University of Reading

Adaptation of industry BIM process standards in a large construction firm

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School of Construction Management and Engineering

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Abstract

The United Kingdom (UK) construction industry is witnessing an increased uptake of Building Information Modelling (BIM) process standards. This research investigates how the adaptation of new industry BIM process standards influences the large construction firm's capacity to deliver projects and sustain competitive advantage. Previous studies have examined the roles of industry product and technical standards, and the standards within the firm, that are associated with innovation, but there is little work on industry BIM process standards. To understand this, the research develops a conceptual framework, building upon the work of Davies and Brady (2000) on project based firm (PBF) organisational capabilities.

The empirical research focuses on the Publicly Available Specification (PAS) 1192:2012 (1-3), which is a successor to British Standard (BS) 1192:2007, and the Construction Operations Building information exchange (COBie) standards. These industry BIM process standards were developed to facilitate, coordinate and control information management activities amongst project teams. Following a preliminary UK industry investigation, a case study strategy is adopted to understand the adaptation of BIM process standards in the large construction firm. Data is drawn from: a) observations of practice in three ongoing projects, b) semi-structured interviews, and c) secondary publications. Thematic data analysis shows that adaptation of the industry process standards transforms the firm's ability to manage, integrate and coordinate business and project processes such as bidding, design and project management. Adaptation stimulates new ways of collaborating design activities and transforms the firm's interactive relations with IT suppliers and standards developers. However, the standards are resisted within the business, and in the projects because they evolve outside the firm. Adaptation becomes unstable because the standards have systemic linkages, are rapidly changing and attract multiple interpretations.

The study contributes to previous work by articulating how the adaptation of industry process standards contributes to the development of project capabilities by the large construction firm. The study identifies mediating complexities that require management attention such as the systemic linkages with other industry standards. This research focused on the single large construction firm, in future, research could assess the implications of the findings in the wider construction industry. Further research could address how other types of industry standards influence the ability to develop strategic and operational level capabilities within firms that produce the built environment.

Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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Energy Nyasha Maradza

Dedication

I dedicate this thesis to my wife Hanah, my daughter Aitashe and Anenyasha - the little somebody growing in mum's tummy. There are not enough words to thank you. Throughout the research, you have been kind and understanding even when I could not be there for you as much as I would want.

I dedicate this thesis to my parents, Shadreck and Shingairai Maradza for working tirelessly to ensure that I got the best upbringing and education in very challenging circumstances. You instilled values in me that have guided me through it all. To my siblings, cousins and your families, I hope to inspire you with this work.

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Glossary

Building Information Modelling is a collaborative process of producing information required to produce and maintain built facilities using digital design and collaboration technologies, and sets of industry standards.

BIM environment refers to the collaborative digital environment in which people involved in the production of built facilitates interact, produce, exchange and communicate information as part of the process of developing and maintaining built facilities.

Capabilities are bundles of unique resources, skills, knowledge and experience that determine the firm's ability to organise internal activities and strategize in dynamic business contexts, to accomplish business objectives and sustain competitive advantage.

Competences are the combinations of resources, knowledge, experience and skills possessed by individuals and teams required by a firm to achieve efficiency and sustain competitive advantage.

Industry BIM process standards are the sets of common, industry level procedures and formats for managing, regulating and controlling the production and exchange of information in BIM environments.

Industry process standards are the sets of voluntary, open and codified consensus driven industry level specifications to which processes, formats or procedures are aligned.

Industry standards refer to common and agreed sets of industry level guidelines "to which all elements of products, processes, formats, or procedures under its jurisdiction must conform" (Tassey, 2000 p.588).

Innovation refers to "a novel product, process, service, or system of organization that changes the prevailing order of an organization, market, or society" (Davies *et al.*, 2014 p.26).

Project Based Firm organisational capabilities are the strategic, functional and project capabilities required to manage production processes and adapt to changing external environments to achieve and sustain competitive advantage.

Project capabilities refer to the "distinctive managerial knowledge, experience and skills, which are located within a single organisation (a firm) and required to establish, coordinate and execute projects" (Davies and Brady, 2015 no pagination).

Resources are the basic physical and non-physical inputs into the firm's production processes.

Technology is "a replicable artefact with practical application, and knowledge that enables it to be developed and used" (Dodgson *et al.*, 2008 p.02).

List of abbreviations

BSI	British Standards Institution
BS	British Standard
BIM	Building Information Modelling
IFC	Industry Foundation Class
IPD	Integrated Project Delivery
ISO	International Organization for Standardization
IT	Information Technology
MVD	Model View Definition
ONS	Office of National Statistics
PAS	Publicly Available Specification
PBFs	Projects-based firms
PM	Project manager
RIBA	Royal Institution of British Architects
RICS	Royal Institution of Chartered Surveyors
R&D	Research and Development
RBV	Resource based view
SDOs	Standards Development Organisations
UK	United Kingdom

Chapter 1: Introduction

The United Kingdom (UK) construction industry is witnessing an increased uptake of Building Information Modelling (BIM) process standards. In the production of the built environment, studies of innovation highlight the benefits of adapting new products, processes (Slaughter, 1993b; Gann and Salter, 2000; Manley, 2008), and digital design tools (Whyte, 2003; Bouchlaghem *et al.*, 2004). However, high profile reviews claim that the UK construction industry does not sufficiently embrace new products, processes and technologies, hence the view that it is less innovative (Construction Task Force, 1998 p.04). This suggests that new industry BIM process standards may present opportunities for the entire construction industry; hence, efforts in many parts of the industry are directed towards the BIM technology. The use of BIM promises improved efficiencies, predictable returns, reduced transactions costs and better information management in the design, construction and maintenance of built facilities (Hardin, 2009; O'Reilly, 2012). Despite the moves to embrace the BIM technology, much remains unknown about the large UK construction firm's experiences of using new, common industry BIM process standards.

This introductory Chapter is structured in sections as follows: section 1.1 explains the research problem and section 1.2 provides a background to the research, whilst section 1.3 addresses the debate on industry process standards and standardisation. The theoretical perspective adopted for the research is outlined in Section 1.4. In Section 1.5, the research's aim and objectives are set out. Sections 1.6 and 1.7 address the research scope and methods respectively. The chapter concludes with an explanation of the research methods and an outline of the thesis structure in Section 1.8.

1.1 The research problem

In the design, construction and maintenance of built facilities, clients, architects, contractors, specialists, suppliers and project managers perform tasks, and exchange volumes of complex, and detailed information. These parties frequently rely on standardised processes to collaborate, communicate, produce and exchange information (Bouchlaghem *et al.*, 2004). In UK construction, such standard processes are becoming associated with the BIM process, which is perceived to be essential in eliminating information reproduction, change and reinterpretation, and they are attracting the attention of academics, policy makers and practitioners (Dawood *et al.*, 2003; Richards, 2010; Bew *et al.*, 2013). Scholars of innovation in construction have addressed the role of standard product components (Gann, 2000b; Gibb, 2001; Edum-Fotwe *et al.*, 2004), technical standards that enhance compatibility of digital design tools (Tolman, 1999; Eastman *et al.*, 2008a), internal standards developed and used within a single firm (Davies and Frederiksen, 2010), and industry standards development *(Kannengiesser and Gero, 2007).* However, the implications of using new industry BIM process standards on the construction firm's capacity to achieve and sustain competitive advantage in the delivery of construction projects is seldom addressed. These

BIM process standards are used to regulate interactions, facilitate collaborations, and coordinate information production in the design, construction and maintenance of built facilities. The adaptation of such industry process standards receives relatively little empirical attention, even though research shows the important functions they play in the production and maintenance of the built environment (Bouchlaghem *et al.*, 2004).

Even as organisational learning and ambidexterity studies in other fields claim that industry process standards influence the firm's exploitation and exploration of knowledge (Benner and Tushman, 2003; 2007), studies are yet to examine the experiences of firms that adapt to industry BIM process standards. Studying the adaptation of the process standards is relevant to understand how the construction-contracting business evolves, transforms its capabilities, innovates and sustains competitive advantage. The research is timely to inform policy and practice given the rapid uptake of the BIM process in the UK construction industry.

1.2 Background to the study

The production of the built environment improves with the adaptation of new products, processes, and digital design tools (Gann, 1993; Bouchlaghem *et al.*, 2005; Boland *et al.*, 2007). In the UK, there are varied opinions about whether or not the construction industry embraces change, with a number of high profile reviews claiming that there is reluctance to adopt and implement new technologies (Joint Government and Industry Construction

Review, 1994; Construction Task Force, 1998). Generally, research on innovation in construction addresses the adoption and implementation of new products, process and digital design technologies (Nam and Tatum, 1989; Slaughter, 2000; Harty, 2005). Scholars are also investigating the way firms are able to adapt, innovate and improve the execution of projects, and sustain competitive advantage (Pries and Janszen, 1995; Miozzo and Dewick, 2004; Reichstein *et al.*, 2005; Dodgson *et al.*, 2014). This research contributes to this work by examining the experiences of large construction firms that are adapting new BIM process standards to produce localised solutions, with an anticipation of improved returns.

In other fields, research shows that adapting industry process standards influences incremental learning and organisational capability exploitation (Benner and Tushman, 2002; Di Stefano *et al.*, 2014). In construction, scholars identify specific features that may challenge the adaptation and exploitation of industry process standards. The prevailing view is that construction is a complex systems industry (Miller *et al.*, 1995; Gann and Salter, 2000), products are often unique and customised, processes are distributed at the business and project levels, and production activities include design, research and development (R&D) (Tatum, 1987; Slaughter, 1993a; Gann, 1996; Seaden *et al.*, 2003). Dubois and Gadde (2002) argue that construction is a loosely coupled system that presents obstacles to learning and innovation. However, they also note that local adaptations of technologies in construction projects are a potential source of innovation. Against this background, how construction firms adapt industry-wide BIM process standards to improve their project delivery capabilities, and ability to sustain competitiveness is an important area for research.

The research builds upon a tradition of scholarship that considers innovation to be a process that leads to the creation of new or significant improved products, services, process of production and delivery, marketing method, and/or managerial method that transforms the existing order within firms, industries and societies (Gann and Salter, 2000; Dodgson *et al.*, 2005; OECD, 2005; Manley, 2008). Technology is the theoretical and practical knowledge, skills and artefact with practical application (Dodgson *et al.*, 2008a p.02). Drawing insights from the Resource Based View (RBV) of the firm, the firm is considered a collection of resources, competences and capabilities (Penrose, 1959; Richardson, 1972; Wernerfelt, 1984). Whereas resources are the basic inputs into the production process, competences are the combinations of resources, knowledge, experience and skills possessed by individuals and teams within a firm, whilst capabilities are the knowledge of the firm – they determine what the firm can and cannot accomplish (Chandler, 1990; Barney, 1991; Teece and Pisano, 1994). The study develops insight into the way the construction firm embraces new industry process standards to develop distinct capabilities that enables it to achieve functional efficiency and sustain competitive advantage in the delivery of projects.

1.2.1 Building Information Modelling

There is not yet a clear and unified definition of Building Information Modelling. For instance, Eastman *et al.* (2011) associate BIM with the creation of parametric 3 Dimensional (3D) digital objects. The prevailing view, which is influential in UK policy making, is that BIM is not only about the creation of the parametric 3D object, but involves the collaborative processes of designing, creating and maintaining the built facility (Richards, 2010; BIM Task Group, 2013; Nisbet, 2014). Therefore, discussions of BIM in UK construction are not only directed at improving technical standards, but also on the process standards that regulate collaborations between professionals working in the BIM environment. In adopting a process perspective, the research considers BIM as a common process that involves the use of digital tools such as 3D, 4D and 5D Computer Aided Design (CAD) software and online data bases, and sets of open, industry-wide technical, product and process standards, that are used to collaboratively produce information used to develop and maintain the built facility (Arayici *et al.*, 2012). BIM has links to CAD design tools that evolved in the early 1960s. Within the BIM process, open product and technical standards such as the Industry Foundation Class (IFC) are necessary for managing compatibility and interoperability of digital design tools (Eastman *et al.*, 2008a); process standards such as the British Standard (BS) 1192:2007, PAS 1192:2012 (1-3) and the COBie schema are aimed at regulating information production and sharing activities and the digital collaborations of professionals (Nisbet, 2012; East *et al.*, 2013).

There are claims that BIM represents a significant technological shift, and promises of certain benefits abound (BIM Task Group, 2012). Indeed the UK government has since mandated the use of BIM in all public contracts by 2016 (Cabinet Office, 2011). Consequently, many large UK construction contracting firms that traditionally rely on public contracts are taking steps to embrace the technology (NBS, 2012; 2013; 2014). Numerous industry level initiatives have also emerged to facilitate BIM uptake, as well as the development of associated industry BIM product, technical and process standards.

1.2.2 Industry BIM process standards

Table 1.1 below identifies the standards that are common in the delivery of projects using the BIM process. This research focuses on the process standards which have received limited empirical attention, namely: the BS1192:2007, its successor the Publicly Available Specification (PAS) 1192:2012 (1-3) and the Construction Operations Building information exchange (COBie) standard schema for information exchange[1]. These BIM process standards set out the agreed, common, industry level procedures required to manage, coordinate and control the processes of producing, communicating and handing over of information in an environment where the BIM process is implemented to design, produce and maintain built facilities (Richards, 2010). Whereas the BS 1192:2007 standard sets out the process of collaboration, the COBie schema provides the common structure for the exchange of information. There is limited research on these BIM process standards. The information available suggests that the standards aim to streamline the behaviour of professionals involved in the execution of projects. There is an expectation that the standards will assist in the reduction of production costs, double handling of information and enhance information management over the life of the built facility (Avanti, 2006; Richards, 2010). The process

[1] In this research, these standards are referred as BIM process standards.

standards could help reduce time wastage and transaction costs (Richards, 2010; Nisbet, 2012). Although there is rapid uptake of BIM, there is limited empirical investigation to understand how BIM process standards are integrated into a firm's processes, made sense of, exploited, and the complexities faced by the large construction firm.

