other types of engineers also directly involved in the use of BIM. In order to formally examine whether the responses were impacted by the positions of the respondents, the full sample was split into two groups: the group of BIM managers/BIM engineers (N = 104), and the group of project managers/non-BIM engineers (N = 84). A series of independent sample t-tests were then conducted to examine the differences in the values of the 14 measurement items listed in Table 6.1 between the groups, and no statistically significant difference was found for any measurement item (the p-values range from 0.067 to 0.898).

The use of single-source and self-reported data for the study may raise concerns about the problems of common method bias in the answers (Podsakoff et al., 2003). As such, Harman's one-factor test was conducted on the five primary variables including IMM, REM, PEM, CEM and BCA (Podsakoff and Organ 1986). The test showed that no single dominant factor emerged and the largest factor only accounted for 28.76 percent of the total variances in the measurements, suggesting that common method bias is unlikely to be a substantial contaminant of the results.

6.4 Data Analyses and Results

Using the collected survey data, three steps of data analyses were conducted to test the theoretical model and research hypotheses proposed in Section 6.2: assessment of the measurement model, descriptive and comparative analyses on BIM implementation motivations, and hierarchical regression analyses on the impacts of BIM capability and other contextual factors on BIM implementation motivations.

6.4.1 Measurement Model Assessment

The measurement items of some motivation constructs in this chapter were newly developed to suit the context of BIM implementation in construction projects. Following the process deployed by Fullerton et al. (2014) and Handley and Benton (2012) to assess measurement models with newly developed scales, both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were used to examine the reliability and validity of the measures deployed in this chapter. While EFA was used to preliminarily assess the item-construct relationships for newly developed measures and to refine the scale measures, CFA was used to further verify the results of EFA and systemically validate the measurement model. EFA was conducted in the SPSS Statistics programme 21.0 and CFA was conducted in Amos 20.0.

An EFA was first conducted to assess the underlying structure for the 11 motivation items listed in Table 6.1. The detailed analysis method was principal component analysis with varimax rotation. As expected, the analysis resulted in the extraction of four different factors reflecting the constructs of image motives, reactive motives, project-based economic motives, and cross-project economic motives. As shown in Table 6.3, the rotated loadings of the manifest items on their intended constructs are all above the recommended threshold of 0.4 (Nunnally, 1978) and larger than the loadings on other constructs. These results preliminarily validated the appropriateness of using the 11 listed motivation items to reflect the four proposed motivation constructs. As a result, no motivation item was removed from the measurement model according to the results of EFA.

Table 6.3 Results of EFA of BIM implementation motivations

Measurement items	Factor loadings			
	Factor 1	Factor 2	Factor 3	Factor 4
IMM1	0.203	0.137	0.021	**0.901**
IMM2	0.195	0.159	0.131	**0.886**
REM1	0.066	-0.109	**0.733**	0.151
REM2	0.022	0.030	**0.859**	0.073
REM3	-0.096	-0.020	**0.831**	-0.078
PEM1	0.232	**0.851**	-0.057	0.099
PEM2	0.150	**0.892**	-0.031	0.123
PEM3	0.119	**0.851**	-0.026	0.110
CEM1	**0.885**	0.187	-0.040	0.138
CEM2	**0.868**	0.170	0.030	0.239
CEM3	**0.898**	0.161	0.006	0.108
Eigenvalue	2.525	2.392	1.990	1.755
Variance explained (%)	22.96	21.74	18.09	15.95
Variance cumulatively explained (%)	22.96	44.70	62.79	78.75

Note: Bold values represent the factor loadings of each measurement item on its intended construct.

CFA techniques based on the maximum likelihood (ML) approach were subsequently used to further verify the reliability and validity of the measurement model. Results suggested that the measurement model with all the five multi-item constructs (i.e., IMM, REM, PEM, CEM and BCA) had acceptable fit level as judged by goodness-of-fit indicators (χ^2/df = 1.325, NFI = 0.941, IFI = 0.985, CFI = 0.985, RMSEA = 0.042). As shown in Table 6.4, the composite reliability values of the examined multi-item constructs all exceed the recommended criterion of 0.70 (Fornell and Larcker, 1981). Convergent validity measures the extent to which the items underlying a particular construct actually refer to the same conceptual variable. The first evidence of convergent validity is provided by the indicator of AVE. As shown in Table 6.4, each AVE is above the threshold of 0.5, indicating that at least 50 percent of the variance in the items can be accounted for by their respective construct. Further evidence of convergent validity is obtained by estimating the factor loadings of the measurement items. As shown in Table 6.5, the standardised factor loadings of the items on their respective constructs are all, with the sole exception of REM1, above the threshold of 0.7 (Fornell and Larcker, 1981) and are significant. Although the loading of REM1 on REM (0.571) is lower than 0.7, it is still above the criterion of 0.5 recommended by Hair et al. (2010).[❶] Overall, the measurement model could be considered as having acceptable convergent validity. Also, it is shown that the square roots of the AVE (values on the diagonal of the correlation matrix in Table 6.4) are all greater than the absolute value of inter-construct correlations (off-diagonal values), suggesting that the constructs possess satisfactory discriminant validity (Fornell and Larcker, 1981).

❶ While using ML-based CFA techniques to assess measurement validity, many scholars (such as Fullerton et al. (2014), Handley and Benton (2012), Wagner and Bode (2014)) have also adopted criteria much lower than 0.7 (such as 0.4) to judge the acceptability of factor loadings.

Table 6.4 Measurement validity for constructs in analysis of BIM implementation motivations

Construct	Mean	SD	CR	AVE	Correlation matrix[a]				
					IMM	REM	PBM	CBM	BCA
Image motives (IMM)	5.81	1.10	0.85	0.74	**0.86**				
Reactive motives (REM)	4.37	1.24	0.75	0.50	0.13	**0.71**			
Project-based economic motives (PEM)	5.53	1.03	0.87	0.69	0.31	-0.07	**0.83**		
Cross-project economic motives (CEM)	5.77	0.86	0.90	0.76	0.41	0.00	0.38	**0.87**	
BIM capability (BCA)	4.16	1.40	0.94	0.83	0.09	0.05	0.29	-0.09	**0.91**

Note: SD = standard deviation; CR = composite reliability; AVE = average variance extracted.
[a] Bold values on the diagonal represent the square root of AVE.

Table 6.5 Results of CFA of constructs in analysis of BIM implementation motivations

Construct	Measurement items	Factor loadings					T-value
		IMM	REM	PBM	CBM	BCA	
Image motives (IMM)	IMM1	0.866					NA[a]
	IMM2	0.855					7.794
Reactive motives (REM)	REM1		*0.571*				NA[a]
	REM2		0.826				6.091
	REM3		0.707				6.454
Project-based economic motives (PEM)	PEM1			0.840			NA[a]
	PEM2			0.888			13.257
	PEM3			0.757			11.419
Cross-project economic motives (CEM)	CEM1				0.871		NA[a]
	CEM2				0.885		15.481
	CEM3				0.855		14.806
BIM capability (BCA)	BCA1					0.885	NA[a]
	BCA2					0.934	19.336
	BCA3					0.917	18.739

Note: Overall fit indices: χ^2/df = 1.325, NFI = 0.941, IFI = 0.985, CFI = 0.985, RMSEA = 0.042.
[a] Indicates a parameter that was fixed at 1.0.

6.4.2 Descriptive and Comparative Analyses

The measurement assessment results in Subsection 6.4.1 have empirically validated the appropriateness of differentiating the four categories of BIM implementation motivations. Further descriptive analysis on the four motivation constructs reveals that image motives and cross-project economic motives have the highest mean values (as shown in Table 6.6), suggesting that these two categories of motivations are currently the strongest reasons for designers and general contractors to implement BIM in construction projects. The mean value of project-based economic motives is also at a relatively high level, suggesting that seeking instant economic benefits in the focal project is also an important motivation for project participants to involve in project-level BIM implementation activities. Although ranked at the bottom of the list, the mean value of reactive motives is still significantly larger than the neutral value of 4 for a seven-point Likert scale ($T = 4.054$, $p < 0.001$). Together with the relatively large standard deviation of the construct compared with those of other motivation constructs, this result indicates that reactively responding to formal or informal requirements from other organisations is also an important reason for some designers and general contractors to involve in project-level BIM implementation activities, thus partly corroborating the findings on the impact of coercive pressures in Chapter 5.

Table 6.6 Results of descriptive and comparative analyses on BIM implementation motivations and BIM capability

Construct	Full sample		Designers		General contractors		Independent sample T-test		
	Mean	SD	Mean	SD	Mean	SD	Difference	T-value	p-value
IMM	5.81	1.10	5.76	1.09	5.86	1.11	-0.10	-0.593	0.554
REM	4.37	1.24	4.54	1.27	4.24	1.21	0.30	1.616	0.108
PEM	5.53	1.03	5.47	1.03	5.58	1.03	-0.11	-0.756	0.451
CEM	5.77	0.86	5.76	0.88	5.78	0.85	-0.02	-0.160	0.873
BCA	4.16	1.40	4.23	1.35	4.11	1.44	0.13	0.612	0.541

Note: IMM = image motives, REM = reactive motives, PEM = project-based economic motives, CEM = cross-project economic motives, BCA = BIM capability; SD = standard deviation.

It is also shown in Table 6.6 that compared with general contractors, designers generally possess more obvious reactive motives but slightly weaker image motives and project-based economic motives underlying their BIM implementation activities in the surveyed construction projects. Independent sample T-tests, however, reveal that none of these differences is statistically significant at the 5% level (p-values range from 0.108 to 0.873). An independent sample T-test for the variable of BIM capability further reveals that BIM capabilities of the surveyed designers and general contractors are not significantly different either, indicating that the non-significant difference in BIM implementation motivations between designers and general contractors is probably not caused by the imbalanced sampling on project participating organisations with non-equivalent BIM capabilities.

With respect to the relationships among different categories of BIM implementation motivations, the Pearson correlation matrix in Table 6.4 illustrates that the correlation coefficients between reactive motives and three other motivation variables are all relatively low and not statistically significant at the 5% level. Distinctly different from their relationships with reactive motives, however, the three other categories of BIM implementation motivations are all highly significantly correlated with each other (p-values are all below 0.001), with the correlation coefficient between image motives and cross-project economic motives reaching a relatively high level of 0.41. These results provide empirical evidence that project participants' social motivations to improve organisational image and their economic motivations to gain technical benefits could coexist rather than necessarily precluding each other during project-level BIM implementation processes. Together with the relatively high mean values of the motivation variables shown in Table 6.6, the results collectively suggest that project participants' motivations to implement BIM under the impacts of institutional isomorphic pressures are relatively complex and multi-dimensional, and that the BIM implementation process is often characterised with the coexistence of social image motives and economic motives (especially long-term economic motives), as well as the coexistence of project-based economic motives and cross-project economic motives.

6.4.3 Hierarchical Regressions

A hierarchical OLS regression approach was used to test the hypotheses on the relationships between BIM implementation motivations and BIM capability. A total of four separate hierarchical regressions were performed, which employed the four categories of BIM implementation motivations (i.e., IMM, REM, PEM, CEM) as their dependent variables respectively. For each of these regressions, the blocks of independent variables were entered individually, starting with control variables (including organisational ownership type, project size, project type and project nature), and then the predicting variable BIM capability. Such a hierarchical regression process enables the incremental effects of BIM capability to be better examined by controlling for the effects of organisational and project characteristics. Since the independent sample T-test results in Subsection 6.4.2 reveal that there is no significant difference in BIM implementation motivations and BIM capability between the surveyed designers and general contractors, all of the hierarchical regressions were performed using the full sample data from both designers and general contractors.❶ Variance inflation factors (VIFs) for the regression models are all within the desired low range from 1.07 to 1.19, suggesting that multicollinearity is not substantively influencing the regression estimates (Cohen et al., 2003). Ordinary least squares (OLS) regression results of the hierarchical regression models are presented in Table 6.7.

Table 6.7 Results of OLS regression models predicting motivations for BIM implementation

Variables	IMM		REM		PEM		CEM	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Ownership type	-0.230**	-0.242**	0.030	0.022	0.039	0.001	-0.256***	-0.246**
Project size	0.120	0.104	-0.055	-0.066	0.103	0.048	0.002	0.016
Project type	0.104	0.094	0.077	0.070	0.201**	0.168*	-0.080	-0.071
Project nature	0.032	0.038	0.000	0.005	-0.170*	-0.148*	0.025	0.019
BIM capability		0.068		0.046		0.228**		-0.058
R^2	0.098	0.102	0.009	0.010	0.099	0.145	0.068	0.071
F-value	4.985***	4.153***	0.395	0.385	5.044***	6.195***	3.318*	2.767**
ΔR^2		0.004		0.002		0.046		0.003
F-value (change)		0.842		0.352		9.826**		0.594

Note: IMM = image motives, REM = reactive motives, PEM = project-based economic motives, CEM = cross-project economic motives; Standardised regression coefficients (β) are reported; *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

While BIM capability is not included in the regression models, as shown in Table 6.7 (Model 1, Model 3, Model 5, Model 7), the four control variables in total could explain 9.8%, 9.9%, 6.8% of the variances in IMM, PEM and CEM respectively, but could only explain 0.9% of the variance in REM. With respect to the separate effects of the control variables, organisational ownership type is revealed to have significant negative relationships both with IMM (β = - 0.230, p < 0.01) and with CEM (β = -

❶ Equivalent hierarchical regressions were also performed using the sub-sample data from designers (N = 81) and from general contractors (N = 107) separately; the results are essentially identical with those based on the full sample data.

0.256, $p < 0.001$). This result provides clear evidence that compared with project participating organisations (i.e., designers and general contractors) from privately-owned and foreign-owned corporations, state-owned project participating organisations generally have more obvious image motives and cross-project economic motives for undertaking project-level BIM implementation activities. Project type ($\beta = 0.201$, $p < 0.01$) and project nature ($\beta = -0.170$, $p < 0.05$) are further illustrated to be positively and negatively associated with PEM, suggesting that designers and general contractors generally have more obvious motivations to gain instant economic benefits from BIM implementation activities in non-residential and public projects.

After BIM capability is added as an independent variable (Model 2, Model 4, Model 6, Model 8), the variance in PEM explained by the regression model significantly increases from 0.099 to 0.145 ($F = 9.826$), but the increases of the explained variances in three other motivation variables (i.e., IMM, REM, CEM) are all non-significant at the 5% level (F-values range from 0.352 to 0.842). The regression coefficients in Table 6.7 similarly reveal that only the relationship between BIM capability and PEM is statistically significant ($\beta = 0.228$, $p < 0.01$), and that the relationships between BIM capability and three other motivation variables are all non-significant at the 5% level. A noteworthy observation is that BIM capability is positively rather than negatively associated with REM ($\beta = 0.046$, $p > 0.05$), suggesting that the relationship between the two variables might be more intricate than a priori hypothesised. To sum up, with respect to the hypotheses on the relationships between BIM capability and BIM implementation motivations, H6-1 and H6-3 are supported while H6-2 and H6-4 are not.

6.5 Discussions of Findings

6.5.1 Categories of BIM Implementation Motivations

Through the categorisation of BIM implementation motivations as well as the characterisation of relationships among different motivation categories, the findings in this chapter could help to further reveal the underlying logic for BIM implementation and thus to deepen the understanding of the relationship between BIM implementation activities and external institutional environments. Drawing on institutional theory, chapter 5 has empirically investigated how three types of institutional pressures exert influences on BIM implementation activities in construction projects, and the results suggest that project BIM implementation activities are closely associated with external institutional environments and may be driven by social motivations. This chapter further illustrates that the motivations of project participants to implement BIM are relatively complex and multi-dimensional, and that the implementation process could be characterised not only with the coexistence of social image motives and economic motives, but also with the confluence of project-based economic motives and cross-project economic motives. These results suggest that for influential and complex innovations like BIM, innovation implementation activities are not simply or invariably reflected as passive conformity to external institutional pressures without economic rationality, instead, organisational responses to external institutional environment, which are characterised with the desires of not only seeking social legitimacy but also maintaining economic efficiency, could be relatively strategic.

Although some organisational theorists (e.g., Oliver, 1991; Pfeffer, 1982) have already underlined the strategic responses of organisations to external environments, the literature using institutional theory to explain innovation implementation activities has a long tradition of decoupling economic efficiency mechanisms from institutionalisation processes, contending that motivations to seek social recognitions in institutional environments and motivations to gain economic benefits generally substitute for each other rather than working in a parallel logic (Tolbert and Zucker, 1983; Westphal et al., 1997). However, the empirical study in this chapter provides evidence that although socially reactive motivations seldom coexist with efficiency-related economic motivations, social motivations of image improvement do not necessarily preclude economic motivations in all situations. Together with recent findings of Kennedy and Fiss (2009) and Lounsbury (2007) in other industries, this result could help to prompt rethinking of the conventional wisdom on the relationships between social and economic motivations in institutionalisation processes. As extant research on other innovations in the construction industry has presented relatively discordant findings on the motivations or reasons for innovation adoption and implementation (e.g., Esmaeili and Hallowell, 2012; Kale and Arditi, 2005; Nikas et al., 2007), the findings of this chapter on the coexistence of different innovation implementation motivations could also help to partly reconcile the discordant findings in the extant construction innovation literature and to enrich our understanding of the complex innovation diffusion process in the construction industry.

6.5.2 Impacts of BIM Capability on BIM Implementation Motivations

In order to provide a more dynamic picture of how BIM implementation motivations may vary as project and organisational contexts change, this chapter has further investigated the impacts of BIM capability and other contextual factors on the four categories of BIM implementation motivations. The results from hierarchical regression analyses support the hypotheses on the positive association between project-based economic motives and BIM capability, and on the non-significant association between image motives and BIM capability. These results suggest that although project participating organisations (i.e., designers and general contractors) will have stronger economic motivations to improve short-term project performances as their BIM capability matures, such an increase in economic motivations does not necessarily require a parallel decrease of desires to improve social image. As such, these results could provide further evidence that social motivations and economic motivations could coexist rather than necessarily precluding each other during institutionalisation processes.

With regard to reactive motives and cross-project economic motives, however, their hypothesised relationships with organisational BIM capability both fail to be supported by the hierarchical regression results. A noteworthy result is that reactive motives are found to have a slightly positive association with BIM capability, which is surprisingly different from the a priori hypothesised negative association between the two variables. Such an unexpected result could be attributed to two aspects of reasons. First, as shown in Table 6.6, the mean values of image motives and cross-project economic motives are much higher than that of reactive motives. Such a distinct difference suggest that for many designers and general contractors with relatively low BIM capability, their BIM implementation activities could primarily stem from image motives or cross-project economic motives rather than necessarily deriving from reactive motives at present. Therefore, it is illustrated that low BIM capability of the surveyed project participating organisations is not necessarily connected with high reactive motives. Second, in those construction projects where designers and general contractors implement BIM primarily out of reactive motives, the compelling pressures on BIM implementation may be often reflected as or accompanied by the tendency of project clients/owners to select organisations with high BIM capability as design and construction service providers. As a result, although high reactive motives of designers and general contractors are probably not inherently induced by their high BIM capability, the two variables are still statistically illustrated to be positively associated with each other.

As for the negative association between cross-project economic motives and BIM capability, the non-significant result may be due to the relative immaturity of BIM development in the Chinese construction industry. At present the problem of lacking BIM expertise is still relatively pervasive in the construction industry in China, and most industry organisations still lack knowledge on how to adjust traditional design and construction processes to meet the requirements of BIM implementation according to their specific organisational and project characteristics (CCIA, 2013). Even for those organisations relatively experienced in implementing BIM, their project teams are generally composed of professional BIM technicians and traditional design and construction engineers, with many team members evidently lacking BIM expertise. Besides the above problems, BIM implementation by designers or general contractors in construction projects also frequently involves other technical and organisational barriers such as interoperability problems and non-collaboration of other project participants. As a consequence, even for those designers and general contractors with higher BIM capability than their counterparts, it might still be not easy for them to fully realise the value of BIM in the short term, and they could still have strong cross-project economic motives of learning BIM implementation process, fostering team members' BIM expertise and guiding the use of BIM in future projects.

6.5.3 Impacts of Contextual Factors on BIM Implementation Motivations

Apart from organisational BIM capability, project type and project nature are also found to have significant impacts on project-based economic motives of designers and general contractors to implement BIM in a construction project. While the result of the impact of project type is probably due to the difference in the complexities of building structure and construction process between residential and non-residential projects, the result of the impact of project nature could be partly attributed to the difference in client/owner support for BIM implementation between public and private projects. As illustrated in Chapter 4, compared with their counterparts in private projects, clients/owners in public projects generally provide more support for BIM implementation such as championing BIM implementation and driving project participants to collaboratively implement BIM. With the support from clients/owners, therefore, designers and general contractors in public projects may be more capable of overcoming related organisational and process barriers of BIM implementation and thus have stronger motivations to gain instant project benefits from BIM implementation activities.

It is also illustrated in this chapter that organisational ownership type is significantly associated with both image motives and cross-project economic motives for BIM implementation. These results could largely be explained by the differences in social responsibility and organisational size between state-owned and non-state-owned corporations in the Chinese construction industry. Compared with their privately-owned and foreign-owned counterparts, state-owned corporations in China are generally expected to assume more social responsibility by responding to public appeals and leading industry development while seeking economic benefits. Facing the long-existing criticisms on their operational inefficiency as well as the increasing industry expectations on BIM technology, therefore, state-owned designers and general contractors would have strong motivations to implement BIM in their participated projects to exhibit good social images of deploying innovative technologies and leading industry development trends. Apart from their difference in the assumed social responsibility, state-owned and non-state-owned corporations in the Chinese construction industry are also substantially different in corporation size, with the average output value of state-owned corporations (¥567.86 million) being 2.20 times higher than that of non-state-owned corporations (¥177.72 million) in 2013 (NBSC, 2014). The larger corporation size would probably cause state-owned corporations to have more slack resources and more intensive needs to establish cross-project capability building mechanisms and, therefore, have stronger cross-project economic motives for BIM implementation.

6.6 Chapter Summary

Based on the analysis of the impacts of institutional isomorphic pressures in Chapter 5, this chapter has further developed and tested a model categorising the motivations of designers and general contractors to implement BIM in construction projects, and investigated how different categories of motivations are associated with organisational BIM capability as well as other contextual factors. The results of factor analysis with project-based survey data collected from 188 designers and general contractors on the Chinese mainland provide clear support for the theoretically developed motivation model, in which organisational motivations for implementing BIM in construction projects are classified into four broad categories: *image motives*, *reactive motives*, *project-based economic motives*, and *cross-project economic motives*. Comparisons of the categorised motivations suggest that image motives and cross-project economic motives are currently the strongest reasons for designers and general contractors to implement BIM in construction projects, and that social motivations and economic motivations underlying BIM implementation do not necessarily preclude each other as conventional wisdom might indicate.

Results of hierarchical regressions support the hypotheses on the positive association between project-based economic motives and BIM capability, and on the non-significant association between image motives and BIM capability. However, hypotheses on the associations between BIM capability and the two other motivations are not supported. While illustrating no significant difference in BIM implementation motivations between designers and general contractors, hierarchical regression results further reveal that both project type and project nature are significantly associated with project-based economic motives, and that project organisations from state-owned corporations generally have stronger image motives and cross-project economic motives to implement BIM than their counterparts from other types of corporations. The findings could help to develop a more comprehensive understanding of the reasons why organisations implement BIM in construction projects, and provide a more dynamic picture of how BIM implementation motivations may vary as organisational contexts change. Through providing evidence that the motivations of project participants to implement BIM under the impacts of institutional pressures are distinctly multi-dimensional and dynamic, the findings could also help to partly reconcile the discordant findings on innovation implementation reasons in the extant construction innovation literature and to deepen the understanding of the complex relationship between innovation implementation activities and external institutional environments.

CHAPTER 7 PERFORMANCE IMPACTS OF BIM IMPLEMENTATION IN CONSTRUCTION PROJECTS

7.1 Introduction

A comprehensive understanding of organisational activities not only requires an examination of how the activities are driven by environmental factors, but also entails an exploration of how the activities further impact organisational performance. Due to the great potential but still limited use of BIM in the construction industry, there has been an increasing research effort in recent years to investigate the practical impacts of BIM implementation activities on design and construction performances. As illustrated in Chapter 2, however, most of these investigations have focused on reporting descriptive statistics of the project benefits gained from BIM implementation activities in specific project contexts (Barlish and Sullivan, 2012; Giel and Issa, 2013; Poirier et al., 2015). While these investigations have valuably illustrated the uncertainty of the performance impacts of BIM implementation, scant scholarly attention has been further devoted to characterising how the resultant project benefits of BIM implementation are influenced by related implementation characteristics and, therefore, explaining why the performance impacts of BIM implementations in different project contexts vary substantially.

Drawing on resource dependence theory (Pfeffer and Salancik, 1978), this chapter aims to develop and test a conceptual model for understanding how project BIM implementation activities impact the performances of project participants from an interorganisational collaboration perspective. Using resource dependence theory as a lens to understand BIM as a boundary spanning tool for project participants to manage interorganisational dependence, the model specifically features BIM-enabled interorganisational collaboration capabilities as mediators between the variables of BIM implementation extent and performance gains. In order to probe deeper into whether individual participating organisations benefit differently from project BIM implementation, the model is empirically tested using two separate datasets collected from designers and general contractors. The remainder of this chapter is organised as follows. The next section uses resource dependence theory as a lens to develop the theoretical model and propose the research hypotheses. Section 7.3 outlines the survey data and measurements used to test the model and hypotheses. This is followed by the presentation of the data analyses and results in Section 7.4. Section 7.5 discusses the findings and Section 7.6 summarises this chapter.

7.2 Theoretical Model and Research Hypotheses

7.2.1 Theoretical Model of Performance Impacts of BIM Implementation

According to resource dependence theory, organisations are rarely self-sufficient in terms of strategically important resources and therefore depend on other organisations for resources to ensure organisational viability (Pfeffer and Salancik, 1978). As a result, organisations need to carefully structure their relationships with external organisations to manage their interorganisational dependence and reduce the resultant uncertainty in organisational processes (Pfeffer and Salancik, 1978). For the present study, the implications of resource dependence theory not only include its accentuation of the importance of interorganisational relationships in ensuring organisational viability, but also the identification of resource dependence as the key antecedent motivating the establishment of interorganisational relationships. In temporary coalitions like construction projects which involve a variety of organisations from different disciplines collaborating to accomplish *ad hoc* and poorly structured tasks, participating organisations are particularly dependent on each other for related resources required for effective functioning (Bankvall et al., 2010). These resources include both physical ones such as equipments and non-physical ones such as information and expertise. Limited by the representation methods of project life-cycle data, however, such interdependence in construction projects is generally deemphasised by traditional project management practices, and the established interorganisational collaboration links between project participants are often ineffective to manage the interorganisational dependence and reduce the resultant uncertainty in design and construction processes (Froese, 2010).

As an innovative technology to parametrically create and visually represent project life-cycle data, BIM could not only provide greater visibility into the underlying resource exchange requirements of involved project participants (Froese, 2010), but also facilitate a more structured interorganisational collaboration process to support better exchange and co-utilisation of resources such as proprietary information and disciplinary expertise (Eastman et al., 2011; Gao and Fischer, 2008; Luth, 2011). From the perspective of resource dependence theory, therefore, BIM could be viewed as a boundary spanning tool for project participants to enhance interorganisational collaboration capabilities and manage interorganisational dependence. As resource dependence theory underlines the criticality of establishing interorganisational links for organisations to ensure resource availability and ongoing viability, this chapter focuses on examining the roles of BIM-enabled interorganisational collaboration capabilities, including BIM-enabled information sharing capability and BIM-enabled collaborative decision-making capability, in realising performance gains from BIM implementation in construction projects.

With regard to the measurement of performance gains from BIM implementation, recent investigations have attempted to use objective project data to quantitatively measure related gains such as accelerated schedule, reduced RFIs, reduced change orders, and lowered project costs (Barlish and Sullivan, 2012; Giel and Issa, 2013). While indicating that BIM implementation activities could not only advance the effectiveness of project tasks but also improve the efficiency of design and construction activities, these investigations also suggest that many of the performance gains from BIM implementation are relatively qualitative and thus difficult to measure using objective data (Barlish and Sullivan, 2012; Giel and Issa, 2013). Even for such quantitative gains as reduced change orders and reduced RFIs, the related quantification process is still quite challenging, as a large amount of information needs to be accurately recorded and extremely similar projects without BIM implementation need to be available for necessary comparisons (Azhar, 2011; Barlish and Sullivan, 2012; Giel and Issa, 2013). In order to structurally compare the performance gains from BIM implementation in different projects and draw conclusions on how they are associated with BIM implementation characteristics and BIM-enabled interorganisational collaboration capabilities, this chapter focuses on examining two perceptual constructs of performance gains: BIM-enabled task efficiency improvement, and BIM-enabled task effectiveness improvement.

On the basis of these considerations, the theoretical model examining the performance impacts of BIM implementation in construction projects is outlined in Figure 7.1. The principal relationships hypothesised in the model are those among the extent of BIM implementation, BIM-enabled interorganisational collaboration capabilities, and BIM-enabled performance gains. In order to further investigate the relationship between BIM implementation process and project non-technical context, the model also incorporates project incentive mechanisms as a contextual factor and examines its impacts on the extent of BIM implementation and BIM-enabled interorganisational collaboration capabilities. Specifically, the variables of interorganisational collaboration capabilities and performance gains are all analysed at the level of project participating organisations (i.e., designers and general contractors), and the extent of BIM implementation and project incentive mechanisms are both analysed as contextual factors at the project level.