Standard	Function	Type	Purpose
Industry Foundation Class (IFC) - BS ISO 16739 ; BS ISO 12006 -3:2007 - International Framework for Dictionaries; Model View Definition; ISO/TS 12911:2012	Interoperability and compatibility	Technical standards	Interoperability and compatibility, 2D and 3D design information production, visualisation, synchronisation
BS ISO 12006-2:2001, Building construction – Uniclass, Omni class	Classification of information	Technical standards	Classification of work elements, Organization of digital information
BS 1192: 2007; PAS 1192 (2-4)	Collaboration	Process standards	Coordinating communication, and collaboration
Construction Operations Building information exchange (COBie)	Information exchange	Process standards	Coordinating and controlling information format and exchange

Table 1:1 Industry BIM standards

Research on BIM has brought to light the complexities of adapting new practices in construction (Howard and Björk, 2008; Maradza *et al.*, 2012; Demian and Walters, 2013). While the term standardisation is often associated with the development of industry standards (Weitzel *et al.*, 2006; Blind, 2009a; Björk and Laakso, 2010), in this research standardisation is considered from the standards user perspective where the focus is on the enactment of industry standard to achieve its intended economic purpose (Tassey, 2000). Contemporary studies address mostly industry product and technical standards (East, 2012; East *et al.*, 2013), in the UK construction, significant effort has been placed to promote the BIM process standards (Richards, 2010).

1.2.3 The UK construction industry

The introduction of BIM into UK construction industry comes at a time when the construction industry has been the subject of many high profile reviews aimed at addressing the industry's productivity and competiveness challenges (Ministry of Public Works and Building, 1964; Department of Trade and Industry, 2002), including the current Construction 2025 strategy (BIS, 2013a)[2]. The UK construction industry is important to the national economic system; the industry contributes on average 9% to the country's Gross Domestic Product (GDP) (BIS, 2013b). The industry develops the infrastructure, accommodation and houses required for people to live. For decades, successive reviews have concluded that the industry does not adequately embrace innovation, hence the industry does not efficiently deliver to its customer's satisfaction (Ministry of Public Works and Building, 1964; Construction Task Force, 1998). There are strong views that the industry is characterised by

[2] In July 2013, the UK government published a report explaining its strategy for construction industry. The report is titled: 'Construction 2015: Industrial strategy – government and industry partnership'. The report explains government intention to work collaboratively with the industry including providing funding for research and development in new technologies such as BIM process standards.

tight regulatory frameworks, limited technological advance, diverging customer requirements, cutthroat competition and there are limited efforts to develop and apply standard processes in production activities (Joint Government and Industry Construction Review, 1994; Construction Task Force, 1998). In a recent report, the UK government noted that the industry has high levels of fragmentation, poor collaboration, and there is limited learning and knowledge transfer (BIS, 2013b p.vii). These issues collectively or separately highlight the potential gains of applying industry process standards.

The construction industry produces unique complex products identified Hobday (2000) as complex products and systems (CoPS), such as roads, railway stations, schools and airports. Large construction projects identified by some scholars as mega projects are executed by temporary coalitions of firms (Davies *et al.*, 2014). In the UK, such projects included the London 2012 Olympic park, the London Crossrail and the High Speed 2 rail scheme. Infrastructure development projects are often large-scale, capital-intensive and financed by the government. These projects often attract intense public interest and scrutiny.

Large construction businesses are central to the delivery of mega projects. Their involvement in public contracts makes them an important factor in the use of industry BIM process standards that have attracted government interest and funding. Typically, large construction firms addressed in this research employ more than 1200 people, have an annual turnover more than one billion pounds and have extensive experience in delivering large infrastructure projects. These firms are often involved in industry level discussions particularly those involving the development and use of new industry process standards.

1.3 Standards and standardisation

Standards play an important role in the functioning of economic systems. Research distinguishes between industry standards (David and Greenstein, 1990; Tassey, 2000; Funk and Methe, 2001) and standards that are developed within the firm that are addressed as routines (Nelson and Winter, 1982; Nelson and Nelson, 2002). Standards perform a variety of functions in quality management, scientific evaluation, compatibility, interoperability, and variance reduction. This research follows a strand within the economics of standards literature, which investigates industry standards (Tassey, 2002; Blind, 2009a). Such a strand distinguishes between *de-jure* and *de-facto* industry standards highlighting the paths followed in the development of the standards (Tassey, 2000). Furthermore, there are differences between industry product, process and technical standards, which are often highlighted in research on standards (Hawkins *et al.*, 1995; Stango, 2004; Jahre *et al.*, 2006; Jakobs, 2006; Weitzel *et al.*, 2006). Research on industry standards has been important to explain the economic effects and to understand the role they play in the evolution and functioning of information systems (Hanseth and Monteiro, 1997; Jakobs *et al.*, 2001; Weitzel *et al.*, 2006).

Research explains the role of industry process standards in facilitating communication, handover of information and managing production processes in firms (Davenport, 2005). Other studies have examined how industry standards facilitate commerce, innovation and the growth of firms (Blind *et al.*, 2010; Swann, 2010). Davenport (2005) explains that process standards improve the firm's capacity to coordinate business processes such as outsourcing activities. In construction, studying the role of industry process standards is important because, BIM process standards for instance, are rapidly becoming integral to the delivery of construction projects, with huge implications for the firms, clients and other stakeholders.

The large body of literature on industry standards emphasises different aspects depending on the researcher's interests. For example political scientists study laws, power relations and legal interpretations (Hawkins *et al.*, 1995) and sociologists focus on the social infrastructures (Star, 1999; Brunsson and Jacobsson, 2000; Lamb and Kling, 2003; Busch, 2011). Institutional theorists address institutional rules (Garud *et al.*, 2002; Jain, 2012); whereas computer scientists focus on technical compatibility and interoperability of information systems (incorporating hardware and software) (Choi *et al.*, 2004; Eastman *et al.*, 2010). Economists concern themselves with trade, division of labour, variance reduction and governance (David, 1985; David and Greenstein, 1990; Swann, 2000). Occasionally scholars transcend disciplinary boundaries to unravel the complex world of standards.

Within the economics literature, Swan (2000) argues that industry standards provide compatibility between products or systems of production; they enhance quality and reduce transaction costs. Furthermore, industry standards are viewed as promoting the understanding of new technologies by providing elaborate information about products, processes and services (DTI, 2005 p.12). Industry standards are to be distinguished from internal standards, which are discussed in studies of firm capabilities (Chandler, 1990, Nelson and Winter, 1982) as routines or internal procedures. Topics such as network externalities (Katz and Shapiro, 1985; Langlois and Savage, 1997), modularity (Baldwin and Clark, 2000), knowledge transfer infrastructures (Nelson and Nelson, 2002) and technical compatibility (Sanchez and Mahoney, 1996; Allen and Sriram, 2000; Hanseth *et al.*, 2006), feature prominently in studies of standards. Building upon this work, the research examines how the large construction firm adapts to sets of industry BIM process standards.

Industry standards in this research refer to the sets of industry level specifications “to which all elements of products, processes, formats, or procedures under its jurisdiction must conform” (Tassey, 2000 p.588). Industry standardisation is often associated with the development of the industry standard either through the voluntary and consensus driven processes (de -jure standardisation see Section 2.3.2), and/or through the efforts of a single organisation (*de-facto* standardisation see Section 2.3.2). However, standardisation can also be associated with the application of the industry standard to fulfil the standard’s economic intentions (Jakobs, 2006). Generally, firms that adopt an industry standard, voluntarily commit to operate within the requirements of the standard in order to benefit from the network effects of the standard. However, the customised nature of construction products raises pertinent issues about whether or not it is feasible to apply the standards without the localised adaptations addressed in Dubois and Gadde (2002), which may be necessary to exploit the economic intentions of the standards.

Firms adopt *de-facto* standards, which do not develop by consensus but become widely available for public use upon agreement with the developing firm, in order to benefit from the network of the standard’s users (Brunsson and Jacobsson, 2000). *De-facto* standards are popular in information and technology industries. Since they are proprietary in nature, the developer firm usually maintains tight control over them. Prahalad and Hamel (1994) note that such standards enhance the developer firm's strategic capabilities and market dominance. *De-jure* standards – the concern of this research, are consensus driven, open, and usually agreed at the national or international level (Tassey, 2000; Swann, 2010). Studies explain how competing interests between multiple stakeholders are managed during the development of *de-jure* standards (Foray, 1994; Jakobs, 2011). Such research has generated new insights into standards development and the implications for the users.

De-jure standards can be categorised as product, process and technical. The International Standards Organisation (ISO) 9001 is an example of a popular industry process standard used in quality management of production process, which has received research attention. In relation to BIM, technical standards include for example the IFC standard. Technical standards are associated with digital design tool compatibility and interoperability (BuldingSmart-UK, 2013). Proprietary digital design tools used in construction include AutoCAD, Revit, ArchiCAD and Microstation. Technical standards also facilitate collaboration in the use of digital technological systems. Since the introduction of CAD technology in the early 1960s, there has been significant research attention to technical standards such as the STEP, IFC and Model View Definition (MVD) standards under the computer integrated construction theme (Björk, 1992; Thorpe and Lewis, 1994; Wix, 1997). Recent advances in BIM have similarly spurred national debates on the need for industry technical standards to support structured data creation using object based modelling technologies (Eastman *et al.*, 2010; Grilo and Jardim-Goncalves, 2010). Many technology scholars (Eastman, 1980b; Wix, 1997) investigated interoperability between digital tools that use technical standards to create digital 3D objects. Research in the use of technical standards in construction, has assisted in addressing challenges of data exchange between diverse digital design tools (Eastman, 1999; Howard and Björk, 2008). This research expands on this work by focusing on process standards that control collaborated information production and use during project execution.

1.4 Theoretical perspective

The study draws upon research on the organisational capabilities of PBFs advanced in Davies and Brady (2000) to understand the implications of adapting to industry BIM process standards for firms that develop the built environment. The PBF organisational capabilities theoretical perspective links ideas from the literature on the capabilities of the firm, projects, and project management (Davies and Brady, 2000; Hobday, 2000; Whitley, 2006). Project based forms of organisation are common in the film, aerospace and construction industries (Brady *et al.*, 2005c; Hobday *et al.*, 2005; Nightingale *et al.*, 2011). Research on the PBF organisational capabilities has improved insight into how firms engaged in the production of built environment develop the strategic, functional and project capabilities required to deliver projects and sustain competitive advantage. For instance, Gann and

Salter (2000) explain that PBFs require capabilities to integrate business and project activities, learn from projects, manage project-based activities, and the dynamic capabilities to adapt to changes in their business environment. Davies and Brady (2000) argued that for PBF to realise production efficiencies and sustain competitive advantage, they require project capabilities. The notion of project capabilities refers to the "distinctive managerial knowledge, experience and skills, which are located within a single organisation (a firm) and required to establish, coordinate and execute projects." (Davies and Brady, 2015, forthcoming no page). By drawing upon the PBF organisational capabilities theoretical perspective, it is possible to explain how the adaptation of BIM process standards influences the firm's development of skills, knowledge and other relevant resources required to manage and deliver construction projects.

The literature on the PBF organisational capabilities has links to theoretical ideas on the resource-based view (RBV) of the firm (Penrose, 1952; Richardson, 1972; Chandler, 1990); technological innovations, organisational learning and adaptation (Teece, 1986; Tushman and O'Reilly, 1996); economics of innovation (Freeman, 1985; Dosi *et al.*, 1988) and systems of innovation (Lundvall, 1985; Carlsson and Stankiewicz, 1991). A PBF's organisational capabilities are the to be bundles of knowledge, experience and skills required to organise, integrate and coordinate the services of suppliers, manage non-routine tasks and respond to changing client demands (Davies *et al.*, 2014). Even as research highlights the capabilities of PBFs (Brady *et al.*, 2005a; Grabher and Thiel, 2015; Winch and Leiringer, 2015), the adaptation of industry BIM process standards stimulates new insights into the way construction PBFs improve their competitiveness.

There are key issues to be understood about the nature of innovation in construction. For example, Winch (2010) explains that construction involves interactions between multiple actors, projects are unique and temporary meaning that knowledge transfer from one project to another is difficult. Moreover, the individual firm has limited influence over the project. Others have argued that construction is a complex systems industry which produces complex products and systems (Miller *et al.*, 1995; Hobday, 1998). For some, the construction process involves many interdependent interactions between systemic components (Hobday, 1998; Engwall, 2003; Davies and Hobday, 2006). Gann and Salter (2000) presented a model outlining the systemic components such as PBFs, the technical infrastructure, suppliers, projects and the regulatory framework. In the background of such a complex systemic innovation environment, the study is relevant to understand how the construction firm adapts to industry BIM process standards to improve its functional efficiency and strategic advantage. Through this research, it is possible to understand the barriers and enablers, and the perceptions of those embedded in business and project environments, as BIM process standards increasingly become a feature in the performance of production activities in complex systemic innovation environments.

As explained in section 1.2.3 above, construction PBFs are perceived to be embedded in systemic innovation environments that play a role in their innovation activities (Kangari and Miyatake, 1997; Gann and Salter, 2000; Blayse and Manley, 2004). The innovation activities are broadly viewed as encompassing the adaptation of new technologies, problem solving and activities in projects and the development of capabilities (Winch, 1998; Dodgson *et al*., 2005). Figure 1.1 below illustrates the position of the construction firm, its systemic innovation environment and its projects. This research stimulates pertinent questions about the business, project and systemic interactions that facilitate the process. Issues raised include, the nature of its interaction with new technology, the sense making process, enablers and hindrances the firm faces. What are the implications to the development of technical skills and knowledge within the construction firm? This research raises a number of issues in relation to industry BIM process standards that need addressing. Addressing these issues is essential in building an understanding of how PBF engaged in the production of built facilities adapt industry-wide process standards. In the next section, the research’s aim and objectives are set out.

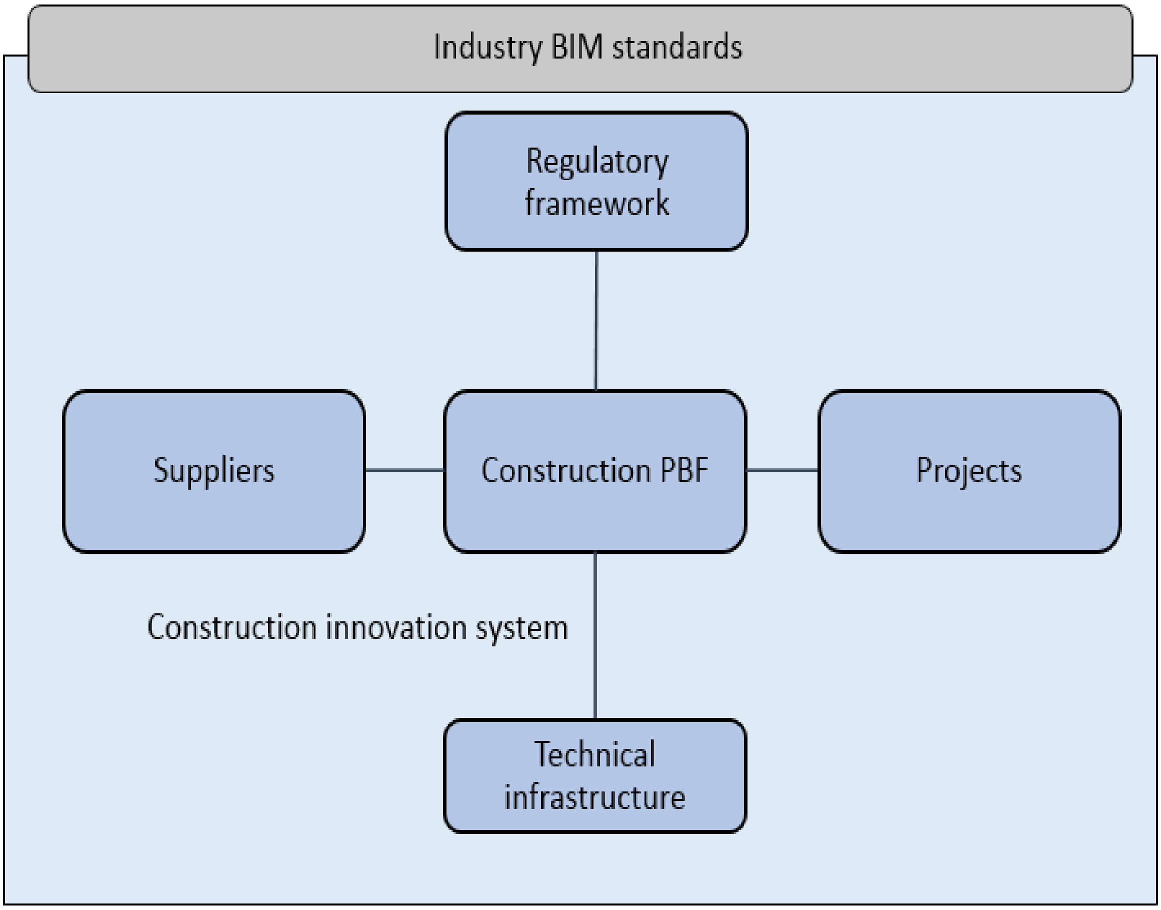

Figure 1:1 Industry BIM standards, Construction PBF and construction innovation system[3]

[3] Framework of interactions adapted from Gann and Salter (2000)

1.5 Aim and objectives

The aim of the research is to investigate how a large construction firm adapts to new industry-wide BIM process standards in order to achieve and sustain competitive advantage.

To address the research aim, the research objectives focus on the application of industry BIM process standards in relation to the barriers and enablers, how the standards are used in construction projects the firm is engaged, and the firm's ability to develop its capabilities through learning, interacting and sharing knowledge with others within the construction innovation system. The specific research objectives are:

- What are the barriers and enablers of new industry BIM process standards use within a large UK construction firm?
- How are new industry BIM process standards used in the projects of a large UK construction firm?
- How does the application of new BIM process standards transform the construction firm's interactive relations with systemic innovation actors such as suppliers, universities and clients?

1.6 Research scope and contribution

1.6.1 Research scope

Section 1.2.2 explains that technical standards such as the IFC standard support interoperability and compatibility of digital design technologies. Process standards such as the PAS 1192:2012 (1-3) play a role in providing a framework for collaboration in BIM enabled projects (BIM Task Group, 2015). The industry process standards constitute a new way of doing things developed with little influence from the construction firm. Therefore, they do not contain the firm's experiences. The individual large construction firm's experiences as a user of BIM process standards is the focus of this research. Since the research focuses specifically on that, it is not concerned with the consensus driven processes of developing industry process standards.

1.6.2 Research contribution

The study contributes to research on BIM, industry process standards, PBF organisational capabilities and innovation in construction. It contributes to the formulation of policy around new technologies such as BIM at the firm, industry and government levels. The research will be useful in guiding the implementation of BIM process standards in UK construction firms. Finally, the research will provide insights into the adaptation of voluntary, industry-wide process standards in firms engaged in the production of the built environment.

1.7 Research methods

This research uses a case study strategy to provide an in-depth account of the human experiences of using BIM process standards. Case studies provide a contextually bounded rich, in-depth analysis of the phenomenon under study (Stake, 1995). The research adopts an interpretive paradigm to understand how people make sense of the new industry BIM process standards and adapt them as part of their day-to-day production processes. According to Creswell (2007), an interpretive paradigm is useful when the researchers intention is to interpret the meanings attached to phenomenon by participants. Adopting an interpretive paradigm helps to understand how industry BIM process standards are adapted, the complexities faced by those involved in the adaptation and the meanings they attach that may influence the organisation's behaviour. To that extent the research will focus on the new forms of organising work that emerge, the challenges faced and the requirements for the standardisation of BIM process standards within a large construction firm.

The research process involved a preliminary interpretive investigation to gain appreciation of the research phenomenon and inform the detailed case study. The preliminary phase was useful to assess the suitability of the research instruments such as the data collection methods, criteria for identifying research participants and the data analysis techniques. The preliminary study provided important information about the firms' participating in BIM standardisation in the UK construction industry. The second phase involved an in-depth inquiry using a case study strategy to develop an understanding of the experiences of adapting industry BIM process standards in a large UK construction firm.

Qualitative data was collected using interviews, observations and from secondary publications. The collection of qualitative data was naturalistic, meaning that the researcher embeds themselves within the participant's social setting (Kvale, 1996). Data collection lasted nine months. The thematic data analysis technique was adopted to code and synthesize the data. Data analysis was iterative, emergent and flexible enough to manage voluminous qualitative data. Thematic data analysis was preferred because it supported the identification, analysis, and building of themes within the collected data set (Braun and Clarke, 2006). As explained in Section 1.4 above, the PBF organisational capabilities theoretical framework was useful to make sense of the findings.

1.8 Structure of thesis

Evans *et al.* (2011) argues that a thesis should be comprised of four sections covering the introduction, background, core and synthesis as illustrated in Figure 1.2 below. The four sections described by Evans *et al.* (2011) are as follows. Chapter 1 forms the introduction. Chapters 2 and 3 provide the background i.e. theoretical and empirical respectively. Chapter 2 discusses the theoretical background and explores the links between the literature on industry process standards, PBF organisational capabilities and innovation in construction.

The chapter concludes with a presentation of the conceptual framework used to make sense of the research findings. Chapter 3 engages with the wider debate on BIM implementation in the UK construction industry. This is important to situate the research within the discussions of productivity, innovation and competitiveness in UK construction.

Chapter 4 and 5 are the core of the thesis. Chapter 4 discusses the interpretive research approach, the research strategies, data collection methods, data analysis techniques and ethical considerations. Chapter 5 presents the findings of the empirical work on BIM process standards adaptation within the large UK construction firm. The findings show how the adaptation of industry BIM process standards shapes the firm's business and project processes, and its ability to achieve and sustain competitive advantage.

Chapters 6 and 7 form the synthesis. Chapter 6 discusses the research findings in relation to the conceptual framework presented in Chapter 2. The discussion highlights the contributions of the research to work on the capabilities of PBFs in construction, industry process standards and innovation in construction. Chapter 7 concludes with an explanation of how the research aim and objectives are fulfilled. The chapter identifies the key theoretical and practical contributions made by the research. Limitations of the research and directions for further studies are highlighted.

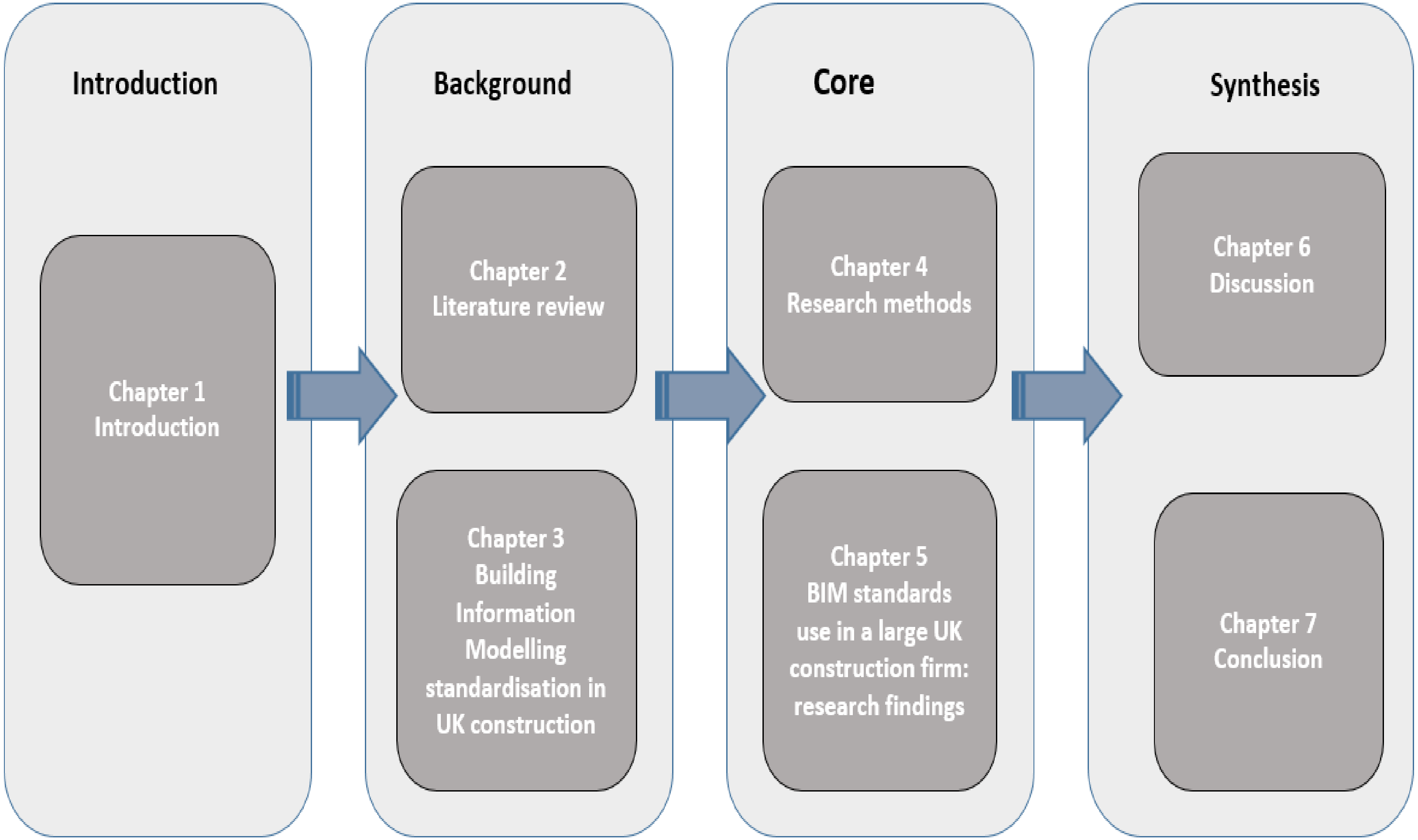

Figure 1:2 Layout of thesis chapters

Chapter 2: Theoretical background

2.1 Introduction

Building upon the introduction in Chapter 1, this chapter provides a theoretical background to the research. The discussion focuses on innovation in construction, standards and the project based firm organisational capabilities, to articulate the limitations of the contemporary literature in relation to industry process standards. The chapter is structured as follows; section 2.2 discusses the literature on innovation in construction, and section 2.3 discusses research on standards and standardisation, and the limitations. Section 2.4 discusses research on the capabilities of PBFs, whilst section 2.5 presents the theoretical framework and explains the reasons behind its adoption. Section 2.6 summarises the chapter.

2.2 Innovation in construction

The vast literature on innovation covers a variety of topics including technological change in the built environment (Nam and Tatum, 1997; Gann, 2000b; Dulaimi *et al.*, 2002; Harty, 2005; Manley, 2006; Whyte and Lobo, 2010; Akintoye *et al.*, 2012). In this area, a range of topics have been addressed by scholars including the: *sources and drivers of innovation* (Nam and Tatum, 1989; Salter and Gann, 2003; Bossink, 2004); *the models of innovation* (Miozzo and Dewick, 2004; Manley, 2008); and the *adoption, implementation* and *diffusion* of technological innovations (Emmitt, 1997; Larsen and Ballal, 2005; Peansupap and Walker, 2006). Yet others consider how firms that produce the built environment innovate through adapting new technologies (Whyte, 2003; Dodgson *et al.*, 2005). Within this latter strand, some studies have shown that innovation is complex because project organisations that deliver complex products and systems (CoPS) involve the activities of many actors (Hobday, 2000; Davies *et al.*, 2004). Here, studies have shown that a firm has little control over project activities, learning between and from projects is difficult, and knowledge transfer is hard to achieve due to the temporary nature of project teams. Hence, PBFs have to create project capabilities to achieve and sustain competitive advantage (Davies and Brady, 2000; Dodgson *et al.*, 2002; Keegan and Turner, 2002; Hobday *et al.*, 2003; Nightingale *et al.*, 2011).

The concept of the PBF advanced in Hobday (1998) identifies firms that use projects to organise production activities. Projects are thus central to the firm's ability to deliver its business functions and sustaining competitive advantage. The project environment therefore forms the core business environment in which the construction firm innovates and performs its business activities (Gann and Senker, 1993). The next section situates this type of work within the wider innovation discourse.

2.2.1 The landscape of innovation research

Since the publication of The Wealth of Nations by Adam Smith (1776; (2005)), classical economic theory has treated the firm as a 'black box' and not offered enough to explain the growth of economic systems. Classic economic theory according to Coase (1937), argues that the economic system is coordinated by price and cost mechanisms. Adam Smith views this coordination as the 'the invisible hand' of the market (Grampp, 2000). Neoclassical economic theory departed from this view arguing that the economic system is driven by the way firms employ resources (Veblen, 1898). Coase (1937) notes that this was the intellectual foundation of transaction cost economics. Joseph Schumpeter (1928) queried the idea that the organisation of resources accounts for the growth of economic systems, arguing instead this was insufficient to explain the emergence, death and growth of firms and in turn economic systems. He advanced the concept of creative destruction (Schumpeter, 1942) to explain how the path dependant nature of technological innovation influences the growth and lack of growth of economic systems. Schumpeter (1942) advances the idea that technological innovation is at the centre of the growth and destruction of economic systems[4]. Drawing insights from evolutionary approaches in biology, Schumpeter (1934) claims that the ability to innovate leads some firms to grow whereas the absence of

[4] This is referred as technological change or Schumpeterian innovation

innovation explains their death. According to Freeman (1985), Schumpeter’s views laid the foundations upon which the vast body of work on the economics of innovation is built.