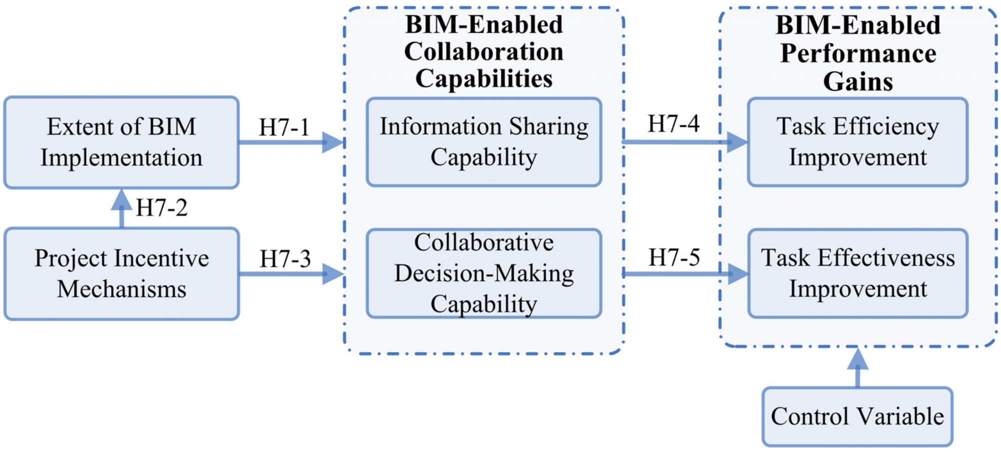

Figure 7.1 Theoretical model of performance impacts of BIM implementation

7.2.2 Impacts of BIM Implementation on Interorganisational Collaboration Capabilities

As a core concept related to the analysis in this chapter, collaboration refers to "a process through which parties with diverse interests and interdependent resources interact to search for solutions to problems that go beyond their own limited vision of what is possible" (Yan and Dooley, 2014, p.60). Extant literature has examined the concept from different perspectives but widely conceived information sharing and collaborative decision-making as two key elements of collaboration in an interorganisational context (Cao and Zhang, 2011; Liao and Kuo, 2014; Sahin and Robinson, 2005; Sanders, 2007; van der Vaart et al., 2012). While information sharing could be described as the "essential ingredient" (Min et al., 2005), "heart" (Lamming, 1996), "lifeblood" (Stuart and McCutcheon, 1996) and "nerve centre" (Chopra and Meindl, 2001) of interorganisational collaboration, collaborative decision-making is a more externally visible element which is directly related to the value creation of collaboration processes. As a construct to reflect the state of the collaboration between interdependent organisations (Allred et al., 2011; Rai et al., 2006), interorganisational collaboration capability also comprises both information sharing capability and collaborative decision-making capability. Within the interorganisational contexts of construction projects examined in this study, specifically, information sharing capability is used to reflect the extent to which a focal organisation (e.g., designers and general contractors) has realised the exchange of proprietary information with its partners in a timely, complete, accurate and consistent manner (Cagliano et al., 2003; Cai et al., 2010; Cao and Zhang, 2011), while collaborative decision-making capability is used to reflect the extent to which a focal organisation has realised the collaboration with its partners to jointly formulate planning and operation decisions optimising the benefits of all related parties (Cai et al., 2010; Cao and Zhang, 2011; Wong et al., 2015). From the perspective of resource dependence theory, these two types of capabilities not only directly relate to the synergy of the non-physical resources of proprietary information and disciplinary expertise, but could also facilitate more efficient and effective interorganisational exchange of physical resources such as equipments. As an innovative technology of an integrated nature, BIM could be used to improve both of these capabilities of related participants (i.e., participating organisations such as designers and general contractors) in construction projects.

As illustrated in Section 1.3, a basic characteristic of BIM is that the technology uses parametric objects to model the information of facility components and their design, construction and operation activities. Compared with traditional 2D information representation methods, such an object-based modelling method could not only enable a more comprehensive and accurate creation of facility life-cycle data, but could also facilitate the created data to be exchanged more consistently among project participants throughout the facility life-cycle (Eastman et al., 2011). Moreover, a comprehensive implementation of BIM in construction projects is not limited to the isolated use of modelling software such as Autodesk Revit and Tekla to create parametric models, but also involves the integrated use of modelling software with project information management platforms (e.g., Bentley Projectwise) and on-site sensing technologies (e.g., RFID) to realise more automatic updates and faster exchange of information within the created BIM models. As such, BIM implementation activities could not only enhance the capability of project participants to interorganisationally share more complete, accurate and consistent information, but also improve the currency of the shared information.

Apart from supporting the creation and sharing of object-based information, BIM can also be implemented in a variety of extended areas including model-based visualisation (e.g., 4D presentation of construction solutions), model-based analysis (e.g., model-based building energy simulation and cost estimation) and model-based project monitoring and control (e.g., model-based automatic monitoring of on-site construction progress, model-based on-site material control). The implementation of BIM in these areas could enable more visual and accurate communications among project participants on related project problems and possible solutions, and provide technical support for the decision-making on project design schemes and construction plans (Eastman et al., 2011; olde Scholtenhuis et al., 2016). As such, BIM as a technical coordination mechanism also has the potential to improve the collaborative decision-making capability of project participating organisations.

Due to the variety of the implementation areas of BIM in a project life-cycle, how BIM implementation activities improve the interorganisational collaboration capabilities of project participants would not be simply determined by whether BIM is adopted in a construction project, but largely impacted by the extent to which

BIM is implemented in design and construction processes by project participants. These arguments lead to the following set of hypotheses.

H7-1a. The extent of BIM implementation in a construction project is positively associated with the BIM-enabled information sharing capability of project participants.

H7-1b. The extent of BIM implementation in a construction project is positively associated with the BIM-enabled collaborative decision-making capability of project participants.

7.2.3 Impacts of Project Incentive Mechanisms on BIM Implementation and Interorganisational Collaboration Capabilities

As illustrated in Subsection 7.2.2, how BIM implementation activities impact interorganisational collaboration capabilities is primarily related to the coordination function of BIM in solving problems of "*not knowing*", whether through enabling the creation and exchange of object-based information in a project life-cycle, or through providing visual communication channels for project participants to jointly analyse project problems and explore possible solutions. However, facilitating interorganisational collaboration not only entails the use of coordination mechanisms including information technologies to solve problems of "*not knowing*", but also requires the design of incentive mechanisms to address problems of "*not wanting to*" which result from the conflicts of interest among interdependent organisations (Gulati et al., 2005, 2012; Picot, 2008). In construction projects, incentive mechanisms are designed by clients/owners primarily through crafting the detailed risk/reward terms of their contracts with other project participants (Meng and Gallagher, 2011; Turner, 2004; Winch, 2001, 2010). Due to the multi-task principal-agent relationship structure of the interorganisational relationships in construction projects, effective project incentive mechanisms designed by a client/owner should not only address the potential conflicts of the interest between the client/owner and other project participants (i.e., designers and general contractors), but also be able to motivate other participants to cooperate with each other to pursue collectively beneficial outcomes (Pryke and Pearson, 2006). Empirical investigations have shown that project incentive mechanisms could significantly shape project activities and impact project performance (Choi et al., 2012; Love et al., 2011a; Meng and Gallagher, 2011). With regard to BIM implementation activities in construction projects, project incentive mechanisms could not only impact the extent of BIM implementation, but also impact the effectiveness of BIM implementation in improving interorganisational collaboration capabilities of related project participants.

While generating benefits, BIM implementation also entails cost-intensive investments (Hanna et al., 2013) and may sometimes conflict with traditional project goals (Suermann and Issa, 2009). As illustrated in Chapter 5, therefore, the extent of BIM implementation in a construction project is significantly associated with client/owner support such as investing BIM-related resources and championing BIM implementation. Due to their limited technical knowledge, however, some clients/owners might be not easily impacted by external pressures to offer direct support for the use of specific technologies like BIM, but only use traditional performance-oriented incentive mechanisms to indirectly manage the technology implementation activities of designers and general contractors. This is partly corroborated by the empirical results in Chapters 4 and 5, which indicate the relatively low levels of client/owner support for BIM implementation in the surveyed projects, and the non-significant association between client/owner support and external normative pressures. As such, BIM implementation activities (e.g., whether to implement BIM or not, and how extensively to implement BIM) of other project participants might be impacted by whether clients/owners design project incentive mechanisms to encourage efforts in pursuing higher project performance. The above considerations lead to the following hypothesis.

H7-2. The use of project incentive mechanisms is positively associated with the extent of BIM implementation in a construction project.

How project incentive mechanisms impact the effectiveness of BIM implementation is closely related to the information representation method of BIM technology. As a technology using parametric objects to multi-dimensionally represent the information in a facility life-cycle, BIM could provide greater visibility into the underlying interdependence among project participants for resources such as proprietary information and expertise (Froese, 2010). As such interdependence has been generally deemphasised in traditional construction project management practices (Froese, 2010; Luth, 2011), to take full advantage of BIM in managing such interorganisational interdependence would involve reshaping the workloads and responsibilities of traditional project activities and thus require reallocating the risks and benefits among project participants. With regard to the BIM-enabled interorganisational information sharing process, for example, since the creation of BIM models generally needs the input of more details than the creation of traditional 2D models, in order to mitigate the risks resulting from possible errors in the added details, project participants may be unwilling to share their BIM models with other participants in a complete and timely manner. With regard to the BIM-enabled collaborative decision-making process, if not appropriately motivated or contractually required, project participants such as designers and general contractors may be also reluctant to change their traditional behaviours to spare more efforts in contributing to BIM-enabled collaborative decision-making processes. As the advancement of BIM worldwide is still in a relatively infant stage and the industry is still exploring how to address BIM-related process and organisational problems, however, it will be rather difficult for clients/owners to prescribe the detailed BIM implementation responsibilities of related project participants in project contracts. Whether clients/owners appropriately use project incentive mechanisms to encourage the potential efforts of designers and contractors to optimise the benefits of the whole project, as a consequence, would probably impact the effectiveness of BIM implementation in improving interorganisational collaboration capabilities. Therefore the following set of hypotheses is proposed.

H7-3a. The use of project incentive mechanisms is positively associated with the BIM-enabled information sharing capability of project participants.

H7-3b. The use of project incentive mechanisms is positively associated with the BIM-enabled collaborative decision-making capability of project participants.

7.2.4 Impacts of Interorganisational Collaboration Capabilities on Project Performance Gains

According to resource dependence theory, organisations need to purposely structure their relationships with other organisations to obtain critical resources and thus achieve desired organisational outcomes (Pfeffer and Salancik, 1978). In the specific context of a construction project, the two types of BIM-enabled interorganisational collaboration capabilities (i.e., BIM-enabled information sharing capability and BIM-enabled collaborative decision-making capability) not only directly relate to the integration of the non-physical resources of proprietary information and expertise, but could also facilitate a more efficient and effective synergy of physical resources such as equipments among project participants. Considering the substantial interdependence among project participants for the exchange of such resources, this study proposes that the two types of BIM-enabled interorganisational collaboration capabilities could further result in substantial performance gains for project participants, including improvements both in task efficiency and in task effectiveness. Specifically, task efficiency is conceptualised as the extent to which a task is completed in the required time frame with the allocated labour resources (Gattiker and Goodhue, 2005). Task effectiveness is conceptualised as the extent to which a task is completed with high-quality outcomes that satisfactorily fulfil the client/owner’s needs (Hoegl and Gemuenden, 2001).

BIM-enabled interorganisational collaboration capabilities could be associated with higher task efficiency of project participants in several ways. If project participants can satisfactorily exchange their required information and collaboratively make critical decisions, they will spend less time in a variety of non-value-adding activities such as waiting for the most recent design information, and waiting for the verification of revised construction plans (Eastman et al., 2011; Gao and Fischer, 2008). BIM-enabled high-quality information sharing and collaborative decision-making could also improve the efficiency of project value-adding activities through enabling faster analysis and communication on emergent project problems, supporting more rapid evaluation on design or construction solutions, and facilitating more off-site prefabrication of facility components (Eastman et al., 2011; Gao and Fischer, 2008). The above discussions lead to the following set of hypotheses.

H7-4a. Project participants with greater BIM-enabled information sharing capability are more likely to achieve a greater extent of BIM-enabled task efficiency improvement.

H7-4b. Project participants with greater BIM-enabled collaborative decision-making capability are more likely to achieve a greater extent of BIM-enabled task efficiency improvement.

An important aspect of the impacts of BIM-enabled interorganisational collaboration capabilities on project task effectiveness is the reduction of design errors and construction rework. Together with other performance problems such as cost overruns and schedule slippages, design errors and resultant construction rework have been relatively common in construction projects all around the world. According to Lopez and Love's (2012) investigation of 139 construction projects in Australia, for example, the average direct and indirect costs caused by design errors could account for 6.85% and 7.36% of project contract value, respectively. Similar to the formation of other performance problems in construction projects, the generation of design errors and construction rework is often related to collaboration problems such as inaccurate exchange of design and construction intention, non-timely communication of project information, and lack of related parties' participation during project decision-making (Love et al., 2011b). As such, BIM-enabled information sharing and collaborative decision-making will naturally facilitate the reduction of design errors and construction rework. Apart from reducing errors and rework, the value of BIM-enabled information sharing and collaborative decision-making could be further reflected in integrating information and expertise resources from different project participants to obtain design and construction solutions that have lower construction and operation costs, possess higher environmental performance, and more satisfactorily fulfil the needs of project clients/owners (Eastman et al., 2011; Gao and Fischer, 2008). These discussions lead to the following set of hypotheses.

H7-5a. Project participants with greater BIM-enabled information sharing capability are more likely to achieve a greater extent of BIM-enabled task effectiveness improvement.

H7-5b. Project participants with greater BIM-enabled collaborative decision-making capability are more likely to achieve a greater extent of BIM-enabled task effectiveness improvement.

7.3 Measurements and Data

7.3.1 Measurement Development

A questionnaire survey was used as the main method to collect project-based data to test the theoretical model and research hypotheses presented in previous section. The measurement items in the survey questionnaire were initially developed based on information gleaned from the relevant literature, as well as previous investigations on the characteristics and institutional drivers of BIM implementation. After the measurement items were initially developed, a pre-test involving 53 respondents (34 from designers and 19 from general contractors) in BIM-based construction projects was conducted via a Chinese online survey system (www.sojump.com) to identify ambiguous expressions and preliminarily test the validity of related constructs. Based on the feedback from these respondents, the author did not revise the content of any measurement item, but only adjusted the format of the questionnaire and the expressions of some incorporated instructions. The questionnaire associated with the analysis in this chapter was structured into three parts (see Appendix C). The first part obtains general information such as project size and project type of the surveyed project. The second part evaluates the extent to which BIM has been implemented in different application areas in the surveyed project, and how project incentive mechanisms have been designed by the project client/owner. The third part assesses the BIM-enabled interorganisational collaboration capabilities of and performance gains for the surveyed project participating organisation (i.e., the designer or general contractor in which the respondent was employed in the surveyed project).

Apart from related project characteristic variables such as project size, a total of six variables have been measured in the questionnaire: extent of BIM implementation (EB), project incentive mechanisms (PIM), BIM-enabled information sharing capability (ISC), BIM-enabled collaborative decision-making capability (CDC), BIM-enabled task efficiency improvement (TEY), and BIM-enabled task effectiveness improvement (TES). In order to improve the comprehensiveness of the implementation measurement, as described previously in Chapter 4, the variable of EB was measured by an aggregated index on BIM usage in 13 application areas in design and construction stages (Table 4.1). In contrast to EB, the variables of PIM, ISC, CDC, TEY and TES were all operationalised as reflective constructs with seven-point scale items ("1" = strongly disagree; "7" = strongly agree), and their detailed measurement items are shown in Table 7.1. The measurement items of PIM were adapted from Kennedy et al. (2009) but reworded to suit the context of construction projects examined in the present study. The operationalisation of ISC was based on Cao and Zhang (2011), with the four adopted items measuring the extent to which a focal project participating organisation has been enabled to share information with other related participating organisations in a timely, complete, accurate and consistent manner based on BIM models (Wixom and Watson, 2001; Setia et al., 2013). The operationalisation of CDC was partly based on the studies of Wong et al. (2015) and Cao and Zhang (2011) in other industries, and the measurement items were largely revised to suit the context of BIM implementation in construction projects. A total of four items were ultimately adopted to reflect the extent to which a focal project participating organisation has been enabled to regularly collaborate with other related participating organisations to jointly formulate design/construction plans, jointly select design/construction solutions, jointly adjust and optimise design/construction solutions, and jointly solve emergent design/construction problems based on BIM models. The items of TEY were adapted from Gattiker and Goodhue (2005) and Chou and Chang (2008), and were reworded to better reflect the impacts of BIM implementation in the context of construction projects. The operationalisation of TES was based on the study of Hoegl and Gemuenden (2001) on teamwork effectiveness and the study of Gao and Fischer (2008) on BIM implementation benefits. Three items were ultimately adopted to reflect the extent to which BIM implementation has helped a focal participant to reduce design errors or construction rework, explore design/construction solutions with higher quality and less cost, and accomplish design/construction products that more satisfactorily fulfil the client/owner's needs. As a control variable used to check possible influences of project characteristics, project size was measured by project investment value.

Table 7.1 Measurement items for constructs in analysis of performance impacts

Construct	Code	Items	References
Project incentive mechanisms (PIM)	PIM1	Client/owner has established appropriate mechanisms to assess the contributions of participating teams to the project performance	Kennedy et al. (2009)
	PIM2	If a team assumes more responsibilities, it will be recognised and rewarded appropriately by the client/owner	

	PIM3	A team will be recognised and rewarded appropriately by the client/owner for additional effort	
	PIM4	If a team fails to accomplish the established design/construction objectives, it will be punished appropriately by the client/owner	
BIM-enabled information sharing capability (ISC)	ISC1	Based on BIM models, our team has been enabled to share information with other related participants in a timely manner	Cao and Zhang (2011)
	ISC2	Based on BIM models, our team has been enabled to share information with other related participants completely	
	ISC3	Based on BIM models, our team has been enabled to share information with other related participants accurately	
	ISC4	Based on BIM models, our team has been enabled to share information with other related participants consistently	
BIM-enabled collaborative decision-making capability (CDC)	CDC1	Based on BIM models, our team has been enabled to regularly collaborate with other related participants to jointly formulate design/construction plans	Wong et al. (2015); Cao and Zhang (2011)
	CDC2	Based on BIM models, our team has been enabled to regularly collaborate with other related participants to jointly compare and select design/construction solutions	
	CDC3	Based on BIM models, our team has been enabled to regularly collaborate with other related participants to jointly adjust and optimise design/construction solutions	
	CDC4	Based on BIM models, our team has been enabled to regularly collaborate with other related participants to jointly solve emergent design/construction problems	
BIM-enabled task efficiency improvement (TEY)	TEY1	BIM implementation has enabled a faster execution of our team's design/construction activities	Gattiker and Goodhue (2005);Chou and Chang (2008)
	TEY2	BIM implementation has increased our team's productivity in related design and construction processes	
	TEY3	BIM implementation has saved time for our team to conduct related design/construction activities	
BIM-enabled task effectiveness improvement (TES)	TES1	BIM implementation has reduced errors and rework in our team's design/construction activities	Hoegl and Gemuenden (2001); Gao and Fischer (2008)
	TES2	BIM implementation has helped our team to explore better design/construction solutions with higher quality and less cost	
	TES3	BIM implementation has enabled our team's design/construction outcomes to more satisfactorily fulfil the client/owner's needs	

Note: Measurement items of extent of BIM implementation (EB) are shown in Table 4.1.

7.3.2 Sampling and Data Collection

Only those well-informed senior and professional individuals directly involved in project BIM implementation activities on the Chinese mainland were considered as targeted respondents for the survey. As indicated in Section 4.2, the use of BIM has been relatively rare in China and, therefore, a completely random sampling method could not be used to elicit BIM-based projects and related project respondents from a specific project database. Instead, respondents from designers and general contractors in a wide variety of BIM-based construction projects were identified by several methods, including searching through related industry publications, obtaining information from online BIM communication communities, interviewing pioneering corporations in BIM utilisation, and contacting professionals participating in BIM industry seminars. Moreover, the respondents for the 106 surveyed BIM-based project in the analysis of BIM implementation characteristics were further invited to participate in this follow-up survey.

After being contacted through personal visits or network-based communications, respondents were asked to answer the survey questions based on their most recent BIM-based project which had already been accomplished or had already entered into the post-design construction stage. The questions related to BIM implementation extent and project incentive mechanisms were designed to collect the information at the project level, while the questions related to BIM-enabled interorganisational collaboration capabilities and performance gains were all designed for the specific project participant (i.e., project participating organisation such as designer or general contractor) employing the respondent in the selected project. It was expected that inviting the respondents to select their most recently involved project would not only enable them to have a more clear recollection of the project BIM implementation process, but also help to reduce the possible response bias as many respondents might otherwise have a tendency to select their most successful BIM-based project. As an attempt to mitigate the impact of confidentiality issues on the response rate, the respondents were not asked to report the name of the selected project, as they were in the survey on BIM implementation practices. After completing the questionnaires, whenever possible, some respondents were also contacted to allow further interpretation of their answers and to provide more details of the surveyed projects. In order to minimise the possible overlap between the surveyed projects and thus improve the representativeness of the sample, it was attempted to distribute the questionnaire to diversified respondents participating in different BIM-based construction projects in different regions in China.

Responses were collected from project designers and general contractors by means of e-mail, personal visits and an online survey system from December 2014 to February 2015. About 570 respondents were contacted through network-based channels such as emails and were informed that they could choose to participate in the survey whether through directly responding to the e-mail or through logging into an online survey system (www.sojump.com). Based on the network-based contacts, 23 responses were collected through email and 247 responses through the online survey system. As for the method of personal visits, about 85 respondents were contacted and 56 responses were collected. Out of the total 326 collected responses, 75 responses contained incomplete or potentially unreliable information and were deemed invalid for this study. As a result, a total of 251 valid responses were ultimately included in subsequent analyses. Among the 251 valid responses, 136 were from project designers and 115 were from general contractors. Detailed sources and demographic characteristics of the samples corresponding to the 251 valid responses are shown in Table 7.2 and Table 7.3.

Table 7.2 Source of samples for analysis of performance impacts

Variable	Category	Designer sample		General contractor sample	
		Number	Percentage	Number	Percentage
Collection method	E-mail	5	3.68	15	13.04
	Personal visit	22	16.18	30	26.09
	Online survey system	109	80.15	70	60.87
Location[a]	North China	16	11.76	13	11.30
	Northeast China	3	2.21	1	0.87
	East China	61	44.85	67	58.26
	South Central China	34	25.00	22	19.13
	Southwest China	14	10.29	5	4.35
	Northwest China	8	5.88	7	6.09

[a] Location of the respondent at the time of the survey, it might be different from the location of the surveyed project.

Table 7.3 Demographic information of samples for analysis of performance impacts

Variable	Category	Designer sample		General contractor sample	
		Number	Percentage	Number	Percentage
Project size	Below ¥50 million	37	27.21	20	17.39
	¥50-200 million	46	33.82	36	31.30
	¥200-1000 million	33	24.26	43	37.39
	Above ¥1000 million	20	14.71	16	13.91
Project type	Residential	28	20.59	18	15.65
	Commercial	46	33.82	40	34.78
	Cultural	6	4.41	13	11.30
	Sporting	3	2.21	3	2.61
	Hospital	3	2.21	7	6.09
	Transportation	13	9.56	17	14.78
	Industrial	20	14.71	9	7.83
	Others	17	12.50	8	6.96
Project nature	Public	76	55.88	71	61.74
	Private	60	44.12	44	38.26

As shown in Table 7.3, the surveyed BIM-based projects are diverse in terms of project size, project type and project nature. Table 7.2 shows, however, that most of the project respondents are from the regions of East China, South Central China and North China (especially from the provinces/cities of Shanghai, Guangdong, Hubei and Beijing), indicating that there is also a probable non-balanced distribution of the locations of the surveyed projects. Apart from being caused by the sampling problem, such a non-balanced distribution could also be partly attributed to the non-balanced development of BIM in different regions in China at present.

After the omission of invalid responses, most respondents in the samples are senior or professional individuals with knowledge of BIM implementation in the surveyed projects. In the designer sample, 11.03% of the respondents are project managers or chief project engineers, 21.32% are BIM managers, 58.82% are BIM engineers, the remaining 8.82% being other types of engineers also directly involved in the implementation of BIM. In the general contractor sample, the percentages of the four types of project respondents are 25.22%, 18.26%, 48.70% and 7.83% respectively. In order to formally examine whether the survey responses were biased due to the positions of the respondents, both the designer and general contractor samples were split into two groups: the group of BIM managers/BIM engineers, and the group of project managers/non-BIM engineers. A series of independent sample t-tests were then conducted to assess the differences in the means of the core multi-scale variables (including PIM, ISC, CDC, TEY and TES) between the two groups. The comparison results shown in Table 7.4 reveal that none of the difference is significant at the 5% level (the p-values range from 0.130 to 0.885), indicating that the position of the respondents has not caused substantial survey biases.

Table 7.4 Comparisons of the data collected from different types of project respondents

Variables	Designer sample				General contractor sample			
	Mean		T-test		Mean		T-test	
	Project Managers /Non-BIM Engineers (N=27)	BIM Managers /BIM Engineers (N=109)	T-value	P-value	Project Managers /Non-BIM Engineers (N=38)	BIM Managers /BIM Engineers (N=77)	T-value	P-value
PIM	4.29	4.62	-1.541	0.130	4.43	4.67	-0.919	0.361
ISC	4.48	4.75	-0.998	0.324	4.53	4.59	-0.234	0.816
CDC	4.75	4.88	-0.553	0.583	5.02	4.94	0.386	0.701
TEY	4.07	4.43	-1.128	0.266	5.21	5.24	-0.145	0.885
TES	5.26	5.52	-1.099	0.279	5.63	5.53	0.623	0.535

Note: The values of PIM, ISC, CDC, TEY and YES are calculated by averaging the scores of their respective measurement items.

The use of single-source and self-reported data for the study may raise concerns about the problems of common method bias in the answers (Podsakoff et al., 2003). Similar to the analyses in previous chapters, Harman's one-factor test was conducted on the variables of EB, PIM, ISC, CDC, TEY and TES to detect the presence of common method bias in the two samples. The test showed that no single dominant factor emerged and the largest factor only accounted for 28.14 and 28.92 percents of the total variances in the measurement items in the designer sample and general contractor sample respectively, suggesting that common method bias is unlikely to be a substantial contaminant of the results (Podsakoff and Organ 1986).

7.4 Data Analyses and Results

PLS, as implemented in the *SmartPLS 2.0 M3* programme, was chosen as the SEM technique to validate the measurements and test the hypothesised research model in this chapter. Compared with covariance-based SEM techniques such as LISREL, PLS is considered to be less sensitive to the problem of non-normal distributions as found in this study (Fornell and Bookstein, 1982). Moreover, as an aggregated factor score based on PCA analysis is employed to gauge the extent of BIM implementation in each project, PLS's ability to analyse research models with single-item constructs makes it particularly appropriate as the analysis technique in this study (Hair et al., 2012). As for the sample size requirement for using PLS, the most commonly cited rule is the "*10 times rule*", which suggests that the sample size should be at least ten times the largest number of structural paths directed at a particular latent construct in the structural model (Barclay et al., 1995; Chin and Newsted, 1999; Hair et al., 2011, 2012). The latent constructs with the largest number of directed structural paths in the present study are the variables of TEY and TES (number of paths is 4 while the direct path from EB is included), and the sample sizes (136 for the designer sample, and 115 for the general contractor sample) satisfactorily meet the requirement of the "10 times rule". To probe deeper into whether individual participating parties benefit differently from project BIM implementation activities, the model was empirically tested using two separate samples of designers and general contractors. The results of measurement model assessment, structural model testing and mediation analysis for the two samples will be separately presented in Subsections 7.4.1 to 7.4.3, and the comparisons of the results for the two samples will be presented in Subsection 7.4.4.

7.4.1 Measurement Model Assessment

The validity of the measurements was assessed in terms of internal consistency, convergent validity and discriminant validity. Internal consistency was assessed through the estimate of composite reliability. For the designer sample, as reported in Table 7.5, the composite reliability values of the examined constructs all exceed the recommended criterion of 0.70 (Fornell and Larcker, 1981). In order to compare the status of project BIM implementation for the design and general contractor samples, the extent of BIM implementation was measured as a summated factor which was calculated through PCA analysis on the data of both samples (N = 251). Therefore, its reliability and validity measures were not calculated in the PLS-based validation process. Further examination of the internal consistency of the summated factor in the program of SPSS Statistics 21.0 also yielded a satisfactory Cronbach's Alpha of 0.853 for the total sample. Convergent validity measures the extent to which the items underlying a particular construct actually refer to the same conceptual variable. The first evidence of convergent validity is provided by the values of AVE. As shown in Table 7.5, each AVE is above the threshold of 0.5, indicating that at least 50 percent of the variance in the items can be accounted for by their respective construct. Further evidence of convergent validity is obtained by estimating the factor loadings of the measurement items. The standardised factor loadings of the items on their respective constructs, as shown in Table 7.6, are all above the threshold of 0.7 and are significant, and there exists no cross-loading problem (Hulland, 1999). Discriminant validity assesses the degree to which different constructs diverge from one another. It is shown that the square roots of the AVE (values on the diagonal of the correlation matrix in Table 7.5) are all greater than the absolute value of inter-construct correlations (off-diagonal values), suggesting that the constructs possess satisfactory discriminant validity (Fornell and Larcker, 1981).

Table 7.5 Measurement validity for constructs in analysis of performance impacts: Designer sample

Construct	Mean	SD	CR	AVE	Correlation matrix[b]					
					EB	PIM	IIC	IDC	TEY	TES
EB[a]	-0.03	0.99	NA	NA	**NA**					
PIM	4.56	1.11	0.89	0.67	0.27	**0.82**				
ISC	4.69	1.29	0.95	0.83	0.31	0.31	**0.91**			
CDC	4.85	1.05	0.94	0.79	0.32	0.29	0.49	**0.89**		
TEY	4.36	1.43	0.95	0.86	0.33	0.37	0.29	0.34	**0.93**	
TES	5.47	0.99	0.91	0.77	0.34	0.30	0.43	0.47	0.55	**0.88**

Note: SD = standard deviation; CR = composite reliability; AVE = average variance extracted.

[a] Values are calculated based on PCA analysis, related measures are not applicable for this construct.

[b] Bold values on the diagonal represent the square root of AVE.