Schumpeter defined innovation as the “new consumers’ goods, the new methods of production or transportation, the new markets, and the new forms of industrial organization” (Schumpeter, 1942 pp.82-83). Moreover he considered the innovation process to be inherently risky, uncertain and heavily resisted (Schumpeter, 1934). He explains that the entrepreneurial firm was central to technological change arguing that those efforts by firms to change the way they produce, market and organise production activities were at the heart of the growth of economic systems. The function of the firm accordingly was to break the social resistance to change and manage resources productively (Schumpeter, 1928 p.380). However, a common critique of Schumpeter’s work is that it does not account for the role of users in the innovation process (von Hippel, 1976; Nelson and Winter, 1982; Lundvall, 1985; von Hippel, 1988; Freeman, 1992).

Schumpeter’s evolutionary approach discussed above did not explain how some firms perform better than others (Penrose, 1952). Developing on the evolutionary idea, Penrose (1955) argues that such a view did not sufficiently explain the differential performance and variations in the growth of firms. Penrose (1959) insists that the firm is a combination of unique internal resources and competences developed from the firm’s idiosyncratic experiences. Building upon these ideas by Penrose, scholars have advanced the resource-based view (RBV) which argues that the creation of valuable, rare, inimitable and non-substitutable internal resources, skills, competences and knowledge (Barney, 1991; Teece *et* *al.*, 1997) explains the variation in the growth and performance of firms. The RBV view however is criticized by some scholars for being static, i.e. it assumes that firms operate within the confines of a given state of resource and skill configurations (Priem and Butler, 2001). Moreover, the RBV concept does not explain how firms regenerate resources (Teece, 2007). Chandler, *et al.* (1998) argues that focusing on the firm's internal capabilities relegates to the periphery the importance of the external environment. Therefore, even though the firm's internal environment plays an important role in keeping the firm distinct and unique, the firm is embedded within a systemic innovation environment.

The innovation literature has grown significantly, broadly covering different aspects such as the role of the individual, organisation, the environment and interactions between firms. As studies focus on the role of the individual, emphasising that firms have bounded rationality (Pettigrew, 1985; March, 1991); others scholars have focused their attention on the implications of organisational structure and the environment (Slappendel, 1996; Swan *et al.*, 1999). Whereas some studies have approached the subject of innovation from an interaction perspective, focusing on action and structure (Van de Ven and Poole, 1990; Hargrave and Van de Ven, 2006), another approach that is closely linked to the interactive approach, is the innovation systems perspective. Here studies emphasise that the firm is embedded within a wider systemic environment. Knowledge creation, exchange and retention, user-producer relations, feedback loops, interactive learning and institutional environment are seen as determinants of the innovation process (Freeman, 1982; Nelson and Nelson, 2002; Lundvall, 2013).

2.2.2 The systems of innovation approach

The systems of innovation (SI) view place the roles of knowledge and learning at the centre of the growth and differential performance of economic systems (Freeman, 1992; Edquist, 1997; Lundvall, 1998; Malerba, 2005; Dodgson *et al.*, 2008b). Scholars that champion this view argue that in the knowledge economy, firms do not innovate in isolation but collaborate with many other firms, non-firms, and innovation is influenced by the institutional environment (Lundvall, 1992; Nelson, 1993; Malerba, 2002). They add that feedback between firms facilitates learning and knowledge flow (Freeman, 1982; Dosi *et al.*, 1988; Lundvall, 1992). Behind this view is the argument that systemic interactive relationships, feedback, learning and knowledge flow between firms and the institutional environment influence technological change (Freeman, 1995; Carlsson *et al.*, 2002).

The expressions of *national* (Edquist, 1997; Lundvall, 2013); *sectoral* (Malerba, 2005); *regional* (Geels, 2004) and *technological* systems of innovations (Carlsson *et al.*, 2002) have been advanced by scholars to differentiate innovation systems for analytical purposes. A common critique of the SI idea is that there is no clarity on the delineation of the innovation system's boundaries, and the function of the system (Hekkert *et al.*, 2007). Edquist (1997) argues that the SI concept seldom addresses the factors that influence innovation. Even as some scholars contend that the purpose of systems is to create and manage knowledge (Carlsson *et al.*, 2002; Fagerberg *et al.*, 2005; Godin, 2007); others argue that analytical boundaries are not adequately explained. Hence Lundvall and Johnson (1994) argue that focus should be on the operational level where knowledge flows are easy to delineate. Such an approach according to Lundvall (2010) yields better insight into the creation and management of knowledge.

2.2.3 The systemic nature of innovation in construction

Despite the criticisms of the SI approach highlighted in Section 2.2.2 above, Miozzo and Bewick (2004) showed that construction firms can improve their ability to compete through sourcing knowledge from the systemic innovation environment. In case studies of innovation in small Australian construction firms, Manley (2008) shows that interactions with advanced clients, prioritising relationship building and protection of intellectual property facilitate improvements in the capabilities of the small firm. Manley's (2008) argues that institutional and regulatory environment play a role in the development of construction firm capabilities. Drejer and Vinding (2006) argued that the problem for construction is not only about the temporary nature of projects, but also the ability of the construction firm to anchor and transfer knowledge. Hence, there is a view that innovation in construction requires the management of internal capabilities, institutional issues, and the systemic innovation environment where the firm is embedded (Miozzo and Bewick, 2002; Manley 2008; Gann, 2000).

The SI approach has links to the idea of high cost complex products and systems (CoPS) (Miller *et al.*, 1995), that has been advanced to explain the complex capital goods that are produced by industries such as construction. CoPS production occurs in complex environments involving many interdependent linkages between clients, principal contractors, subcontractors, designers, regulators, government, material suppliers and specialist suppliers (Hobday, 1996; Davies, 1999; Acha *et al.*, 2004; Dorée and Holmen, 2004). Research has shown that firms that produce CoPS such as rail stations, airports, schools and roads are embedded in systemic interactions (Gann and Salter, 2000; Sydow *et al.*, 2004; Brady *et al.*, 2005b) that influence their capacity to innovate. Figure 2.1 below outlines an analytical model of the construction innovation system[5]. Gann and Slater (2000) argue that the components involved in the production of built facilities are the project-based firms, technical support infrastructure, regulatory institutions, and supply networks. Whilst the model is important to identify the key components, limitations are that the model does not sufficiently explain the nature of interactions between the actors inside the components.

[5] Drawing insight from Gann and Salter (2000), Manley (2008) and Seaden *et al.* (2003), the term construction innovation system is used to refer to the systemic innovation environment in which the construction firm is embedded. The systemic actors are conceptualised as the PBF, projects, technical infrastructure, suppliers and regulatory framework. These are the key components of the innovation system that designs, constructs and maintains the built environment.

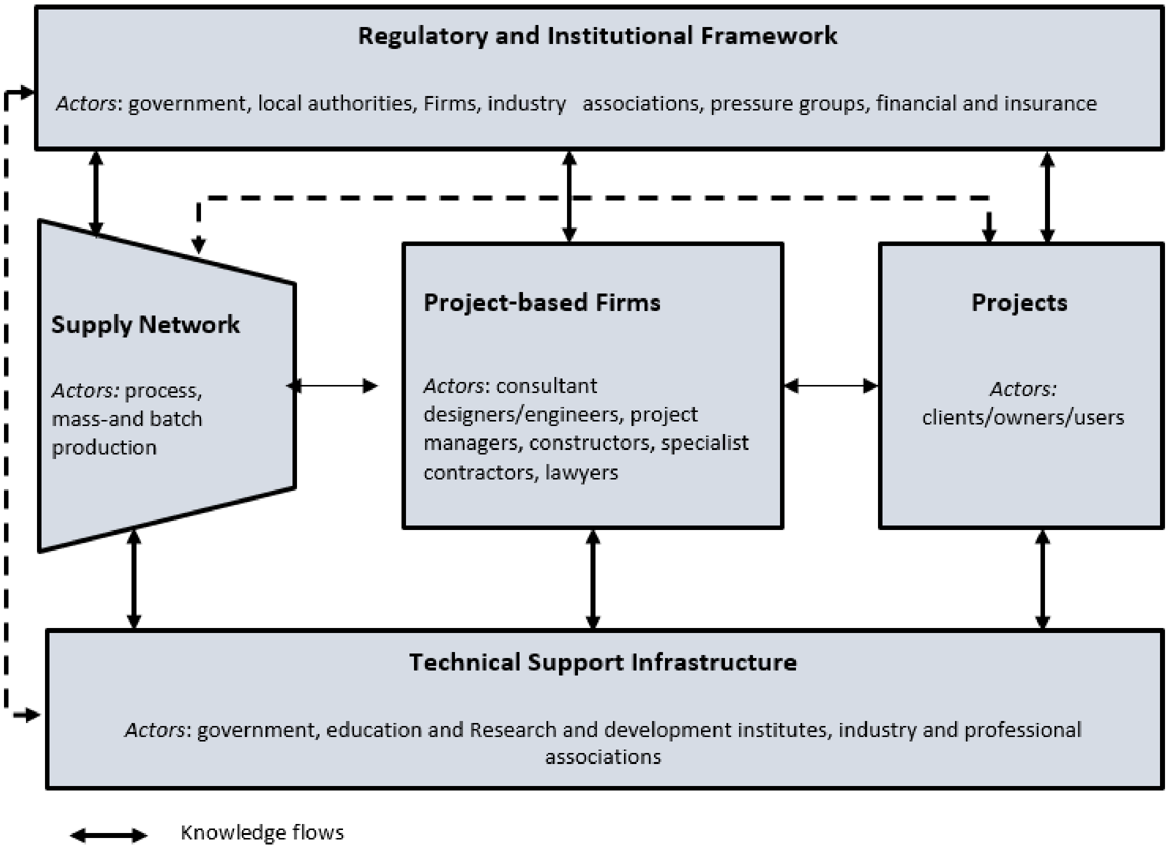

Figure 2:1 Model showing knowledge flows in construction activities[6]

2.2.3.1 Distributed nature of resources in construction

The interface between the PBF and its project has been the subject of intense scrutiny by researchers (Nightingale, 2000; Gann and Salter, 2003; Nightingale *et al.*, 2011; Whyte and Lobo, 2015). Figure 2.2 below shows an illustration of the flow of resources between the PBF and the project. Gann and Salter (2000) argue that the effective integration of resources by the PBF is important for the firm to perform its business functions. As illustrated in Figure 2.2, the project sits at the margins of the firm's influence. The project involves

[6] Sourced from Gann and Salter (2000 p.960)

heterogeneous firms whose interests may not align with those of the construction PBF. Therefore, important issues to be understood are: a) how an industry level consensus driven standard is applied in such an environment. b) It is also essential to understand the experience of adapting an industry standard in an environment where resources are distributed in business and project activities. c) Finally, within the PBF's business environment interactions occur with many firms, some of which form an important source of knowledge for innovation activities. It is important to understand how the application of industry process standards affects systemic interactions with such sources of knowledge. Figure 2.2 shows that the PBFs is involved in knowledge exchange activities at both levels (Winch, 1998; Gann and Salter, 2000). Research has yet to explain how the flow of resources within the firm is transformed by the adaptation of industry process standards, and whether or not the PBF's influence on project activities is altered. These issues are important to understand the nature of innovation activities in construction, as BIM process standards are adapted in the construction PBF.

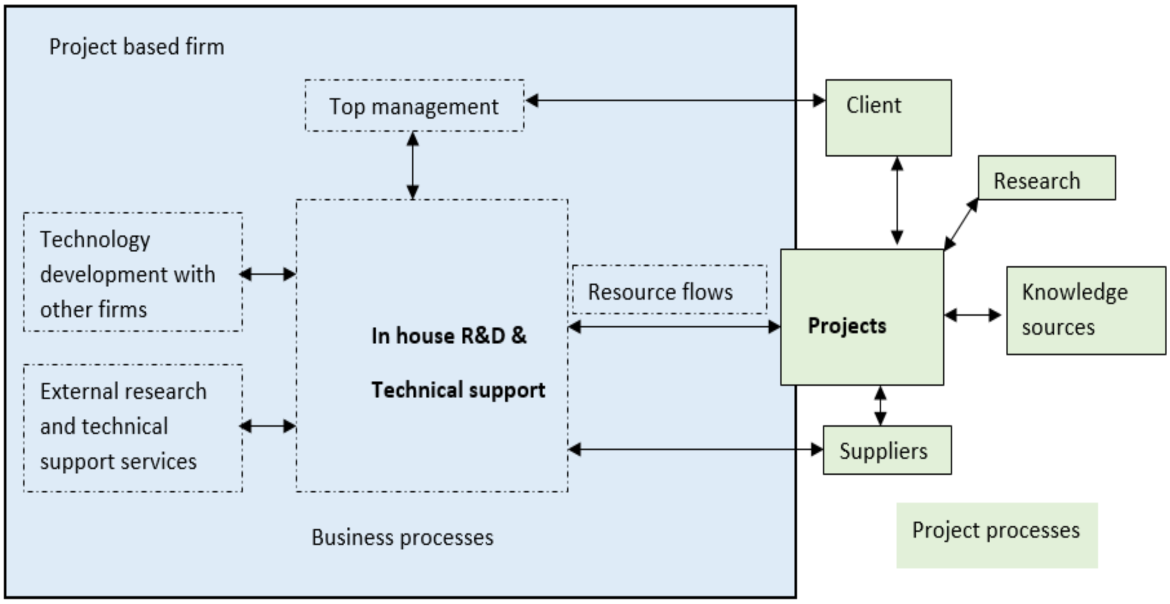

Figure 2:2 The distribution of resources in construction PBFs[7]

Winch (1998) presented a model of innovation in construction as shown in Figure 2.3.