Table 7.6 Results of CFA of constructs in analysis of performance impacts: Designer sample

Construct	Measurement items	Factor loadings					T-value
		PIM	ISC	CDC	TEY	TES	
PIM	PIM1	**0.852**	0.367	0.275	0.322	0.295	27.513
	PIM2	**0.891**	0.234	0.266	0.348	0.222	23.500
	PIM3	**0.798**	0.130	0.168	0.382	0.187	12.422
	PIM4	**0.722**	0.253	0.213	0.188	0.260	11.106
ISC	ISC1	0.254	**0.915**	0.457	0.231	0.378	42.093
	ISC2	0.250	**0.933**	0.445	0.262	0.386	57.740
	ISC3	0.334	**0.943**	0.468	0.309	0.433	93.479
	ISC4	0.294	**0.844**	0.403	0.236	0.346	26.128
CDC	CDC1	0.218	0.433	**0.855**	0.292	0.335	23.868
	CDC2	0.236	0.416	**0.905**	0.298	0.368	45.075
	CDC3	0.258	0.423	**0.872**	0.316	0.457	33.256
	CDC4	0.303	0.456	**0.912**	0.285	0.476	49.183
TEY	TEY1	0.352	0.288	0.298	**0.898**	0.502	32.252
	TEY2	0.347	0.277	0.279	**0.941**	0.499	58.928
	TEY3	0.344	0.237	0.355	**0.945**	0.517	58.817
TES	TES1	0.212	0.336	0.337	0.394	**0.850**	23.260
	TES2	0.249	0.369	0.466	0.578	**0.884**	35.920
	TES3	0.322	0.414	0.414	0.452	**0.901**	36.121

Note: Bold values represent standardised factor loadings of the items on their respective constructs.

For the general contractor sample, as reported in Table 7.7, the composite reliability values of the examined constructs also all exceed the recommended threshold of 0.70 (Fornell and Larcker, 1981). As evidences of convergent validity, the AVE values reported in Table 7.7 are all above 0.5, and all except one item loading reported in Table 7.8 are above the criterion of 0.7 and are significant at the 0.1% level (Hulland, 1999). Although slightly lower than the criterion of 0.7, the loading of item PIM4 on PIM is still larger than the criterion of 0.4 recommended by Hulland (1999) and Hair et al. (2012) for exploratory studies.❶ As the loading is statistically significant at the 0.1% level and there is no cross-loading problem, the measurement of PIM could also be considered to have acceptable convergent validity. Also, it is shown in Table 7.7 that the square roots of the AVE are all greater than the absolute value of inter-construct correlations, suggesting that the constructs possess satisfactory discriminant validity (Fornell and Larcker, 1981).

Table 7.7 Measurement validity for constructs in analysis of performance impacts: GC sample

Construct	Mean	SD	CR	AVE	Correlation matrix[b]					
					EB	PIM	IIC	IDC	TEY	TES
EB[a]	0.03	1.02	NA	NA	**NA**					
PIM	4.59	1.37	0.91	0.73	0.28	**0.86**				
ISC	4.57	1.31	0.94	0.81	0.33	0.39	**0.90**			
CDC	4.96	1.15	0.95	0.82	0.33	0.32	0.44	**0.91**		
TEY	5.23	1.10	0.94	0.85	0.32	0.40	0.33	0.37	**0.92**	
TES	5.56	0.88	0.89	0.74	0.32	0.33	0.44	0.42	0.55	**0.86**

Note: SD = standard deviation; CR = composite reliability; AVE = average variance extracted.
[a] Values are calculated based on PCA analysis, related measures are not applicable for this construct.
[b] Bold values on the diagonal represent the square root of AVE.

❶ While using PLS technique to assess measurement validity, many scholars (such as Setia et al. (2013) and Teo et al. (2003)) have also adopted criteria lower than 0.7 to judge the acceptability of factor loadings.

Table 7.8 Results of CFA of constructs in analysis of performance impacts: GC sample

Construct	Measurement items	Factor loadings					T-value
		PIM	ISC	CDC	TEY	TES	
PIM	PIM1	**0.879**	0.401	0.364	0.292	0.320	34.886
	PIM2	**0.930**	0.364	0.229	0.347	0.290	49.376
	PIM3	**0.903**	0.359	0.254	0.416	0.310	36.156
	PIM4	***0.688***	0.158	0.238	0.320	0.199	7.300
ISC	ISC1	0.381	**0.892**	0.364	0.215	0.309	30.869
	ISC2	0.355	**0.924**	0.438	0.342	0.487	48.068
	ISC3	0.331	**0.919**	0.423	0.298	0.363	41.889
	ISC4	0.339	**0.858**	0.362	0.335	0.389	27.759
CDC	CDC1	0.371	0.453	**0.901**	0.306	0.404	33.883
	CDC2	0.208	0.401	**0.912**	0.338	0.359	42.136
	CDC3	0.257	0.379	**0.930**	0.360	0.395	67.381
	CDC4	0.322	0.373	**0.877**	0.318	0.343	28.784
TEY	TEY1	0.421	0.361	0.342	**0.927**	0.501	52.661
	TEY2	0.310	0.318	0.355	**0.946**	0.519	77.391
	TEY3	0.368	0.231	0.308	**0.887**	0.491	21.123
TES	TES1	0.217	0.263	0.352	0.400	**0.813**	10.628
	TES2	0.277	0.376	0.352	0.519	**0.897**	33.578
	TES3	0.351	0.464	0.367	0.484	**0.867**	22.484

Note: Bold values represent standardised factor loadings of the items on their respective constructs.

7.4.2 Structural Model Testing

A bootstrapping procedure with 5000 resamples was performed to compute standard errors and thus test the statistical significance of path coefficients in the structural model. The results of the bootstrap-based PLS analyses for the designer sample and the general contractor sample are presented in Figure 7.2 and Figure 7.3 respectively. For the designer sample, as shown in Figure 7.2, the impact of BIM implementation extent on the two BIM-enabled interorganisational collaboration capabilities (i.e., ISC, CDC) are both significant at the 0.1% level, thus Hypotheses 7-1a and 7-1b are supported. It is also shown that the links from PIM to the extent of BIM implementation, ISC, CDC are all significant at the 0.1% or 1% level, providing evidence for Hypotheses 7-2, 7-3a and 7-3b. As expected, the associations between CDC and both variables of performance gains (i.e., TEY and TES) are statistically significant at the 0.1% or 5% level, hence Hypotheses 4b and 5b are also supported. With respect to ISC, the results show that the variable is associated with TES at the 1% level but not significantly associated with TEY after controlling for the impact of project size. Therefore Hypothesis 5a is supported while Hypothesis 4a is not. A noteworthy result is that while CDC are significantly associated with both TEY and TES, the path coefficient for TES ($\beta = 0.331$, $p < 0.001$) is larger than that for TEY ($\beta = 0.248$, $p < 0.05$). These results collectively suggest that while designers' collaboration with other project participants to share high-quality information and jointly make decisions does have the potential to create substantial performance gains, its impact on design effectiveness is stronger than that on design efficiency. As for the control variable, project size is significantly associated with neither TEY nor TES while the impacts of ISC and CDC are considered.

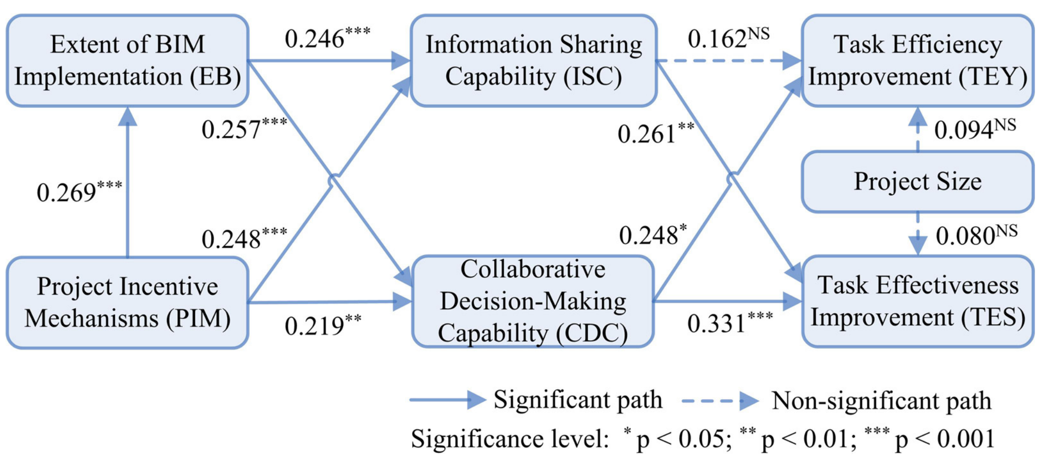

Figure 7.2 Results of PLS analyses for the model of performance impacts: Designer sample

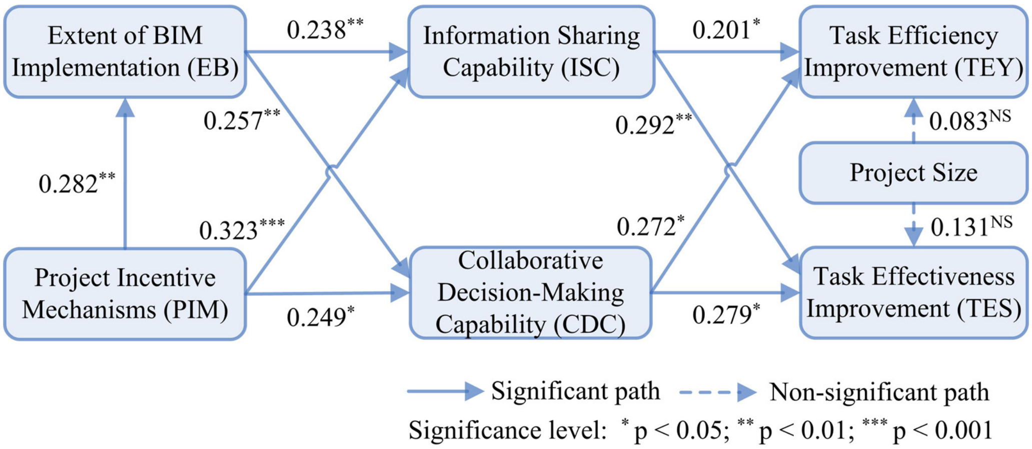

Figure 7.3 Results of PLS analyses for the model of performance impacts: GC sample

The hypothesis testing results for the general contractor sample are shown in Figure 7.3. It is evident that the extent of BIM implementation is significantly associated with the two variables of BIM-enabled interorganisational collaboration capabilities (i.e., ISC and CDC) which are, in turn, both significantly associated with TEY and TES. Therefore, Hypotheses 7-1a, 7-1b, 7-4a, 7-4b, 7-5a, 7-5b are all supported by the data of the general contractor sample. It is also evident that PIM is not only significantly associated with the extent of BIM implementation but also ISC and CDC. Therefore Hypotheses 7-2, 7-3a and 7-3b are also supported. As for the control variable, project size is again significantly associated with neither TEY nor TES while the impacts of ISC and CDC are considered.

7.4.3 Mediation Analyses

Similar to the analysis in Subsection 5.4.3, the mediation effects of ISC and CDC on the relationships between the extent of BIM implementation and the two variables of performance gains (i.e., TEY and TES) were assessed using both the causal steps approach (Baron and Kenny, 1986) and the bootstrapping approach (Preacher and Hayes, 2004, 2008). Specifically, the causal steps approach was used primarily due to its ability in providing a relatively direct understanding on the relationships among the related variables, and the bootstrapping approach was used not only to further validate the analysis results based on the causal steps approach but also to quantitatively assess the collective mediation effects of ISC and CDC.

Mediation analyses based on the causal steps approach were performed using the PLS technique in the *SmartPLS 2.0 M3* programme, with the calculated path coefficients for the designer sample and the general contractor sample shown in Table 7.9 and Table 7.10 respectively. The path coefficients were then carefully examined using the criteria suggested by Andrews et al. (2004). Taking the mediation effect of ISC on the relationship between EB and TEY for the designer sample as an example, as the path coefficient between the mediating variable and the dependent variable (i.e., the coefficient for the ISC-TEY link reported in Model 1a in Table 7.9) is not statistically significant at the 5% level, it is suggested that ISC has no significant mediation effect on the examined relationship. With regard to the mediation effect of CDC on the relationship between EB and TEY for the designer sample, although the coefficients of the related paths all meet the criteria suggested by Andrews et al. (2004), the path coefficient between the mediating variable and the dependent variable (i.e., the coefficient for the CDC-TEY reported in Model 3a in Table 7.9) becomes non-significant at the 5% level after the direct path from the independent variable (i.e., EB) to the dependent variable (i.e., TEY) is added. This result suggests the effect of CDC on TEY is relatively weak when compared with that of EB on TEY. Therefore, it is concluded that the mediation effect of CDC on the relationship between EB and TEY for the designer sample was also not fully validated using the causal steps approach.

Table 7.9 Mediation effects of ISC and CDC: Results based on causal steps approach (designer sample)

Path	Dependent variable: TEY			Dependent variable: TES		
	Model 1a	Model 2a	Model 3a	Model 4a	Model 5a	Model 6a
EB→ISC	0.246***		0.246***	0.246***		0.246***
EB→CDC	0.257***		0.257***	0.257***		0.257***
ISC→TEY	0.162		0.116			
CDC→TEY	0.248*		0.204			
ISC→TES				0.261**		0.226*
CDC→TES				0.331***		0.298**
EB→TEY		0.322***	0.221*			
EB→TES					0.332***	0.168*
R^2						
ISC	0.155		0.155	0.155		0.155
CDC	0.144		0.144	0.144		0.144
TEY	0.142	0.114	0.181			
TES				0.275	0.121	0.298

Note: Standardised path coefficients (β) are reported; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Table 7.10 Mediation effects of ISC and CDC: Results based on causal steps approach (GC sample)

Path	Dependent variable: TEY			Dependent variable: TES		
	Model 1b	Model 2b	Model 3b	Model 4b	Model 5b	Model 6b
EB→ISC	0.238**		0.238**	0.238**		0.238**
EB→CDC	0.257**		0.257**	0.257**		0.257**
ISC→TEY	0.201*		0.165			
CDC→TEY	0.272*		0.230*			
ISC→TES				0.292**		0.267**
CDC→TES				0.279*		0.250*
EB→TEY		0.310***	0.181*			
EB→TES					0.293**	0.127
R^2						
ISC	0.204		0.204	0.204		0.245
CDC	0.164		0.164	0.164		0.239
TEY	0.177	0.107	0.204			
TES				0.268	0.117	0.281

Note: Standardised path coefficients (β) are reported; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Mediation analyses based on the bootstrapping approach were performed using the SPSS macro developed by Preacher and Hayes (2008), and the analysis results are essentially identical with those based on the causal steps approach. With regard to the mediation effects of ISC and CDC on the relationship between EB and TEY for the designer sample, for example, their bias-corrected (BC) bootstrap confidence intervals (CIs) shown in Table 7.11 both contain zero, suggesting that the two mediation effects are both non-significant at the 5% level. As validated using both the causal steps approach and the bootstrapping approach, to sum up, all the examined mediation effects of ISC and CDC on the impacts of EB on TEY and TES for the designer and general contractor samples are significant at the 5% level with three exceptions: the mediation effects of ISC and CDC on the relationship between EB and TEY for the designer sample, and the mediation effect of ISC on the relationship between EB and TEY for the general contractor sample.

Table 7.11 Mediation effects of ISC and CDC: Results based on bootstrapping approach

Mediation path			Designer sample			General contractor sample		
IV	DV	MV	BC 95% CI		Significance	BC 95% CI		Significance
			Lower	Upper		Lower	Upper	
EB	TEY	ISC	-0.027	0.121	Non-significant	-0.007	0.132	Non-significant
		CDC	-0.001	0.162	Non-significant	0.012	0.180	Significant
		Total	0.027	0.199	Significant	0.058	0.250	Significant
EB	TES	ISC	0.011	0.168	Significant	0.023	0.173	Significant
		CDC	0.031	0.191	Significant	0.002	0.203	Significant
		Total	0.081	0.273	Significant	0.074	0.309	Significant

Note: IV = Independent variable, DV = Dependent variable, MV = Mediating variable; The number of resamples is 5000.

Although three of the eight individual mediation effects of ISC and CDC are found to be non-significant, the bootstrapping results shown in Table 7.11 reveal that the collective mediation effects of the two capability variables on the relationships between EB and the two variables of performance gains (i.e., TEY and TES) are all significant for both samples.❶ These results provide strong evidence regarding the important role of BIM-enabled interorganisational collaboration capabilities in generating performance gains for project participants. Despite this importance, the results based on the causal steps approach also reveal that all the examined separate mediation effects are partial mediation with only two exceptions: the mediation effects of ISC and CDC on the relationship between EB and TES for the general contractor sample.❷ These results indicate that apart from improving interorganisational collaboration capabilities of project participants, the implementation of BIM could also enhance the efficiency and effectiveness of project activities through other channels, such as improving intra-organisational collaboration capabilities of project participants and generating automational effects.

7.4.4 Comparative Analyses of Designer and General Contractor Samples

In order to identify how individual participating organisations benefit differently from project BIM implementation activities, the data analysis results of the performance impacts of BIM implementation for the two samples from designers and general contractors were further compared. As this study did not follow a dyadic sampling approach to collect data from matched pairs of designers and general contractors in the same BIM-based projects, the projects reported by designers and

❶ The results based on the causal steps approach could not directly explain the collective mediation effect of multiple mediating variables.

❷ The results based on the bootstrapping approach do not differentiate full and partial mediations.

general contractors do not strictly correspond to each other. Before comparing the analysis results of performance impacts for the two samples, therefore, it is necessary to first guarantee the equivalence between the two samples in project characteristics (e.g., project size, project type, project nature) and project contexts (e.g., extent of project BIM implementation, use of project incentive mechanisms) which are related to the performance gains of project participants.

As project characteristic factors including project size, project type and project nature are all category variables, a series of χ^2 tests were conducted to examine the difference between the designer and general contractor samples in their project characteristics. With regard to the characteristic factor of project type, as the frequency of some categories (such as sporting and hospital categories) are relatively low and may impact the validity of χ^2 test results, the eight categories of project type listed in Table 7.3 were combined into three categories: residential, commercial and others. From the χ^2 test results shown in Table 7.12, it is evident that the differences between the designer and general contractor (GC) samples in project size, project type and project nature are all non-significant at the 5% level (p-values are 0.096, 0.591 and 0.348 respectively). With regard to the differences in project technical and non-technical contexts, independent sample T-tests were performed to compare the mean values of EB and PIM for the two samples. As shown in Table 7.13, the differences in the means of the two examined variables are both non-significant at the 5% level. Based on the results of χ^2 tests and independent sample T-tests, the samples collected from designers and general contractors could be considered to be equivalent in terms of project characteristics, the extent of project BIM implementation and the use of project incentive mechanisms.

Table 7.12 Comparisons of project characteristics for designer and general contractor samples

Variable	Category	Number (Percentage)		χ^2 test
		Designer sample	GC sample	
Project size	Below ¥50 million	37 (27.21%)	20 (17.39%)	χ^2=6.337, df=3
	¥50-200 million	46 (33.82%)	36 (31.30%)	p=0.096
	¥200-1000 million	33 (24.26%)	43 (37.39%)	
	Above ¥1000 million	20 (14.71%)	16 (13.91%)	
Project type	Residential	28 (20.59%)	18 (15.65%)	χ^2=1.053, df=2
	Commercial	46 (33.82%)	40 (34.78%)	p=0.591
	Others	62 (45.59%)	56 (49.57%)	
Project nature	Public	76 (55.88%)	71 (61.74%)	χ^2=0.881, df=1
	Private	60 (44.12%)	44 (38.26%)	p=0.348

Table 7.13 Comparisons of construct values for designer and general contractor samples

Variable	Designers		General contractors		Independent sample T-test			
	Mean	SD	Mean	SD	Difference	T-value	p-value	Significance
EB	-0.03	0.99	0.03	1.02	-0.06	-0.491	0.624	No
PIM	5.03	1.08	5.11	1.32	-0.08	-0.538	0.591	No
ISC	4.69	1.29	4.57	1.31	0.12	0.725	0.469	No
CDC	4.85	1.05	4.96	1.15	-0.11	-0.786	0.433	No
TEY	4.36	1.43	5.23	1.10	-0.87	-5.461	0.000	Yes
TES	5.47	0.99	5.56	0.88	-0.10	-0.814	0.416	No

Based on the examination of the equivalence of the two samples in project characteristics as well as project technical and non-technical contexts, the between-sample differences in the values of ISC, CDC, TEY and TES were further compared using independent sample T-tests. As these capability and benefit variables were all measured at the level of project participating organisations (i.e., designer or generational contractor), the differences in the values of these variables between the two samples could directly reflect how designers and general contractors differ in their BIM-enabled interorganisational collaboration capabilities and BIM-enabled performance gains. From the T-test results shown in Table 7.13, it is evident that the differences in the mean values of ISC ($T = 0.725$, $p = 0.469$), CDC ($T = -0.786$, $p = 0.433$) and TES ($T = -0.814$, $p = 0.416$) are all non-significant, but the mean value of TEY for the general contractor sample is significantly higher than that for the designer sample ($T = -5.461$, $p < 0.001$). A paired-samples T-test further reveals that the mean of TEY, which is relatively close to the neutral of "4" for a seven-point Likert scale, is also significantly lower than that of TES for the designer sample ($T = -10.599$, $p < 0.001$). These results provide evidence that current BIM-enabled performance gains for designers have been primarily related to the enhancement of task effectiveness, and that the gains related to the improvement of task efficiency for designers have been much less substantial than those for general contractors.

With regard to the relationships among the examined variables, it is evident from Figures 7.2-7.3 and Table 7.9-7.11 that the structural model testing results and the mediation analysis results are quite similar between the two samples. First, most of the hypothesised relationships among EB, ISC, CDC, TEY and TES are supported by data from both samples, and the collective mediation effects of ISC and CDC on the relationships between EB and the two performance gain variables (i.e., TEY and TES) are found to be significant for both samples. These results provide strong evidence regarding the important role of BIM-enabled interorganisational collaboration capabilities in generating performance gains for both designers and general contractors. Second, the hypothesised relationship between PIM and EB is supported for both samples. As the variables of PIM and EB both reflect the situations at the project level, the consistent analysis results for the two different samples could corroborate each other and thus provide compelling evidence regarding the significant impact of project non-technical context on the extent of project BIM implementation. Third, the hypothesised relationship between PIM and the two collaboration capability variables (i.e., ISC and CDC) are also supported for both samples. These results, together with those of the relationship between PIM and EB, suggest that project incentive mechanisms could not only impact the extent of BIM implementation, but also influence the effectiveness of BIM implementation after controlling for the effect of BIM implementation extent.

Accompanying these similarities, a distinct difference in the results for the two samples is that the association between ISC and TEY is significant at the 5% level for the general contractor sample but non-significant for the designer sample (β = 0.162, $p > 0.05$). This result provides evidence that BIM-enabled interorganisational collaboration in sharing high-quality information does not necessarily equivalently benefit related collaborating parties in terms of improving the efficiency of both design and construction activities. Further comparisons of the results of structural model testing and mediation analyses also suggest that while designers' collaboration with other project participants to share high-quality information and jointly make decisions does have the potential to create substantial performance gains, its impact on design effectiveness is stronger than that on design efficiency.

7.5 Discussions of Findings

The primary research objective of this chapter is to use resource dependence theory as a lens to understand how BIM implementation activities impact the performances of project participants. Most of the hypothesised relationships are supported by the data from both designers and general contractors, and BIM-enabled interorganisational collaboration capabilities as a whole are found to significantly mediate the relationships between the extent of project BIM implementation and BIM-enabled performance gains for both designers and general contractors. These results validate the perspective of resource dependence theory in the context of construction projects, and provide evidence for the important boundary spanning role of BIM in assisting project participants to manage interorganisational dependence and improve organisational performance. In fact, the interdependence among project participants is not a new claim in the construction industry, and the establishment of coordination mechanisms to manage the interorganisational dependence has been rather common in construction project management practices (Bankvall et al., 2010; Shen and Chang, 2011; Winch, 2010). Limited by the 2D representation methods of project life-cycle data, however, traditional project management practices has often focused on managing visible interorganisational dependence for physical resources, but deemphasised the underlying interdependence for non-physical resources such as proprietary information and disciplinary expertise (Froese, 2010). As a result, critical information is often shared among project participants neither promptly nor consistently, and design and construction solutions are often formulated by some of the related participants and then “thrown over the wall” to other participants (Froese, 2010; Jacobsson and Linderoth, 2010). As an innovative technology to parametrically create and visually represent project life-cycle data, BIM could not only provide greater visibility into the underlying resource dependence among project participants (Froese, 2010), but also facilitate a more structured interorganisational collaboration process to support the integration of non-physical resources such as proprietary information and disciplinary expertise and, therefore, to facilitate the synergy of related physical resources (Eastman et al., 2011). As such, the value of BIM is naturally related to the technology’s response to the collaboration requirements resulting from the resource dependence among project participating organisations, and BIM-enabled interorganisational collaboration capabilities naturally play important roles in creating project benefits from BIM implementation.

While providing evidence for the important roles of BIM-enabled interorganisational collaboration capabilities, the results also suggest that there is a non-equivalence of the BIM-enabled performance gains for designers and general contractors. In details, the results reveal that BIM-enabled task efficiency improvement for designers is much less substantial than that for general contractors, and the resultant BIM implementation benefits for designers have been primarily related to the enhancement of task effectiveness. Such a non-equivalence could be partly attributed to the different roles played by BIM technology in design and construction processes. During construction processes, BIM is mainly used to guide the planning and execution of construction activities and, therefore, primarily acts as a supportive tool. During design processes, however, the integrated use of BIM requires designers to abandon the traditional 2D design paradigm and to conduct design activities based on fundamentally new design platforms and processes. Compared with construction processes, therefore, design processes will undergo more fundamental adjustments after the introduction of BIM technology. Due to the complexity of BIM-based design software, such adjustments will involve relatively long learning curves and may not necessarily lead to higher efficiency in design activities. As a designer in a hotel project in Xi'an commented:

The interface of (the modelling software we are using) is relatively complex, especially for we 'green hands' … the development of 'component families' for (the modelling software we are using) in the industry is still at an early stage, and using this software generally involves more time in carrying out design tasks … in those projects with tight design schedules, it is generally preferable for us to use 'traditional' 2D CAD tools instead.

The non-equivalence in the improvement of task efficiency for designers and general contractors could also be partly attributed to the difference in the impacts of BIM-enabled interorganisational collaboration on design and construction activities, as the hypothesis testing results further reveal that the association between BIM-enabled information sharing capability and task efficiency improvement is more substantial for the general contractor sample than for the designer sample. From the resource dependence theory perspective, the difference in the impacts of

BIM-enabled information sharing capability on design and construction efficiency is closely related to the different roles played by designers and general contractors within BIM-enabled interorganisational resource exchange processes. Due to the ability of BIM to increase the visibility of project data and support the automatic detailing of construction-level building models, a collaborative BIM implementation process generally requires designers to assume more responsibilities of construction detailing and to provide design models with more detailed information to other participants including general contractors (Eastman et al., 2011). Therefore, collaborative BIM implementation activities in construction projects will increase the responsibilities of designers as model-based information providers, and strengthen the dependence of other project participants (e.g., general contractors) for the information provided. Although designers are also dependent for other participants' related information and could also gain efficiency-related benefits from BIM-based information sharing processes, such benefits may be offset by the increase of model detailing workloads and thus lead to the non-significant association between BIM-enabled information sharing capability and BIM-enabled task efficiency improvement. With regard to BIM-enabled collaborative decision-making capability, the variable is found to be significantly associated with the performance gains for designers, especially in the aspect of task effectiveness improvement. This result provides evidence that designers are particularly dependent on the expertise of other participants to ensure the effectiveness of design activities and, therefore, underlines the importance of integrating the expertise from different disciplines during the early design stage within a project lifecycle.

It is also revealed in this chapter that project incentive mechanisms as a non-technical contextual factor could not only affect the extent of project BIM implementation, but also further impact the effectiveness of BIM implementation in enabling interorganisational collaboration after controlling for the impact of BIM implementation extent. This result suggests that BIM-based interorganisational collaboration in construction projects involves problems of both “not knowing” and “not wanting to”, and that BIM as a technical coordination mechanism alone is not sufficient to assist project participants in addressing all the problems in managing interorganisational resource dependence. This is also corroborated by the comment from a design director in a commercial building project in Chongqing:

The implementation of BIM (in this project) falls considerably short of its potential ... Other participating organisations in this project have been used to traditional methods. Even if our party is willing (to cooperate with them to collaboratively implement BIM), the collaboration process is still rather complex. The willingness from one party is far from sufficient (to realise interorganisational collaboration). If there is no compelling force to drive and regulate the activities of related project participants, it will be quite difficult to realise the collaborative implementation of BIM throughout the project life-cycle ... During the past twelve months, our company has already unwillingly terminated the implementation of BIM in several projects due to the non-collaboration of other project participants.

7.6 Chapter Summary

Drawing on resource dependence theory, this chapter has developed a conceptual model for understanding how project BIM implementation activities impact the performances of project participants. In order to probe deeper into whether individual participating organisations benefit differently from BIM implementation, the model have been tested using two separate project-based datasets from 136 designers and 115 general contractors on the Chinese mainland. Data analysis results based on the PLS technique and the bootstrapping mediation approach reveal that BIM-enabled interorganisational collaboration capabilities as a whole play an important role in impacting the BIM-enabled performance gains (including the improvements in task efficiency and task effectiveness) for both designers and general contractors. These results validate the perspective of resource dependence theory in the context of construction projects, and provide evidence for the important boundary spanning role of BIM in assisting project participants to manage interorganisational dependence and improve organisational performance. Further comparison of the datasets reveals that designers and general contractors do not benefit equivalently from project BIM implementation, with BIM-enabled task efficiency improvement for designers being much less substantial than that for general contractors, and the benefits for designers being primarily limited to the enhancement of task effectiveness. From the resource dependence theory perspective, this non-equivalence could be partly attributed to the different roles of designers and general contractors within BIM-enabled interorganisational resource exchange processes. It is also revealed that project incentive mechanisms could not only affect the extent of project BIM implementation, but also impact the effectiveness of BIM implementation in enabling interorganisational collaboration after controlling for the impact of BIM implementation extent. This result points to the complexity of interorganisational relationships in construction projects, and suggests that BIM as a technical tool alone is not sufficient to address all the problems in the collaboration among project participants. Taken together, the findings in this chapter contribute to deepened understandings of how individual participating organisations benefit differently from collaborative BIM implementation activities in construction projects, and why the performance impacts of BIM implementation vary across different project contexts.