He explained that at the business level, the PBF sources new technologies from the external business environment and is thus involved in adoption and implementation activities. The project acts as the platform to address problems and to learn. Hence, he argued that projects are the primary environment for learning and problem solving activities in construction. Since the project has its own external environment and the project sits at the

[7] Sourced from Gann and Salter (2000 p. 969)

margins of the firm's influence (Gann, 1993; Miozzo and Dewick, 2004) the adaptation process becomes an interesting area to study because of the complexities, uncertainties, risks, and negotiations that may be involved.

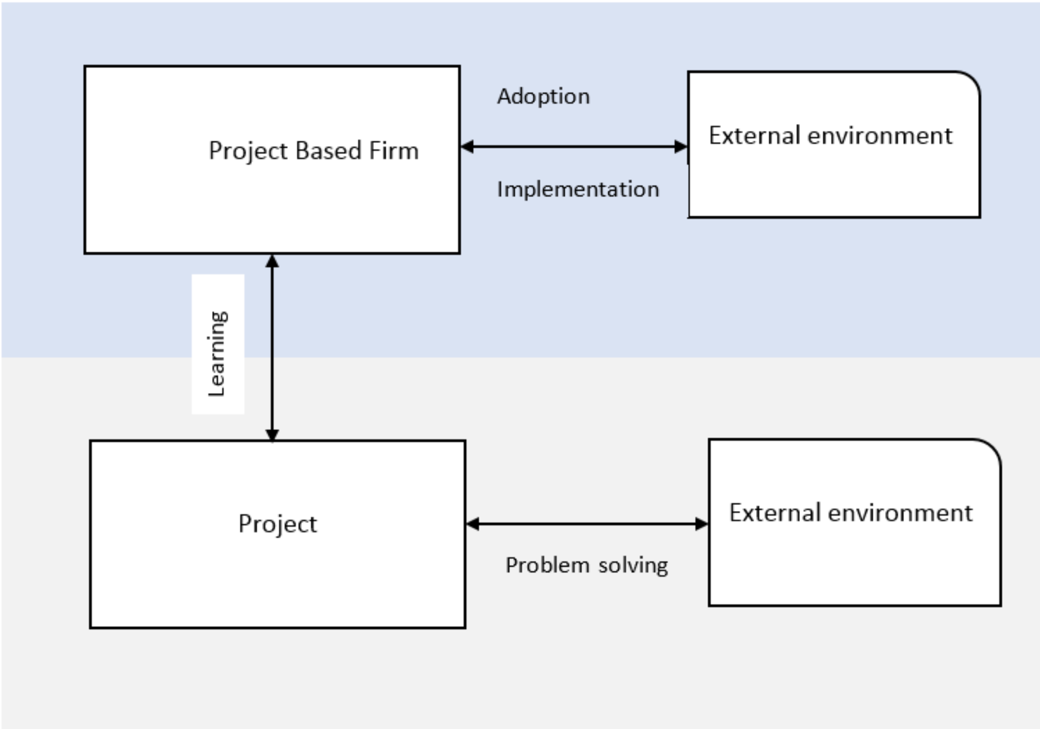

Figure 2:3 Process of innovation in constructing the built environment[8]

2.2.4 Types of innovation in construction

Schumpeter (1942) distinguishes between five types of innovation namely: new products, new production processes, and new sources of supply, new markets and new ways of organizing the business. Fagerberg *et al.* (2005) argues that product and production

[8] Source from Winch (1998 p.273)

technology distinctions are important because they address the creation of products and production processes. Subsequently, research has focused on product and process innovations because of their wide-ranging social impacts.

Edquist *et al.* (2001 p.07) explains that distinguishing between taxonomies of innovation is important to conceptualise innovation. Edquist *et al.* (2001 p.11) subdivides process innovations into technological and organisational innovations arguing that new goods for production (i.e. technological process innovation) often lead to changes in the organisation of production processes (i.e. organisational innovation). Product innovations relate to changes in existing, and/or the development of new physical products, whereas process innovations are changes in the ways of creating products and services (Tidd *et al.*, 2005). Product innovations are associated with the outcome of process innovations, i.e. what the business delivers to its clients; process innovations focus on the new processes of controlling and organising production processes (Dodgson, *et al.*, 2008). Reichstein *et al.* (2005) explain that these two types of innovations have intricate linkages that make it difficult as well as interesting to study. This research focuses on both process and organisational innovation arguing that innovation in the development of or adoption of a new standards can stimulate waves of process and organisational innovation in the adopting firm. Hence, it is argued that a multi-pronged approach is essential to address user feedback into the development of a new standards i.e. continuous development of the industry process standard, and innovation within the user's organisational environment i.e. the building of capabilities or organisational transformations.

2.2.5 Extent of innovation in construction

2.2.5.1 Incremental and radical innovations

The extent of innovation has implications for the way the firm approaches its adaptation. For instance, radical innovations are a departure by a technology from the underlying norm, whilst incremental innovations are minor changes in the existing technology (Tidd *et al.*, 2005). Therefore, investment by management required to adapt to incremental and radical innovations differs. Incremental and radical innovations have improved the ability to predict the employing of external technologies in firms (Dewar and Dutton, 1986). Tidd *et al.* (2005) argue that radical innovations can dramatically shift an organisation’s underlying technologies, markets, social and regulatory structures. These ideas show how the extent of innovation may influence the trajectory of adaptation by the firm.

Slaughter (1998) investigated radical, incremental, systemic, architectural and modular innovations. She argues that incremental innovations can necessitate localized changes to production processes (Slaughter, 1998). Given that, construction projects are often temporary and unique, an important question is how firms innovate and transform their capabilities to benefit over the long term. Radical innovations shift the knowledge of the firm, and the structure of the industry, and have unpredictable implications for the adopting firm (Slaughter, 2000). These understandings of the extent of innovation are important in conceptualising the implications of adapting industry-wide process management standards within a large construction business.

2.2.6 Sources of innovation in construction

Studies of innovation have advanced different models to explain the process of innovation. Common models include the science – push model, market pull model, the coupling model, and systems integration model (Freeman, 1992; Rothwell and Dodgson, 1992; Hobday *et al.*, 2003). Most of these models emanate from a view that R&D plays an important function in innovation. Von Hippel (1986) argues that R&D is not the only important factor; instead, users have an equally important function. In advancing the SI idea discussed in Section 2.2.2 above, Lundvall (1992) acknowledges the influential role of user-producer interactions. Slaughter (1993) concludes that interactions with new technologies can stimulate further innovation within the adopting firm. Other scholars have suggested that the use of new technologies can be a source of new localised solutions (Ling, 2003; Bossink, 2004). Therefore, the process of innovation is interactive, users of technologies play a role, and the use of new industry-standards may affect the firm's ability to innovate.

The above discussion has shown that the complexities and influences of the institutional environment are relevant to the debates on innovation in construction. The systemic nature of innovation in construction has been discussed before (Miozzo and Dewick, 2004; Manley, 2008). Engwall (2003) argues that projects are "contextually-embedded open systems" (p.790). The "operations at project level, … projects at the organizational level, and central routine activities of the firm" are embedded in systemic interactions (Engwall, 2003 p.791). This shows that the systemic nature of the environment is a factor in understanding innovation in construction.

Consideration of this literature on innovation in construction suggests that it does not sufficiently address the following: a) The complexities of adapting industry process standards in PBFs. b) The types of innovations that result from the adaptation of industry process standards, and finally c) the interactive learning and knowledge sharing activities between the numerous actors that occurs at the operations level that is foundational level are not sufficiently captured. It is further noted that adopting a systems approach offers a better insight into the relationship between industry process standards use and innovation in firms that produce the built environment. The next section focuses on the literature on standards and standardisation.

2.3 Standards and standardisation

Standardisation has a long history and the concept attracts many meanings[9]. Whilst standardisation may refer to what has been described as the "turning of a desired action into a default action" (Price and Lu, 2013 p.50). As explained in Section 1.3, the research views standardisation as the application of an industry standard. The Henry Ford automobile producing company has used standardisation to maximise production economies (Baldwin and Clark, 2000). In the Japanese construction industry, the production of homes using

[9] For a detailed account of standards and standardisation, the reader is referred to Lampland and Star (2009).

standardised components has been successful with important lessons for other countries (Gann, 1996). However, in the UK, standardisation has been successful in the production of standard components such as precast concrete panels, windows, doors and roof tiles components. The underlying view is that productivity can be improved through prefabrication, manufacturing standard products in bulk, and production in factory-controlled conditions (Barlow and Jashapara, 1998). Many of the available studies of standards in construction are directed at the production of physical components. A case has been made for the development of IT based process standards for information management to be used in quality management (Sommerville *et al.*, 2004). Studying the application of established industry process standards is important to understand the implications of standards. In this section, the discussion focuses on the concepts of standards and standardisation.

2.3.1 The economics of standards

Standards are found in many aspects of social and economic life. There are standards for managing the quality of products and services, health and safety, environment and energy management and compatibility of information systems (Tassey, 2000; Blind *et al.*, 2010; International Organization for Standardization, 2015). According to Blind (2006) standards are characterised by explicit rules for regulating human behaviour; voluntary in most instances which means that they are not formally enforced, and are developed for broader and unrestricted adoption. This means that standards are open to interpretation, even though the adopters commit themselves to act according to the requirements of the standard.

Due to their broad reach, scholars and practitioners approach standards differently. Swann (2000) notes that the "academic community around standards is multi-disciplinary and the practitioner community multifaceted". Whilst there are different approaches to standards, some economists have focused on the impact of standards on the economic system (Blind, 2006). A strand within the economics of standards literature investigates the relationship between standards and innovation. There is a view that standards can enable and/or hinder innovation depending on the mix between regulation intensity and market entry barriers. For instance studies have attempted to explicate the conditions under which standards enhance or hinder innovation (David and Greenstein, 1990; David and Steinmueller, 1994). At the micro economic level, studies have sought to explain how standards influence the firm's ability to achieve and sustain competitiveness (David and Greenstein, 1990; Swann, 2000).

Studies of standards have addressed different topics, for instance, some focus on law and regulation (Kahan and Klausner, 1997), and the strategists emphasise the first mover advantages through standards (Lieberman and Montgomery, 1988), engineering and process managers concern themselves with quality management and production economies (Dale and Oakland, 1991; Abdul-Rahman, 1995; Love and Li, 2000). Others have examined network externalities, modularity, technical compatibility and interoperability using standards in research of information systems (Katz and Shapiro, 1994; Baldwin and Clark, 2000; Yoo *et al.*, 2005; Weitzel *et al.*, 2006). Hawkins *et al.* (1995) argues that standards blend old ideas with new ones, thence they view industry standards as providing a 'bridge' for technological progression. Nelson and Nelson (2002) note that standards provide an infrastructure for collaboration. As a result, standards have received significant attention albeit from different angles.

2.3.2 Defining standards and standardisation

Industry standards are sets of voluntary, open, codified and commonly agreed specifications to which agreed common processes, formats or procedures are aligned (Tassey, 2000). Standardisation considered from the perspective of the user refers to the enactment of a standard to exploit its economic benefits. A distinction is made in this research between 'home grown', 'local' standards or internal standards that are established as best practice and are embodied in the firm's routines (Lundin and Söderholm, 1995), from voluntary, codified industry standards. Internal standards reflect a firm's norms and routines that are established from experience over time (Steinmueller, 2003). Internal standards are similar to what Davies and Hobday (2005) describe as product or service modules that are important in building project capabilities to achieve economies of repetition and recombination. In contrast, industry standards relate to the collection of best practice of the industry. Such standards are developed from consensus and are voluntarily adopted by the firm. A defining feature is that *de-jure* industry standards are not strictly enforced, in some industries such as construction, instead they may rely on perceived legitimacy (Brunsson *et al.*, 2012). The research focuses on industry process standards, because as noted in Davenport (2005), how such standards are brought to use and the complexities faced by the firm could benefit from empirical research.

2.3.3 Different traditions of research on standards

While this research draws on the literature on innovation in construction, particularly in relation to PBFs and organizational capabilities, there are different traditions of work on standards that have informed the development of the constructs. The discussion in the next subsections 2.3.3.1 – 4 explains these different scholarly traditions.

2.3.3.1 Standards as infrastructures for coordination

In sociology and organizational studies, industry standards are discussed as providing boundary objects and infrastructure. Star (2002) argued that standards are invisible infrastructures that become embedded in IT systems (Star and Griesemer, 1989b). In earlier work Star and her co-authors, advanced the concept of *boundary objects* to explain that standards provide an infrastructure that spans between social boundaries (Star and Griesemer, 1989a; Bowker and Star, 1999; Star, 2010). Brunsson and Jacobsson (2000) explain that standards provide a common language that can be uniformly interpreted by the individuals of a particular social grouping. Bishop *et al.* (2000) explain that in information systems, standards provide the infrastructure that supports communication, digital information exchange and coordination. Generally, the underlying view in this tradition is that standards provide a common language that mediates interaction between social groups.

2.3.3.2 Standards as routines

In economic studies, standards have been discussed as embodied in routines, where routines are seen as “regular and predictable behavioural patterns of firms” (Nelson and Winter, 1982 p.14). Following a similar view Langlois and Savage (1997) argue that standards are the “… the knowledge, routines, and capabilities that give economic value” (Langlois and Savage, 1997 p.157). Generally, the concept of routines is associated with internal standards. Whereas industry standards are different as they are considered to reflect the best practice of groups of firms.

2.3.3.3 The standard as an innovation

In economic theory, there are broad views about the economic functions of standards. Some studies address standards as innovations that help firms to achieve market dominance (Fontana, 2008), enhance network externalities (Kano, 2000; Zhu *et al.*, 2006), manage modularity (Langlois, 1999; Baldwin and Clark, 2000) and achieve compatibility (David, 1985; Farrell and Saloner, 1985; Katz and Shapiro, 1985; Schilling, 2000). For instance, studies of dominant designs such as Betamax, Compact Disc and Video Cassette Recorders have helped to explain the standard wars that firms engage in to sustain competitive advantage (David and Greenstein, 1990; Stango, 2004). In information systems, scholars explain that failure to develop a standard (i.e. innovation) and attract a network of followers could mean the loss of competitive advantage for the firm (Weitzel *et al.*, 2006; Funk, 2009). David (1985) notes that the costs of developing a dominant technology are high and attracting a network of followers can be complicated, hence many firms become 'locked in' to a dominant technology. Many of these studies focus on firms in industries other than construction.