CHAPTER 8 CONCLUSIONS

8.1 Summary of Major Findings

Drawing on institutional theory and resource dependence theory, this thesis aims to identify how institutional isomorphic pressures drive the implementation of BIM in construction projects, and how BIM implementation activities in turn impact the performances of involved project participants. To achieve these aims, project-based data from the Chinese mainland were collected and analysed to sequentially investigate: (1) the characteristics of BIM implementation in terms of application areas and project participants' roles; (2) the impacts of institutional isomorphic pressures on BIM implementation; (3) the motivations of project participants to implement BIM under the impacts of isomorphic pressures; and (4) the impacts of BIM implementation on the task efficiency and effectiveness of involved project participants. The major findings of these investigations are summarised as follows.

(1) With regard to the characteristics of BIM implementation, the results reveal that the implementation of BIM across different application areas generally follows a trajectory from model-based visualisation to model-based analysis and model-based management, and that in the surveyed projects the in-depth implementation of BIM has been principally limited to the areas of visualisation. As for the roles of project participants, the results suggest that general contractors have surpassed designers as the participants most frequently involved in the BIM implementation activities in the surveyed projects, and that the overall support for

BIM implementation by clients/owners is limited, despite their increasing absorption of BIM related costs. The results also provide evidence that BIM implementation practices, in terms of both the extent of BIM implementation across different application areas and client/owner support for BIM implementation, are significantly associated with project characteristic factors including project type and project size.

(2) With regard to the impacts of institutional isomorphic pressures, the results from PLS analyses reveal that coercive and mimetic pressures both significantly influence the extent of project-level BIM implementation. However, this study does not find support for a significant influence of normative pressures. The results further indicate that client/owner support plays a crucial but varied mediating role in the influences of these different isomorphic pressures. Overall, the results provide evidence that external isomorphic pressures as a whole can significantly drive BIM implementation activities in construction projects, suggesting that project BIM implementation should be regarded as a complexly socialised activity that is closely associated with external institutional environments.

(3) Considering the impacts of institutional isomorphic pressures, the motivations of project participants to implement BIM in construction projects could be classified into four broad categories: image motives, reactive motives, project-based economic motives, and cross-project economic motives. Comparisons of the categorised motivations suggest that image motives and cross-project economic motives are currently the strongest reasons for designers and general contractors to implement BIM in construction projects, and that social motivations and economic motivations

do not necessarily preclude each other as conventional wisdom might indicate. Results of hierarchical regressions support the hypotheses on the positive association between project-based economic motives and BIM capability, and on the non-significant association between image motives and BIM capability. However, hypotheses on the associations between BIM capability and the two other motivation variables are not supported. While illustrating no significant difference in BIM implementation motivations between designers and general contractors, hierarchical regression results further reveal that both project type and project nature are significantly associated with project-based economic motives, and that project organisations from state-owned corporations generally have stronger image motives and cross-project economic motives to implement BIM than their counterparts from other types of corporations.

(4) With regard to the performance impacts of BIM implementation, PLS analysis results reveal that BIM-enabled interorganisational collaboration capabilities as a whole significantly mediate the relationships between the extent of project BIM implementation and BIM-enabled performance gains (including the improvements in task efficiency and task effectiveness) for both designers and general contractors. These results validate the perspective of resource dependence theory in the context of construction projects, and provide evidence that BIM could play an important boundary spanning role in assisting project participants to manage interorganisational dependence and improve organisational performance. The results further reveal that designers and general contractors do not benefit equivalently from

project BIM implementation, with BIM-enabled task efficiency improvement for designers being much less substantial than that for general contractors, and the benefits for designers being primarily limited to the enhancement of task effectiveness. It is also revealed that project incentive mechanisms could not only impact the extent of project BIM implementation, but also impact the effectiveness of BIM implementation in enabling interorganisational collaboration after controlling for the impact of BIM implementation extent. This result points to the complexity of interorganisational relationships in construction projects, and suggests that BIM as a technical tool alone is not sufficient to address all the problems in the collaboration among project participating organisations.

8.2 Theoretical Contributions

This study makes several contributions to the extant literature on BIM and construction innovations. First, as an exploratory effort to apply institutional theory in the context of innovation implementation in the conservative construction industry, this study has empirically investigated how three types of institutional isomorphic pressures impact the implementation of BIM in construction projects, and characterised how client/owner support mediates the relationships between isomorphic pressures and the extent of project-level BIM implementation. Through providing empirical evidence that external isomorphic pressures as a whole can significantly impact BIM implementation activities in construction projects, the findings not only extend and validate the applicability of the institutional theory perspective in a new context, but also contribute to a theoretically rigorous understanding regarding the relationship between innovation implementation activities in construction projects and external institutional environments.

Second, based on the investigation of the impacts of institutional isomorphic pressures, this study has further differentiated the motivations of designers and general contractors to implement BIM in construction projects, and investigated how different motivations are associated with organisational BIM capability as well as other contextual factors. The findings could help to develop a more comprehensive understanding of the reasons why construction organisations implement BIM in construction projects, and provide a more dynamic picture of how BIM implementation motivations may vary as organisational contexts change. Through providing evidence that the motivations of project participants to implement BIM under the impacts of institutional pressures are distinctly multi-dimensional and dynamic, the findings could also help to partly reconcile the discordant findings on innovation implementation reasons in extant construction innovation literature and to deepen the understanding of the complex relationship between innovation implementation activities and external institutional environments.

Third, from a resource dependence theory perspective, this study has revealed that BIM-enabled interorganisational collaboration capabilities as a whole plays an important role in determining the impacts of BIM implementation on the performance gains of project participants, and illustrated that project incentive mechanisms significantly influence the extent and effectiveness of BIM implementation in construction projects. The findings could contribute to a deepened understanding of the pathways through which the implementation of BIM improves the performance of project participating organisations, and provide theoretical explanations for the variations of the performance impacts of BIM implementation in different project contexts. Based on the comparison of the data collected from different project participants, this study also contributes to the evolving BIM literature by providing evidence for the non-equivalence between the BIM-enabled performance gains for designers and general contractors.

8.3 Practical Implications

First, through revealing that isomorphic pressures as a whole can significantly influence the extent of BIM implementation in construction projects, the results reinforce the need to regard project-level BIM implementation as a complexly socialised activity and suggest that related institutional forces can be utilised as manoeuvres to facilitate the diffusion of BIM in the construction industry. Since the results indicate that client/owner support plays a significant mediating role in the influences of external pressures, government agencies and other BIM promoters should work closely with project clients/owners to wield more effective influence on project BIM implementation activities. This is especially important for the wielding of normative pressures, as the results indicate that clients/owners could not be easily impacted by normative influences, and this will also limit the influences of normative pressures on other project participants. Moreover, based on the comparison of the effects of different types of isomorphic pressures, the results also seem to suggest that industry professional bodies should not only highlight the potential trend towards BIM implementation practices while exerting normative influences on specific projects. In order to improve the effectiveness of their influence, they need to rely more on exhibiting the best practices and successful experiences of BIM implementation in similar projects.

Second, while government agencies and other BIM promoters utilise institutional forces to facilitate the diffusion of BIM, care also needs to be taken to establish a healthier BIM implementation culture in the industry and avoid causing practitioners' blind BIM implementations without considering their specific project needs. This is especially important as the comparison on the means of image motives and project-based economic motives provides clear evidence that BIM is used by designers and general contractors as an image management tool distinctly more than a project performance management tool. Although image motives may also be capable of resulting in high levels of BIM implementation, related implementation efforts would be exerted primarily for image management purposes rather than necessarily being targeted to addressing specific project performance problems. As a consequence, these implementation efforts may fail to fully consider the specific performance needs in related projects to maximize the core value of BIM in improving project performance.

Third, as the empirical results provide evidence that BIM-enabled interorganisational collaboration capabilities as a whole play an important role in determining the impacts of BIM implementation on the efficiency and effectiveness of project activities, during project BIM implementation processes it is important for project participants to purposefully manage the extent to which BIM improves the quality of interorganizational information sharing and collaborative decision-making in order to maximize the potential benefits from BIM implementation. Moreover, the empirical result related to the impacts of project incentive mechanisms provides evidence that that project BIM implementation involves a distinct problem of "not wanting to" and BIM technology alone could not address all of the collaboration problems among project participating organisations. In order to maximise the BIM implementation benefits in a project, therefore, particular attention should also be paid by the project client/owner to designing appropriate contractual risk/reward terms in order to address the problem of unwillingness during BIM implementation.

Fourth, while providing evidence for the important role of BIM-enabled interorganisational collaboration capabilities in project BIM implementation processes, the empirical results also reveal that there is a non-equivalence of the BIM implementation benefits for designers and general contractors. As such, in order to improve the fairness of the benefit sharing among project participants and thereby to facilitate their interorganisational collaboration on project BIM implementation, it is also important for project clients/owners to appropriately offset the naturally formed non-equivalence of BIM implementation benefits while designing the contractual risk/reward terms for designers and general contractors.

8.4 Future Research Directions

While making the stated contributions, this study still has several limitations that could provide opportunities for future research. First, considering the potential impact of the number of analysed variables on the stability of model analysis results given the limited sample sizes, this study focuses on examining the drivers and performance impacts of BIM implementation from certain theoretical perspectives, and has only incorporated the most relevant variables in the research models. As a result, some other important variables may have been omitted. Applying other theoretical perspectives such as resource-based view and social capital, future research could examine more relevant variables in the models and therefore develop a more comprehensive theoretical framework for understanding the drivers and performance impacts of BIM implementation activities in construction projects.

Second, with the intrinsic advantage of allowing replicability and thus enabling structured comparisons across different projects, questionnaire survey was deployed as the main method to collect perceptual data from project respondents. This may generate potential response biases related to subjectivity and social desirability. As a procedural control technique, the respondents were guaranteed that all their answers would be kept confidential; as a statistical control technique, Harman's one-factor tests also showed that common method biases are unlikely to be substantial contaminants of the results. However, potential response biases still could not be completely excluded. Future research could attempt to collect project-based data from multiple sources, and use both objective and perceptual data to measure the variables related to performance gains. These could help to cross-validate the collected data and, therefore, further control the negative impacts of potential response biases on data analysis results.

Third, this study was conducted in a specific cultural and market context in the Chinese construction industry. This may limit the generalisability of the related results to other cultural and market contexts. Such a limitation may be particularly evident in the results related to the impacts of institutional isomorphic pressures on BIM implementation activities, as how project participants respond to external institutional pressures may be significantly influenced by the industry culture. As such, a natural extension of the present study would be to conduct related cross-cultural and cross-national research in the future, and validate the applicability of the analysis results in different cultural and market contexts.

APPENDICES

Appendix A: Questionnaire on Practice Characteristics and Institutional Drivers of BIM Implementation in Construction Projects

Note: This appendix is a translation of the original questionnaire (in Chinese) which was used for collecting project-based data through the method of personal visits. The questionnaires for the two other data collection methods (i.e., e-mail, and an online survey system) are identical with the appended version except for the format and incorporated instructions. Only the question items related to the analyses in this thesis are included in this appendix, and the detailed format has been adjusted.

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Dear Sir or Madam,

You are cordially invited to spare your precious time to participate in our survey. As an important part of the research project on BIM implementation which is financially supported by the National Natural Science Foundation of China (Grant No. 71272046), this survey aims to investigate how BIM has been implemented in Chinese mainland construction projects. Please select a BIM-based construction project which you participated in,[❶] and answer the questions based on the actual information in the selected project. There are no right or wrong answers for all the questions in this survey. The questionnaire will take about 15 minutes for you to complete, and your answers are important for the quality of this research.

All the data collected in this survey will be used only for academic purposes. The project-related details of the completed questionnaires and the personal information of the respondents will both be kept confidential, and will not be included in the

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❶ The respondents were orally advised that they could either select the project a priori identified by the surveyor, or select another project which they were more familiar with.
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final report. If you are interested in the research results, we will send you an electronic copy of the research report upon the accomplishment of this research. We sincerely appreciate your support for our research.

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Part I: Project Information

Instruction: Please provide the basic information of the selected project.

1. Project Name: ____
2. Which project participating organisation do you belong to? ( )   A. Client/Owner B. Designer C. General contractor D. Subcontractor   E. Consultant F. Others (please specify:________________)
3. Your job position in the project: ____
4. The year for the commencement of the project construction activities: _______________
5. The province/municipality where the project is located: __________________________
6. The investment value of the project is ( )   A. Below ¥50 million B. ¥50-200 million C. ¥200-1000 million D. Above ¥1000 million
7. The investment nature of the project is ( )   A. Public projects (including government-funded projects and public-private partnership projects)   B. Private projects
8. The delivery system used for the project is ( )   A. Design-bid-build (design and construction services are separately and sequentially procured)   B. Engineering, procurement and construction (EPC) route   C. Others (please specify:_____________________________)

Part II: Project BIM Implementation Practices

BIM Application Areas

Instruction: Please indicate how BIM was implemented in the listed areas in the selected project using any symbol (such as “√”) to mark the appropriate option: "0" (not used), "1" (some use) and "2" (extensive use). If you are not clear about the implementation status in an area, you could choose the option of “N” (not clear).
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Project stage	BIM application areas	Status			
		2	1	0	N
Design stage	Analysing project site location				
	Exploring and comparing design options based on 3D models				
	Three-dimensional (3D) presentation of complex structures to non-professionals				
	Coordinating design of architectural, structural, and MEP systems				
	Project cost estimating during design stage				
	Analysing building's energy distribution and consumption				
	Analysing building's other performances such as lighting, acoustics, ventilation and air flows, and pedestrian circulation				
	Others (please specify:________________________________)				
Construction stage	Checking conflicts among building systems prior to construction				
	Designing and analysing the construction of complex building systems in order to increase planning				
	Simulating master schedules and construction sequences				
	Quantity takeoff and cost estimation during construction stage				
	Integration with schedules and onsite information to manage the storage and procurement of project materials and equipments				
	Generating digitized information to facilitate greater use of prefabricated components				
	Others (please specify:________________________________)				

<u>Roles of project participants in BIM Implementation</u>

Instruction: Please indicate the roles of project participants in BIM implementation in the selected project <u>using any symbol (such as "√") to mark the appropriate option</u>: "leading" (i.e., coordinating the whole process of creating, reviewing and utilising BIM models), "participating" (i.e., involved in but not leading the BIM implementation process) and "not involved".

Project participants	Leading	Participating	Not involved
Client/owner			
Designer			
General contractor			
Subcontractors			
Others (please specify:____________________)			
Which participant assumed the majority of the BIM costs in this project? ( ) A. Client/owner B. Designer C. General contractor D. Others (please specify:_________)			

Part III: Project BIM Implementation Background

Instruction: Please indicate the actual background for BIM implementation in the selected project. You could use any symbol (such as "√") to mark the appropriate option: "1" (strongly disagree), "2" (disagree), "3" (slightly disagree), "4" (neutral), "5" (slightly agree), "6" (agree) and "7" (strongly agree).

External pressures on and internal needs for BIM implementation in the project	Disagree			>			Agree
	1	2	3	4	5	6	7
The government required our project to use BIM							
Industry associations required our project to use BIM							
Peer projects that had implemented BIM had benefitted greatly							
Peer projects that had implemented BIM had gained good reputations in the industry							
Peer projects that had implemented BIM were perceived favourably by others in the industry							
Software vendors strongly advocated the use of BIM in our types of projects							
Industry consultants strongly advocated the use of BIM in our types of projects							
Universities strongly advocated the use of BIM in our types of projects							
Industry associations strongly propagated the value of BIM in our types of projects							
The structure of the built facility in this project is relatively complex, it is difficult to use traditional 2D methods to design and construct it							
This project has relatively high requirements on cost and schedule, it is difficult to use traditional methods to conduct related analyses							
The project design and construction process is relatively complex, it is difficult to use traditional methods to realise the effective communication among different project participants							
Client/owner support for BIM implementation in the project	Disagree			>			Agree
	1	2	3	4	5	6	7
Client/owner invested substantial resources in BIM use in the project							
Client/owner regarded BIM use as a priority of project activities							
Client/owner put much effort in driving project participants to collaboratively use BIM							

Thanks a lot for your support for our research!