Others describe different functions of standards as social technology for transporting knowledge and learning between economic actors (Nelson and Nelson, 2002; Fagerberg *et al.*, 2005). Drawing upon the SI perspective, Edquist (1997) explains that standards provide a facility to moderate knowledge sharing relationships, helping to foster a dominant convention of openness within the innovation system. Generally, studies of industry product standards in mass-production inform these views.

2.3.3.4 Standards as technology

In the economics of innovation, there is a view that standards provide the technology for reducing variety (Tassey, 2000 p.04). Here scholars emphasise that standards enhance production economies through variance reduction. By reducing variance, firms can maximise on economies of scale. Tassey (2000) explains that this may create issues for smaller firms especially if larger firms dominate the development of the standard. For instance, costs for aligning to the industry's standard may be higher for the smaller firm.

Rather than focusing on the use of product standards to reduce variations, the regulation, control and confining of people's behaviour is achievable with process standards. Such standards seek to align people's behaviour to a commonly agreed way of doing things (Hawkins *et al.*, 1995). Reducing variance in the way people behave reduces the costs of interaction and enhances the firm's ability to maximise production economies. The underlying view is that economic exploitation of resources is enhanced with the reduction of variety. The standard thus prescribes a common code for communication and behavior to those that adopt it. This research follows the view that industry process standards are ways of reducing variance.

2.3.4 Taxonomies of industry standards

The process by which industry standards develop often distinguishes them. *De-facto*[10] standards emerge from sponsorship by one or more actors that retain proprietary interest over the standard. In contrast *de-jure* standards result from consensus driven market mediated processes (Foray, 1994; Kano, 2000). In the UK, the development of *de-jure* standards is overseen by organisations such as the British Standards Institution (BSI). Table 2.1 below categorises *de-jure* standards and summarises the differences between them.

[10] Tassey (2000) defines de facto standards as standards that emerge out of no formal promulgation whereas de jure standards are formally developed codified standards that emerge out of consensus between economic actors.

2.3.4.1 Product standards

De-jure standards can be technical, product or process oriented. Product standards are associated with modularity, quality assessment and compatibility. Some studies address product standards as outcome standards because they define the particular characteristics of the product. Product standards ensure that products meet certain pre-agreed sets of specifications and quality requirements (David and Greenstein, 1990; Hawkins *et al.*, 1995; Tassey, 2000). Product standards can be used to minimize selection and diversity (Fagerberg *et al.*, 2005; Blind, 2009b). This allows firms to realise economies of scale and scope by producing to a set of agreed specifications (Freeman, 1995).

Studies of innovation in construction associate product standards with the production of components that form the built facility (Barlow, 1999). Research has shown that product standards have been useful in the mass production of built facilities in Japan (Gann, 1996). According to Davies and Frederiksen (2010), product standards allow components to be "specified, adjusted and integrated in various predetermined ways to meet the individual needs of each customer" (p.197). Polesie (2013) argues that the use of product standards in construction requires significant review having found that standards restrict choice thus limiting the ability to pursue different alternatives.

Type	Function	Economic purpose

Quality standards[11]	Social, determining minimum level of performance, compliance, reliability, protection, inform	Performance, assurance and regulation
Technical standards	Interoperability, compatibility and modularity	Manage interface between multiple technological systems
Product standards	Variety reduction, compatibility and modularity	Maximise economies of scale in production processes
Process standards or non-product standards[12]	Interface between processes, structuring of interactive relations between individuals and facilitate process integration.	Efficiency in the core production processes Efficiency in information management Coordination and control of human behaviour

Table 2:1 Types of *de-jure* standards

2.3.4.2 Technical standards

Hawkins *et al.* (1995 p.01) defines technical standards as “agreed external points of reference to which the physical and performance characteristics of technologies can be compared”. They also facilitate interface management between different technological systems. David and Greenstein (1990) suggested that technical standards assure the user that the component will fit into a larger system of components. Other researchers have suggested that technical standards address interoperability, compatibility and modularity (Kano, 2000; Tassey, 2000).

[11] There are similarities between quality and ‘social standards’ a term that used in Leveque in Hawkins et al., 1995 in that they help to protect society from the negative effects of externality seeking firms.
[12] Non-product standards is a term that is used in Tassey (2000) to refer to process standards

Technical standards associated with digital tools that are used in construction have been categorised by Bingunath *et al.* (2001 p.03) as follows:

- Standards for the exchange of structured business data
- Standards for Computer Aided Design (CAD) based exchange of files using Document Exchange Format (DXF) and Drawing (DWG) formats.
- Standards for product or Object Based exchange of information (e.g. the STEP and IFC standards), and
- Standards for the exchange of electronic documents based on the Extended Markup Language (XML), and web standards.

Studies have shown how the above technical standards facilitate information communication, storage, creation and exchange between different technological systems (Eastman, 1980b; Björk and Laakso, 2010). Others have examined the interchangeable use of digital models, file exchange and interoperability of digital design tools (Tolman, 1999; Eastman *et al.*, 2010; Nawari, 2011; Wang *et al.*, 2012). Researchers have noted that these standards simplify interfaces between digital design technologies. They also help to spur innovation through reducing fragility in the technical system used to produce and manage construction information (Jeong *et al.*, 2009; Grilo and Jardim-Goncalves, 2010; Sacks *et al.*, 2010). Although important in the production of information, these technical standards are different from process standards such as the PAS 1192:2012 (1-3) that are aimed at controlling the collaboration of professionals involved in the production of construction information.

2.3.4.3 Industry process standards

Industry process standards described in this research are the sets of voluntary, open and codified consensus driven industry level specifications to which processes, formats or procedures are aligned (Tassey, 2000; Davenport, 2005). Studies of process standards in construction often address either internal standards or standards for managing the production of physical components. For example, Barlow and Ozaki (2005) explain that internal process standards facilitate " the production of a variety of models using the same machinery and material inputs" (p.15). Drawing insights from the sociology tradition as discussed in Section 2.3.3.1, Whyte and Lobo (2010) view internal standards as part of a much wider digital infrastructure for collaborating the delivery of construction projects. Whyte and Lobo (2010) conclude that standards provide the means by which information exchange between teams involved in construction projects is coordinated. Edum-Fotwe *et al.* (2004) explain that standards provide the structured processes required to manage information thus ensuring economies of production and maintaining information. Others note of the functions of internal process standards in supporting systems integration (Gann, 2000b; Davies *et al.*, 2009a), realisation of economies of scale and scope (Gibb, 2001) and in coordinating and controlling project activities (Polesie, 2013). These findings explain the role of standards in coordinating economic activities; they have little to say about how the construction firm exploits them to improve its strategic advantage.

2.3.5 The systemic nature of standards

Tassey (2000) suggests that standards within "a product or service system interact with each other to create the overall economic effects of standardisation" (p.596). Link and Tassey (1987) argue that standards have many interfaces that facilitate the modularization and customisation of production activities. In a separate field, De Oliveira Matias and Coelho (2002) emphasise the importance of integrating standards due to the systemic linkages between standards. This is important to understand that BIM standards may have systemic linkages with other standards, which may influence their application.

2.3.6 Standards and user-innovation

Studies of standards examine the development and adoption of standards, with relatively little focus on the implication of industry standards to the user's ability to innovate. Users fall into different categories. As shown in Figure 2.4, Jakobs (2006) distinguishes between:

i) The users that incorporate the industry standards into technological systems such as Information Technology (IT) suppliers, and

ii) The users of the technological systems such as construction PBFs. Such firms are likely to integrate the technological system into their processes.

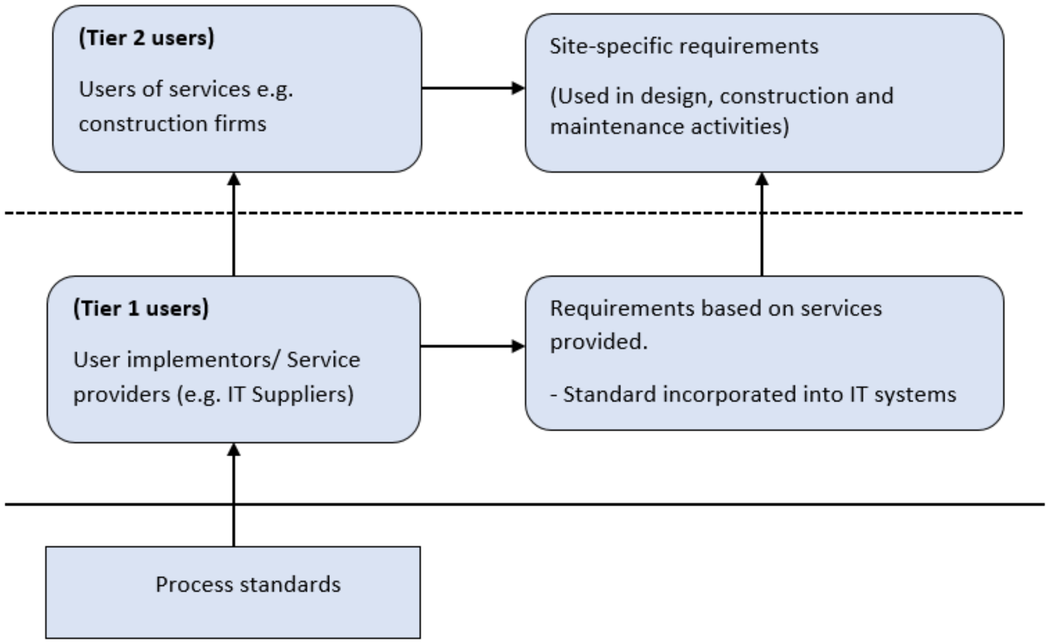

Figure 2:4 Categories of standards users[13]

As users rely heavily on the services of IT suppliers that integrate national standards into IT systems, it is important to understand the complexities faced by such users in construction. The next section focuses on the capabilities of PBFs.

[13] Adapted from Jakobs (2006 p.29)

2.4 The capabilities of Project Based Firms

2.4.1 Project Based Firms and projects

PBFs are common in construction, as well as in the film and telecommunication industries (Hobday, 2000; Hobday *et al.*, 2003; Davies *et al.*, 2011). PBF utilise projects to organise production activities. According to Hobday (2000 p.874) the project is "the primary business mechanism for coordinating and integrating all the main business functions of the firm". Gann and Salter (2000) explain that the project is the prime environment for innovation within the PBF; however, as discussed before in Section 2.2, innovation in construction is complex, occurs in projects and the business levels, and is influenced by the systemic innovation environment in which the firm and the projects are embedded (Gann, 2000).

The literature on projects distinguishes between product development projects (Leonard-Barton, 1992) and project organisations that are popular in construction (Shenhar and Dvir, 1996; Turner and Simister, 2001; Söderlund, 2004; Van Marrewijk *et al.*, 2008). Project organisations are capital intensive, involve multiple disciplines and they take long to realise. In construction, projects organisations are often used to manage the production of built facilities at the order of the client.

The PBF view (Hobday, 1998, Gann and Salter, 2000, Winch, 2003) draws insights from the organisational design literature that sees project organisations as different from other organisational forms such as functional or matrix organisations (Galbraith, 1974; Mintzberg, 1979; Larson and Gobeli, 1987). In the literature of organisations, there is a view that structure has implications on the ability to organise production, innovate and sustain competitiveness (Galbraith, 1974; Mintzberg, 1979; Larson and Gobeli, 1987). Functional organisations organise resources according to the business functions. Matrix[14] organisations exploit structural hierarchy and lateral relationships (Larson and Gobeli, 1987). Projects "have a main emphasis on the project dimensions rather than the functional dimensions of organizational structure and processes" (Sydow *et al.*, 2004 p.1476). Galbraith (1977) comments that projects are effective at managing uncertainty. Hence, projects have distinguishing features from matrix and functional organisations.

The body of literature on projects is also linked to the project management literature that initially emphasized the management of time, quality and planning (Söderlund, 2004; Morris *et al.*, 2010). The project management literature has now advanced from its initial focus to address projects as a form of organisation (Lundin and Söderholm, 1995). The literature addresses issues such as the management by projects, project management and management of projects (Morris, 1984; Turner and Simister, 2001; van Donk and Molloy, 2008; Winch, 2014) and innovation management in project organisations (Keegan and Turner, 2002; Turner and Müller, 2003).

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[14] In studies of product development, Larson and Gobeli (1987) describe matrix organisational forms in relation to the influence of the project and functional managers: functional matrix, project matrix and a balanced matrix organisation.

According to Turner and Muller (2003 p.07)'s the project is a " temporary organization to which resources are assigned to undertake a unique, novel and transient endeavour of managing the inherent uncertainty and need for integration in order to deliver beneficial objectives of change". Due to the capital-intensive nature of the project and the length of time required to procure CoPS, the client's preferences may change. Hence projects seen as inherently risky and uncertain (Geyer and Davies, 2000; Winch, 2010).The project also involves complex interactions between diverse actors (Manley, 2008). Further still, built facilities are difficult to define in advance; hence, they are decided and negotiated in-situ (Barlow, 2000; Scott, 2008; Whyte and Lobo, 2010). Therefore, the business and project activities of PBFs occurs in risky, complex and uncertain environment, which collectively influence the application of new industry BIM process standards.

2.4.2 Defining the concept of capabilities

Research on the capabilities of construction PBFs (Gann and Salter, 2000, Winch, 2010, Davies and Brady, 2014) has origins in the resource-based view (RBV) of the firm (Schumpeter, 1934; Penrose, 1959; Prahalad and Hamel, 1990; Grant, 1991; Chandler, 1992; Teece and Pisano, 1994) which was discussed earlier in subsection 2.2.1. The firm is viewed as a collection of resources, skills, competences and capabilities (Chandler, 1990). The concept of capabilities argues that physical resources, knowledge, skills, competences and routines are required by the firm to perform its business functions (Chandler, 1992; Teece and Pisano, 1994). Without the capabilities, the firm lacks the capacity to thrive.

The notion of capabilities is rooted in evolutionary economic theory and management literature dating back to the works of Schumpeter, Penrose and Nelson and Winter as explained before. Capabilities are associated with the concepts of organisational routines (Nelson and Winter, 1982); core competences (Prahalad and Hamel, 1990); core capabilities (Leonard-Barton, 1992); combinative capabilities (Kogut and Zander, 1992) and dynamic capabilities (Teece *et al.*, 1997; Eisenhardt and Martin, 2000). Nelson and Winter (1982) define routines as regular and predictable patterns of a firm's behaviour. Chandler (1990) argues that organisational capabilities are the top and middle strategic and functional management skills of the organisation. According to Chandler *et al.* (1998), the strategic and functional capabilities are required to exploit production economies in order that the firm may grow and sustain competitive advantage. Becker *et al.* (2005), explain that organisational capabilities are key to understand organisational transformation, learning and adaptation.