If you are interested in the research results, you could write down your email address ______________________________, we will send you an electronic copy of the research report upon the accomplishment of this research.

Appendix B: Questionnaire on Motivations for BIM Implementation in Construction Projects

Note: This appendix is a translation of the original questionnaire (in Chinese) which was used for collecting project-based data through the method of personal visits. The questionnaires for the other data collection method (i.e., an online survey system) are identical with the appended version except for the format and incorporated instructions. Only the question items related to the analyses in this thesis are included in this appendix, and the detailed format has been adjusted.

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Dear Sir or Madam,

You are cordially invited to spare your precious time to participate in our survey. As an important part of the research project on BIM implementation which is financially supported by the National Natural Science Foundation of China (Grant No. 71272046), this survey aims to investigate the primary motivations and basic modes of project participants to implement BIM in construction projects in China. Please select the most recent BIM-based construction project which you have participated in and which has already been accomplished or has already entered into the post-design construction stage (note: please do not intentionally select the most successful BIM-based project), and answer the questions based on the actual information in the selected project. There are no right or wrong answers for all the questions in this survey. The questionnaire will take about eight minutes for you to complete, and your answers are important for the quality of this research.

All the data collected in this survey will be used only for academic purposes. The project-related details of the completed questionnaires and the personal information of the respondents will both be kept confidential, and will not be included in the final report. If you are interested in the research results, we will send you an electronic copy of the research report upon the accomplishment of this research. We
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sincerely appreciate your support for our research.

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Part I: Project Information

Instruction: Please answer the questions based on the actual information of the selected BIM-based construction project.

1. Which project participating organisation do you belong to? (　　　　　)	
A. Designer	B. General contractor
C. Others (please specify:________________)	
[This questionnaire survey is only for designers and general contractors]	
2. What is your job position in the project? (　　　　　)	
A. Project manager/project chief engineer	B. BIM manager
C. BIM Engineer	D. Others (please specify:_________________)
3. What is the ownership type of the project participating organisation you belonging to? (　　　　)	
A. State-owned	B. Privately-owned
C. Foreign-owned	D. Others (please specify:_________________)
4. The year for the commencement of the project construction activities: _______________	
5. The investment value of the project is (　　　　　)	
A. Below ¥50 million　B. ¥50-200 million	C. ¥200-1000 million　D. Above ¥1000 million
6. The facility type of the project is (　　　　　)	
A. Residential　B. Commercial	C. Cultural
D. Sporting　E. Hospital	F. Transportation
G. Industrial　G. Others (please specify:___________)	
7. The investment nature of the project is (　　　　　)	
A. Public projects (including government-funded projects and public-private partnership projects)	
B. Private projects	

Part II: Project BIM Implementation Motivations and Contexts

Instruction: The term “we” in the listed statement refers to the design team or the general contractor team which you belong to, and the phrase “other project participants” refers to other participating organisations in the selected project. Please indicate the actual status of BIM implementation motivations and contexts of your
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team in the project. You could <u>use any symbol (such as "√") to mark the appropriate option</u>: "1" (strongly disagree), "2" (disagree), "3" (slightly disagree), "4" (neutral), "5" (slightly agree), "6" (agree) and "7" (strongly agree).

No.	**Motivations for BIM Implementation:** Our team implements/implemented BIM in this project because:	Disagree			>	Agree		
		1	2	3	4	5	6	7
01	We want/wanted to maintain a good image for using advanced technologies							
02	We do/did not want to lag behind industry counterparts in using BIM							
03	We need/needed to comply with BIM use requirements from governments or other project participants							
04	We have/had to promise to use BIM to improve our competitiveness in project bidding							
05	We have/had to participate in using BIM as many other participants are/were using BIM in the project							
06	We want/wanted to use BIM as a tool to solve related design and construction problems in the project							
07	We want/wanted to use BIM as a tool to improve cost and schedule performances in the project							
08	We expect/expected that the direct economic benefits of BIM use will outweigh its costs in the project							
09	We want/wanted to become more familiar with BIM implementation process through using BIM in the current project							
10	We want/wanted to foster BIM expertise of our team members through using BIM in the current project							
11	We want/wanted to better guide the implementation of BIM in future projects through using BIM in the current project							
No.	**BIM capability** of your team during the implementation of BIM in the project	Disagree			>	Agree		
		1	2	3	4	5	6	7
01	Our team is/was experienced in implementing BIM							
02	Our team is/was capable to solve the possible technical problems in BIM implementation							
03	Our team has/had the knowledge necessary for implementing BIM in such types of projects							

Thanks a lot for your support for our research!

If you are interested in the research results, please write down your email address, we will send you an electronic copy of the research report upon the accomplishment of this research. You could also write down your suggestions on our research here:

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Appendix C: Questionnaire on Performance Impacts of BIM Implementation in Construction Projects

Note: This appendix is a translation of the original questionnaire (in Chinese) which was used for collecting project-based data through the method of personal visits. The questionnaires for the two other data collection methods (i.e., e-mail, and an online survey system) are identical with the appended version except for the format and incorporated instructions. Only the question items related to the analyses in this thesis are included in this appendix, and the detailed format has been adjusted.

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Dear Sir or Madam,

You are cordially invited to spare your precious time to participate in our survey. As an important part of the research project on BIM implementation which is financially supported by the National Natural Science Foundation of China (Grant No. 71272046), this survey aims to investigate the BIM-enabled interorganisational collaboration in Chinese mainland construction projects and its impacts on the performances of involved project participants. <u>Please select the most recent BIM-based construction project which you have participated in and which has already been accomplished or has already entered into the post-design construction stage (please do not intentionally select the most successful BIM-based project)</u>, and answer the questions based on the actual information in the selected project. There are no right or wrong answers for all the questions in this survey. The questionnaire will take about ten minutes for you to complete, and your answers are important for the quality of this research.

All the data collected in this survey will be used only for academic purposes. The project-related details of the completed questionnaires and the personal information of the respondents will both be kept confidential, and will not be included in the final report. If you are interested in the research results, we will send you an
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electronic copy of the research report upon the accomplishment of this research. We sincerely appreciate your support for our research.

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Part I: Project Information

Instruction: Please answer the questions based on the actual information of the selected BIM-based construction project.

1. Which project participating organisation do you belong to? (   ) A. Designer   B. General contractor C. Others (please specify:________________) [This questionnaire survey is only for designers and general contractors]
2. What is your job position in the project? (   ) A. Project manager/project chief engineer   B. BIM manager C. BIM Engineer   D. Others (please specify:____________________)
3. The investment value of the project is (   ) A. Below ¥50 million   B. ¥50-200 million C. ¥200-1000 million   D. Above ¥1000 million
4. The facility type of the project is (   ) A. Residential   B. Commercial   C. Cultural D. Sporting   E. Hospital   F. Transportation G. Industrial   G. Others (please specify:__________)
5. The investment nature of the project is (   ) A. Public projects (including government-funded projects and public-private partnership projects) B. Private projects

Part II: Project BIM Implementation Practices and Contexts

BIM Application Areas

Instruction: Please indicate how BIM is/was implemented in the listed areas in the selected project using any symbol (such as "√") to mark the appropriate option: "0" (not used), "1" (some use) and "2" (extensive use). If you are not clear about the implementation status in an area, you could choose the option of "N" (not clear).
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Project stage	BIM application areas	Status			
		2	1	0	N
Design stage	Exploring and comparing design options based on 3D models				
	Three-dimensional (3D) presentation of complex structures to non-professionals				
	Coordinating design of architectural, structural, and MEP systems				
	Project cost estimating during design stage				
	Analysing building's energy distribution and consumption				
	Analysing building's other performances such as lighting, acoustics, ventilation and air flows, and pedestrian circulation				
	Analysing project site location				
Construction stage	Checking conflicts among building systems prior to construction				
	Designing and analysing the construction of complex building systems in order to increase planning				
	Simulating master schedules and construction sequences				
	Quantity takeoff and cost estimation during construction stage				
	Integration with schedules and onsite information to manage the storage and procurement of project materials and equipments				
	Generating digitized information to facilitate greater use of prefabricated components				

Design of project incentive mechanisms

Instruction: Please indicate the actual status of the design of project-level incentive mechanisms in the selected project using any symbol (such as "√") to mark the appropriate option: "1" (strongly disagree), "2" (disagree), "3" (slightly disagree), "4" (neutral), "5" (slightly agree), "6" (agree) and "7" (strongly agree).

No.	Design of **project incentive mechanisms** in the selected project	Disagree			>	Agree		
		1	2	3	4	5	6	7
01	Client/owner has established appropriate mechanisms to assess the contributions of participating teams to the project performance							
02	If a team assumes more responsibilities, it will be recognised and rewarded appropriately by the client/owner							
03	A team will be recognised and rewarded appropriately by the client/owner for additional effort							
04	If a team fails to accomplish the established design/construction objectives, it will be punished appropriately by the client/owner							

Part III: BIM-enabled interorganisational collaboration and performance gains

Instruction: The phrase “we/our team” in the listed statement refers to the design team or the general contractor team which you belong to, and the phrase “other project participants” refers to other participating organisations in the selected project. Please indicate the actual status of BIM-enabled interorganisational collaboration and performance gains in the project. You could <u>use any symbol (such as “√”) to mark the appropriate option</u>: "1" (strongly disagree), "2" (disagree), "3" (slightly disagree), “4” (neutral), "5" (slightly agree), "6" (agree) and "7" (strongly agree).

No.	**BIM-enabled interorganisational information sharing**	Disagree			>	Agree		
		1	2	3	4	5	6	7
01	Based on BIM models, our team has been enabled to share information with other related participants in a timely manner							
02	Based on BIM models, our team has been enabled to share information with other related participants completely							
03	Based on BIM models, our team has been enabled to share information with other related participants accurately							
04	Based on BIM models, our team has been enabled to share information with other related participants consistently							
No.	**BIM-enabled interorganisational collaborative decision-making**	Disagree			>	Agree		
		1	2	3	4	5	6	7
01	Based on BIM models, our team has been enabled to regularly collaborate with other related participants to jointly formulate design/construction plans							
02	Based on BIM models, our team has been enabled to regularly collaborate with other related participants to jointly compare and select design/construction solutions							
03	Based on BIM models, our team has been enabled to regularly collaborate with other related participants to jointly adjust and optimise design/construction solutions							
04	Based on BIM models, our team has been enabled to regularly collaborate with other related participants to jointly solve emergent design/construction problems							

No.	BIM-enabled task efficiency improvement	Disagree			>		Agree	
		1	2	3	4	5	6	7
01	BIM implementation has enabled a faster execution of our team's design/construction activities							
02	BIM implementation has increased our team's productivity in related design and construction processes							
03	BIM implementation has saved time for our team to conduct related design/construction activities							
No.	**BIM-enabled task effectiveness improvement**	Disagree			>		Agree	
		1	2	3	4	5	6	7
01	BIM implementation has reduced errors and rework in our team's design/construction activities							
02	BIM implementation has helped our team to explore better design/construction solutions with higher quality and less cost							
03	BIM implementation has enabled our team's design/construction outcomes to more satisfactorily fulfil the client/owner's needs							

Thanks a lot for your support for our research!

If you are interested in the research results, please write down your email address, we will send you an electronic copy of the research report upon the accomplishment of this research. You could also write down your suggestions on our research here:

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Appendix D: Results of OLS Regression Analyses on the Impacts of Isomorphic Pressures on BIM Implementation

Note: As discussed in Section 5.4, there is an ongoing debate among scholars over the minimum sample size requirements for using SEM techniques (Bagozzi and Edwards 1998; Hair et al., 2010), but many scholars suggest that PLS as a component-based SEM technique has an advantage over other SEM techniques in processing smaller sample size data (Barclay et al., 1995; Chin, 1998; Chin and Newsted, 1999; Hair et al., 2011, 2012). As the construct of client/owner support is examined in chapter 5, in order to mitigate the response bias, 14 responses from project clients/owners were excluded from the sample and the sample size for the analysis in Chapter 5 became 92. Such a size satisfactorily meets the requirement of the "*10 times rule*", which suggests that the sample size for using the PLS technique should be at least ten times the largest number of structural paths directed at a particular latent construct in the structural model (Barclay et al., 1995; Chin and Newsted, 1999; Goodhue et al., 2012; Hair et al., 2011, 2012). In order to further validate the model estimation results based on the PLS technique, however, a series of ordinary least squares (OLS) regressions were also performed in the program of SPSS Statistics 21.0 to estimate the hypothesised relationships within Chapter 5. The parameter estimates of OLS regressions, as illustrated in details in Appendix D1 and Appendix D2, are substantially similar to the results based on the PLS technique, and the hypothesis testing results using the two different analysis techniques are essentially identical with each other.

Appendix D1 Results of regression analysis for the model of isomorphic pressures

Dependent variable	Significance of regression	R^2	Code	Independent variable	Regression coefficient	T-value	p-value	Result
Client/owner support (COS)	p<0.001	0.226	H2a	CP	0.308	2.854	0.005	Supported
			H3a	MP	0.247	2.316	0.023	Supported
			H4a	NP	-0.009	-0.094	0.926	Not supported
Extent of BIM implementation (EB)	p<0.001	0.311	H1	COS	0.274	2.620	0.010	Supported
			H2b	CP	0.193	1.795	0.076	Supported
			H3b	MP	0.229	2.183	0.032	Supported
			H4b	NP	-0.007	-0.074	0.941	Not supported
			NA	Size[a]	0.035	0.369	0.713	NA

Note: CP = coercive pressures, MP = mimetic pressures, NP = normative pressures; With regard to Hypothesis H5-2b, the relationship between coercive pressures and the extent of BIM implementation is found to be non-significant while the effect of client/owner support is included, but the relationship become significant while the effect of client/owner support is excluded (see Appendix D2), so H5-2b is also supported; Variance inflation factors (VIFs) for the regression model are all within the desired low range from 1.03 to 1.43, suggesting that multicollinearity is not substantively influencing the regression estimates.

[a] Refers to project size measured by investment value. Due to the skewness in the size distribution for the surveyed projects, natural logarithms of the investment values were used for data analysis.

Appendix D2 Results of regression analysis for the alternative model of isomorphic pressures

Dependent variable	Significance of regression	R^2	Code	Independent variable	Regression coefficient	T-value	p-value	Result
Extent of BIM implementation (EB)	p<0.001	0.256	H2b	CP	0.269	2.515	0.014	Supported
			H3b	MP	0.291	2.761	0.007	Supported
			H4b	NP	-0.004	-0.041	0.968	Not supported
			NA	Size[a]	0.094	0.990	0.325	NA

Note: VIFs for the regression model are all within the desired low range from 1.03 to 1.33, suggesting that multicollinearity is not substantively influencing the regression estimates.

[a] Refers to project size measured by investment value. Due to the skewness in the size distribution for the surveyed projects, natural logarithms of the investment values were used for data analysis.

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