Capabilities are a bundle of valuable, rare, inimitable and non-substitutable resources created from the firm's idiosyncratic experiences (Wernerfelt, 1984; Grant, 1991). Resources are the inputs into the production process (Grant, 1991). Resources can be physical, for example: capital equipment; financial; human for instance: employees; technological for example: soft and hardware technology; strategic and organisational (Penrose, 1959; Grant, 1991). The firm's capabilities are path dependent and are embodied in the firm's routines (Richardson, 1972; Nelson and Winter, 1982) – the things the firm has expertise in doing. Since resources and skills are the building blocks of a firm's capabilities (Dosi *et al.*, 2000);

Grant (1996) argues that capabilities are a higher order resource, skill and knowledge combination. Chandler (1990) refers to capabilities as the skills of the organisation.

Even though the concept of capabilities has been important in explaining the way firms achieve and sustain competitive advantage, some issues need addressing. For example, how does the dynamic nature of the external environment influence the capabilities of the firm? Some scholars addressed this issue (Teece and Pisano, 1994; Ambrosini and Bowman, 2009; Helfat *et al.*, 2009). A growing body of research on *dynamic capabilities* (Cohen and Levinthal, 1990; Hamel and Prahalad, 1994; Teece *et al.*, 1997; Helfat *et al.*, 2007) (see section 2.4.3) and *systems integration* (Prencipe *et al.*, 2003; Hobday *et al.*, 2005; Davies *et al.*, 2009b) under the theme of strategic management addresses this issue.

Leonard-Barton (1992) argues that firms have to continuously develop their capabilities to address changes in the external and internal environment, lest the core capabilities become core rigidities. The idea of core rigidities emerged to contrast the core capabilities of an organisation. The argument by Leonard-Barton (1992) is that the renewal of core capabilities is important for the firm; otherwise, they become core rigidities that limit the firm's ability to continuously achieve and sustain competitive advantage. Cohen and Levinthal (1996) advanced the concept of absorptive capacity to explain that firms require the adaptive capacity to make sense of foreign technologies in order to improve their own capabilities. The concept of capabilities has been used to understand the strategic management aspects of business (Teece, 2007; Burgelman *et al.*, 2009). In the context of the above discussion, the external environment is a factor in the renewal or development of new capabilities.

Chandler's ideas on organisational capabilities explain how firms that are involved in the production of the built environment achieve and sustain competitive advantage through transforming their capabilities. Hence, the association highlighted by scholars between innovation and capability development (Davies and Brady, 2000; Brady and Davies, 2004; Whitley, 2006).

2.4.3 Dynamic capabilities

There is an argument that the RBV idea is not sufficient to explain the capabilities required by firms to adapt to rapidly changing business contexts (Barney, 2001; Eisenhardt and Graebner, 2007; Wang and Ahmed, 2007; Helfat *et al.*, 2009). Advancing the concept of dynamic capabilities, Teece and Pisano (1994) argued that firms require such capabilities so as to transform the firm's resource base in rapidly changing environments. Dynamic capabilities are the core strategic management function of creating, deploying and protecting tangible and intangible resources that sustain long-term business performance. Accordingly, the concept of dynamic capabilities refers to the "appropriate adapting, integrating, reconfiguring of internal and external organisation skills, resources and functional competencies towards a changing environment" (Teece and Pisano, 1994 p.538). According to this prevailing thinking, dynamic capabilities are the management function required to "sense and shape opportunities and threats, seize opportunities, and maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring …intangible and tangible assets" (Teece, 2007 p.1319). Indeed, there are important similarities between the strategic capabilities identified in Chandler (1990) and those identified by Teece and Pisano (1994). For instance, both scholars identify the strategic role of management. Davies and Brady (2015) explain that dynamic capabilities are the strategic management capabilities required to transform the operational or project level capabilities of the PBF.

The concept of dynamic capabilities has been criticised as being conceptually diffuse (Priem and Butler, 2001; Wang and Ahmed, 2007). The idea of dynamic capabilities emerged from studies of firms other than those involved in construction, hence it may be less relevant to address construction firms (Davies and Brady, 2000). Eisenhardt and Martin (2000) explain that dynamic capabilities are the knowledge required by an organisation to obtain and reconfigure organisational resources. Teece and Pisano (1997) focus on the strategic function of altering the capabilities of the organisation. Helfat *et al.* (2007 p.04) prefer a broader definition of dynamic capabilities arguing that such capabilities reflect the organisation's capacity to "purposefully create, extend, and modify its resource base". Despite the different ideas around the concept, there is some agreement in that dynamic capabilities are a strategic function of senior management to act upon the capabilities of the firm. For Zollo and Winter (2002), the dynamic capabilities of the firm include the following:

- functional capabilities,
- dynamic improvement capabilities,
- innovative capabilities and,
- learning to learn capabilities

Dynamic capabilities are required to address the business activities of the firm (Davies and Brady, 2015). The concept advances a top down approach to the firm and thus assumes that management have unfettered influence over the firm's business activities. By advancing a top-down management approach, the concept assumes that senior managers have influence over the firm's activities in all contexts (Gann and Salter, 2000). As explained in Section 2.2, this may not apply to construction PBFs because of the limited influence the firm may have over project actors. This makes the dynamic capabilities concept less relevant for use in firms that are engaged in business and projects environments, where bottom up processes of learning from projects are equally important. Davies and Brady (2015) however, argue that dynamic capabilities are relevant because they relate to the knowledge required by the PBF to transform its project capabilities, and adapt to changes in the external environment. Hence, despite the weaknesses, the concept is relevant to address the way construction PBFs adapts to new process standards and sustains competitive advantage.

2.4.4 Organisational capabilities

Chandler (1992) argued that organisations require capabilities to function efficiently and compete in the market. According to Chandler (1990), the firm requires strategic and functional capabilities to manage physical production facilities and non-tangible skills to achieve economies of scope and scale. Organisational capabilities develop from "…solving problems of scaling up the processes of production, from acquiring knowledge of customers' needs, coming to know the availabilities of supplies and the reliability of suppliers, and in becoming knowledgeable in the ways of recruiting and training workers and managers" (Chandler, 1992 p.84). For Chandler (1992), firms grow through: a) developing efficiencies in the use of resources through economies of scale and scope, b) establishing a viable management structure that transcends functional and hierarchical organisational boundaries, and finally c) establishing an efficient marketing and distribution process (Chandler, 1992 p.98). His ideas were useful to explain how mass production firms could move up and down the production chain to realise production economies. These ideas evolved from studies of mass production firms; it has been argued before that construction is different. Chandler's ideas although relevant, have little to say about the capabilities of firms, which use project based forms of organising resources to deliver their business functions.

2.4.5 The organisational capabilities of project-based firms

Chandler (1990) provided the foundations for Davies and Brady (2000)'s PBF organisational capabilities theoretical framework that includes the concept of project capabilities. Davies and Brady (2000) argued that project based organisations especially the ones preferred in construction, are considerably different from functional and matrix organisations. PBF, according to these scholars require project capabilities in addition to strategic and functional capabilities (Brady and Davies, 2004). They claim that in mass production, economies of scale and scope are the core focus, whereas in construction the concern is to manage, learn from projects, integrate business and project process, and managing design and R&D

activities that form part of the production process. Learning from and between projects is crucial for the project based business to achieve and sustain competivity (Prencipe and Tell, 2001). Therefore the capabilities of PBF are different from those of mass production firms addressed in Chandler's work (Davies and Hobday, 2005). Table 2.1 below identifies the organisational capabilities of the PBF according to Davies and Brady (2000).

Davies and Brady (2000) argued that PBFs require functional, strategic and project capabilities. Functional capabilities are required to improve the PBFs production activities. They involve R&D, product design, production activities, distribution, general management and marketing. According to Davies and Hobday (2005 p.68), the functional capabilities of PBFs are required to manage: a) one off production, b) uncertain and novel tasks, c) complex product systems production and, d) bid and project management efficiency. These capabilities are distributed at the business and project levels.

According to Chandler (1990), strategic capabilities are required to "recruit and motivate middle managers, define and allocate responsibilities, coordinate their activities and … the activities of the whole organisation" (p.594). As shown in Table 2.1 below, the strategic capabilities of PBFs include its absorptive capacity (see discussion in section 2.4.3), and integrated solution capability (Davies *et al.*, 2003). These together with project and functional capabilities are seen as necessary for the PBF to achieve and sustain competitive advantage (Hobday and Davies, 2005).

In addition to absorptive capacity and integrated solutions, Hobday *et al.* (2003) argue that systems integration capabilities are necessary for the PBFs to collaborate outsourced production activities. Systems integration capabilities are competencies, skills and knowledge required to "integrate changes in internally and externally designed and produced inputs into effective products and production systems" (Pavitt, 1999 p.19). PBFs employ systems integration capabilities to move up and down the supply chain, to select the appropriate supply chain partner and integrate services delivered by a number of suppliers and subcontractors (Davies, 2003). Brady *et al.* (2005) argue that the systems integration capabilities are important for the PBF to deliver integrated solutions, however integrations solutions capabilities are important for the PBF to combine pre bid and post implementation activities in the CoPS life cycle. According to Davies *et al.* (2005), PBFs engaged in the production of CoPS move from a product or service centered approach to a customer focused integrated solutions approach. Rather than focusing on the traditional design and construction competencies, PBFs are developing integrated solutions capabilities to manage pre and post bid activities (Davies *et al.*, 2005).

Within research on innovation in PBF, a large body of literature is emerging around the notion of project capabilities (Bresnen *et al.*, 2003; Brady and Davies, 2004; Melkonian and Picq, 2011; Nightingale *et al.*, 2011; Winch and Leiringer, 2015). Despite the growth in research on the project delivery capabilities of PBFs, relatively little is known of the role of industry-wide process standards in the development of such capabilities. Indeed, there is insufficient knowledge of how the construction firm may position itself to grow, learn and develop project capabilities from the adaptation of industry process standards such as BIM process standards. This study identifies this as a limitation in knowledge, and contributes to build the knowledge base in the area.

Core organisational capability	Capability
Strategic capability	Absorptive capacity Integrated solutions Dynamic capabilities
Functional capability	IT supplier services Research and development Cross functional project team management
Project capability	Pre-bid, bidding and offer activities Project management Project design Operational support and Maintenance Technical capabilities

Table 2:2 The PBF's organisational capabilities[15]

2.4.5.1 The project capabilities of PBFs

Modifying Chandler (1990)'s organisational capabilities theoretical framework, Davies and Brady (2000) argued that project capabilities are necessary for the PBF to learn from projects, grow and deliver repeatable but unique solutions. Project capabilities are essential for the PBF "to perform strategic, functional and project activities associated with its

[15] Developed by the researcher from a synthesis of the literature on PBF organisational capabilities

evolving technology and market" (Davies and Hobday, 2005 p.225). According to Davies and Brady (2015), project capabilities, which are a subset of organisational capabilities, refer to the "distinct managerial knowledge, experience and skills which are located within a single organisation (a firm) and required to establish, coordinate and execute projects" (p.01). Project capabilities are "the appropriate knowledge, experience and skills required to perform pre-bid, bid, project and post project activities" (Davies and Hobday, 2005 p.62). Table 2:3 shows the project capabilities of PBFs. These capabilities develop from project execution experience (Davies and Brady, 2015). By developing capabilities in bidding, design and project management, PBFs achieve economies of repetition, which are important in sustaining competitive advantage (Davies and Brady, 2000; Gann and Salter, 2000).

2.4.5.2 The development of project capabilities

There is a growing literature that addresses the development of project capabilities (Prencipe and Tell, 2001; Brady and Davies, 2004; Defillippi *et al.*, 2009; Davies *et al.*, 2011; Bossink, 2013). Davies and Brady, (2004) explain that vanguard projects may be useful to develop project capabilities. Such projects allow the firm to move into new markets and new technological domains through exploring and exploitative learning (Brady and Davies, 2004). Whilst vanguard projects might be useful in some sectors, construction is different because the product is capital intensive and draws from a diverse pool of skills and (Davies, 1999; Davies and Brady, 2000; Gann, 2000b; Winch, 2010). Therefore, it is not economically feasible to use vanguard projects in construction (Whyte and Lobo, 2015). There are important questions about the development of project capabilities in PBFs that are adopting new industry level technologies that challenge the existing order in the firm.

Gann (2000) notes that technical standards may be important to develop project execution capabilities. Citing IFC standards as an example, he argues that technical standards provide the compatibility required for information technology interoperability. This he explains is important to support the delivery of projects. Steinmueller (2003) argues that technical standards provide the technical compatibility to control and coordinate inter-organisational activities. He notes that standards contain the collective memory of the organisation that supports coordination. Gann (2000) claims that construction PBFs perform the role of the systems integrator as they coordinate design, facilitate the integration of products and services and provide feedback to suppliers and users up and down the supply chain. Therefore, technical standards perform an important role in facilitating the integration of the activities of firms involved.

Even though the research on project capabilities has been important to understand how PBFs achieve and sustain competitiveness, much remains to be uncovered in relation to the development of project capabilities. For instance, how does a construction firm transform its project capabilities through the application of new industry level process management standards?

	Project competences	Activities
Project capabilities concept (Davies and Brady, 2000)	Bidding capabilities	- Design & Estimation - Procurement of subcontractors & Scheduling and planning of activities - Specifying material components - Preparing contractual agreements
	Project management capabilities	- Integrating organisational and project functions - Programming, planning and managing resources - Arranging aftersales support and maintenance Integrating ICT and systems integration - Coordinating, integrating and facilitating feedback
	Technical capabilities	- Integrating IT in design and construction activities - Inter-disciplinary skills to integrate specialist skills - 3D visualisations, & digital coordination, simulation & collaboration - ICT systems and data management

Table 2:3 Project capabilities of PBFs[16]

Thus far, the discussion has focused on innovation in construction and the capabilities of PBFs. The construction project environment is complex, involving interdependent interactions between many firms. Furthermore, construction PBFs operate in business and project environments. The delivery of CoPS is difficult because the products are often unique and customised, and design, and R&D activities are often part of the production process.

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[16] Developed by researcher with ideas from Davies and Brady (2000) and Gann (2000)

Such firms require project capabilities to deliver in project-based environments. In such environments, the capacity to integrate the services offered by multiple firms is important. The development of capabilities requires the firm to learn from its experience, however learning in projects is difficult to manage because projects are temporary making it hard to transfer knowledge from one project to another. Important issues concern the development of construction PBF capabilities. The next section presents the conceptual framework.

2.5 The conceptual framework

This section explains the conceptual framework adopted for the research. The framework as illustrated in Figure 2.5 was developed from reading the literature on industry standards, PBF capabilities, projects and innovation systems discussed before. The concept of industry process standards was used to distinguish industry standards from other types of industry standards, and the standards that develop within the firm that are sometimes referred as routines (see discussion in Section 2.3). The concept of construction PBF identifies the construction firm (Section 2.4.1), and the concept of projects identifies the temporary organisation used by PBFs for production activities. PBF organisational capabilities are the capabilities required by the PBF to manage production activities, grow and sustain competitive advantage (Section 2.4.4). The construction innovation system approach develops from the work on innovation systems (Section 2.2.2).

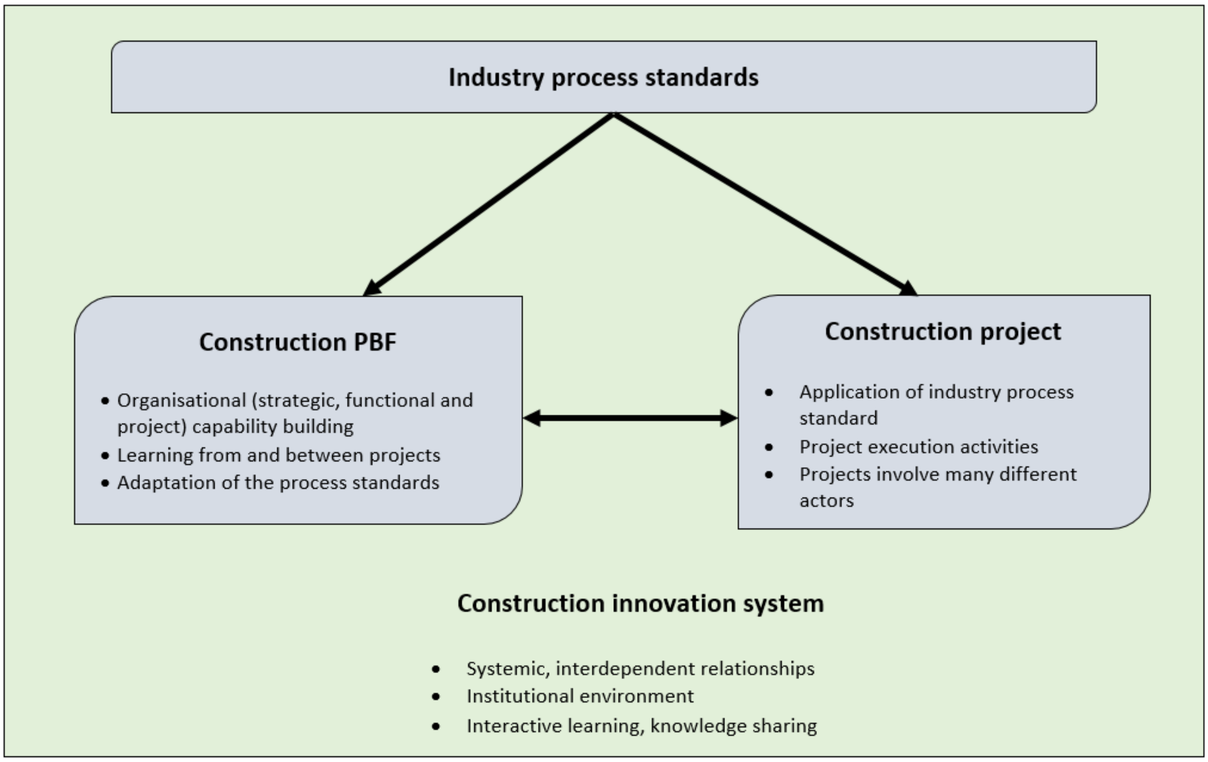

Figure 2:5 The conceptual framework[17]

2.5.1 Justification for the conceptual framework

The PBF organisational capabilities view is relevant because it addresses the strategic (Section 2.4.4), functional (Section 2.4.4.) and project capabilities (Section 2.4.5.1). As explained before strategic capabilities associated with dynamic capabilities (Section 2.4.3) are the business level capabilities required to coordinate internal activities, adapt to technological changes and the external environment and reconfigure the firm's capabilities.

[17] The conceptual framework has been developed with ideas from Manley (2008) on the systemic nature of innovation in construction, Chandler (1990, 1992) - organisational capabilities; Davies and Brady (2000) - on project capabilities and Tassey (2000) on the characteristics of industry standards.

Operational level capabilities include functional capabilities that are required to improve the firm's production activities (Davies *et al.*, 2005), and project capabilities that are necessary for the PBF to perform pre-bid, bid, project and post project activities (Davies and Hobday, 2005). Davies and Brady (2000) argue that construction PBFs require strategic, functional and project capabilities. However, they do not explain how such capabilities are shaped by industry-wide process standards.

The organisational capabilities framework advanced by Chandler (1990) is not adequate on its own to explain the firm's interactions with industry process standards because it only addresses the strategic and functional aspects. It does not recognise the distinctness of construction. The dynamic capabilities concept advanced by Teece and Pisano (1994) is also inadequate because it focuses on the strategic management functions and assumes that management have overriding influence on the firm's activities. The project capabilities concept is relevant to explain the capabilities of PBFs; less is known of the role of industry process standards in the development of project capabilities.

The literature on industry standards and standardisation (Section 2.3) distinguishes process standards from other types of standards. Whereas research addresses standards for production, quality management, safety and compatibility of information systems (i.e. product and technical standards) (Section 2.3.4), industry process standards that reduce variance in the performance of production activities have received limited empirical attention.

The literature on innovation (Section 2.2) is relevant to explain the systemic nature of innovation in construction, and to identify the enablers and barriers to the application of new technologies in construction. A systems approach to innovation is useful to make sense of the knowledge sharing interactive relations between construction actors and to explain the transformations in the interactive processes between such actors as BIM standards are applied. The innovation systems literature brings into focus the interactive learning activities and the user-producer interactions that influence the innovation process (Gann and Salter, 2000; Blayse and Manley, 2004; Manley, 2006). A broader definition was adopted that helps to understand innovation as "a novel product, process, service, or system of organization that changes the prevailing order of an organization, market, or society" (Davies *et al.*, 2014 p.26). This definition is important to understand innovation in the development of capabilities and organisational changes that are stimulated by the adaptation of industry process standards. In the background, Figure 2.6 below illustrates in detail the relationship between industry BIM process standards, the large construction firm, the projects, and the context of the innovation system within which adaptation occurs.

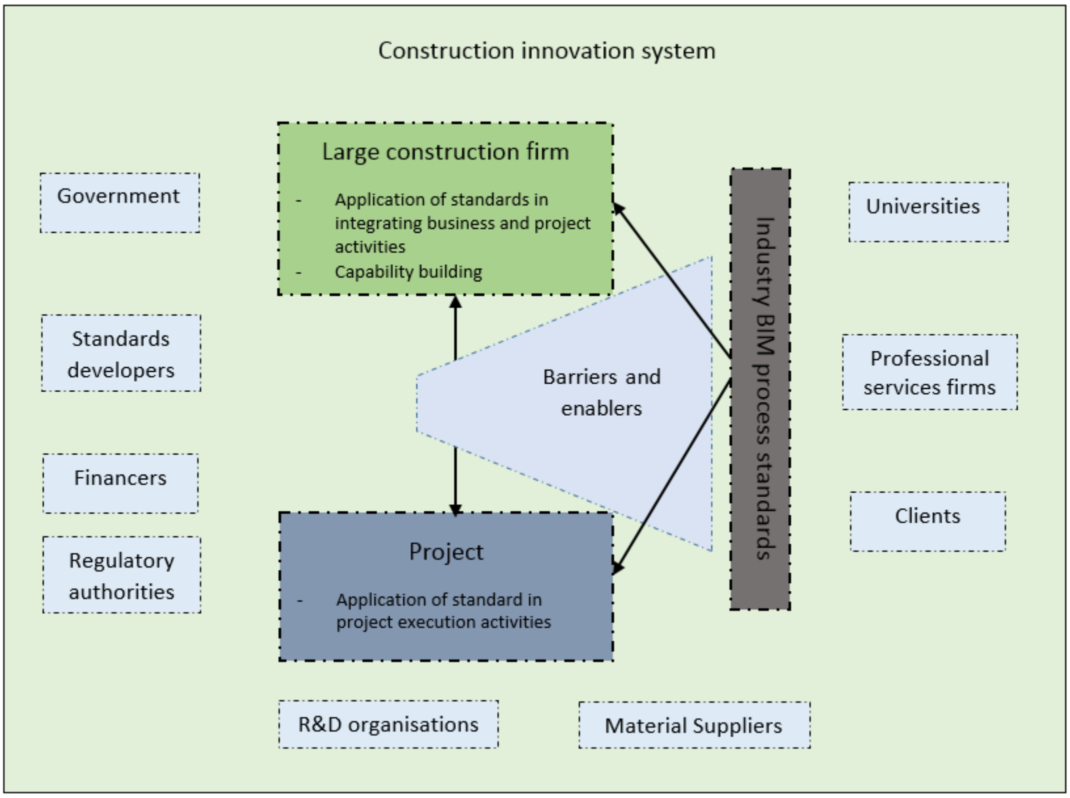

Figure 2:6 Relationship between BIM process standards, large construction firm, projects and construction innovation system

2.6 Summary

This chapter discussed the limitations of the existing theoretical understandings. In this chapter, it has been argued that research on innovation in construction and construction PBF capabilities seldom addresses industry process standards. The adopted theoretical framework is important to make sense of the research on the adaptation of industry BIM process standards within a large UK construction firm. The next chapter gives the background to the context of the UK construction industry, which as explained in Section 2.2.5.1 may influence the adaptation of industry BIM process standards.

Chapter 3: Building Information Modelling process standards in the UK construction industry

3.1 Introduction

The previous chapter discussed the literature on innovation, innovation in construction, standards, standardisation and the development of organisational capabilities in firms that produce the built environment. The discussion shows that the business and project environments may play a role in the PBFs innovation activities. The chapter concluded with a presentation of the conceptual framework, which is important to make sense of the construction firm's adaptation to industry BIM process standards. This chapter discusses BIM standards and the empirical context of the UK construction industry to show the distinctions between BIM standards and the environment in which the construction firm is embedded. The review will also show the differences between product, technical and process standards associated with the BIM process. Drawing insights from the discussion in Section 2.2, this chapter argues that the empirical context of the UK construction industry shapes the adaptation of BIM process standards in construction firms.

The chapter is structured in sections as follows. Section 3.2 discusses BIM and the current UK agenda for the uptake of this new process. Section 3.3 discusses the differences between BIM standards. Section 3.4 defines and discusses the UK construction industry. Section 3.5 concludes with a summary of the discussion in this chapter.

3.2 Building Information Modelling

BIM involves the use of digital design and collaboration tools, and standardised practices to facilitate the production of information in the management of construction projects. BIM is linked to CAD that was first introduced in the early 1960s, and standards that have been developed to supports its operationalisation. The BIM process is relatively new to the UK construction industry. Foreseeing the potential benefits of the technology, the UK government has mandated its use in public contracts. The UK government, which has placed BIM at the centre of its construction policy, has welcomed the numerous initiatives aimed at improving the standards associated to this process (see Section 3.2.4). This section defines BIM, discusses its origins and explains the current UK BIM implementation agenda.

3.2.1 What is BIM?

Building Information Modelling is a collaborative process that involves the use of digital tools, and sets of industry standards that combine to facilitate the creation, management, exchange, storage and retrieval of digital construction information (Grilo and Jardim-Goncalves, 2010; Richards, 2010; Arayici *et al.*, 2011a; Azhar, 2011; Eadie *et al.*, 2013; Succar *et al.*, 2013). The definition advanced in this research focuses on BIM as a process that supports the coordinated use of information. Thus far, many of the scholarly publications on BIM have addressed the 3 Dimensional (3D) aspect of creating information (Eastman *et al.*, 2008a).

The process of constructing a built facility involves interactions between multiple stakeholders such as the client, construction firm, material suppliers and regulators to mention but some (see discussion in Section 2.2.2.1). The BIM process involves project team members relying on a common source of information that is accessed using digital technologies. Proponents of this process argue that in a project environment, professionals perform many different tasks, are located in different geographical locations and simultaneously pursue varying interests that collectively help to deliver the built facility (BIM task group, 2103, Richards, 2010, Eastman *et al.*, 2011). Underlying the BIM process is the view that the project team in its entirety requires a common source of information to execute the project (Bew *et al.*, 2013)

3.2.2 The origins of BIM

The pre-history of BIM goes back to Ivan Edward Sutherland's pioneering work on the SKETCHPAD (Sutherland, 1963). Sketchpad the predecessor to CAD was the first to show that people could use computers to produce drawings. CAD was introduced as an improvement from pen and paper drawing production in the 1960s (Sutherland, 1963; Bridgewater, 1993). In its early use, CAD supported 2 Dimensional (2D) information production (see Figure 3.1 below for an example of 2D drawing). Coupled by advances in digital tools for communicating and storing information; a combination of the use of CAD and information technologies now plays a prominent role in the delivery of built facilities (Whyte, 2003; Whyte and Lobo, 2010).

Until the 1980s, CAD remained largely unknown and used only to supplement traditional methods of 2D information production (Blakemore and Rabun, 1997). CAD was costly to acquire, required investment in additional human and technical resources, and needed extensive learning before it could be used. Therefore, the technology was widely viewed as uneconomic, expensive and beyond the reach of many firms (Weisberg, 2008). Following technological advances in computing; IT firms such as Autodesk, Bentley and Graphisoft seized upon the commercial opportunities and invested significantly in R&D to improve the CAD technology (Chuang *et al.*, 2011). AutoCAD, Revit, Microstation and Archicad are some of the technologies widely used in the construction industry.

Over the past four decades, digital tools have become integral to the management of construction projects (Whyte and Levitt, 2011). Research shows that digital tools are used to create, exchange, communicate and store information in construction projects (Boland *et al.*, 2007; Goulding *et al.*, 2007; Ewenstein and Whyte, 2009). Much of the research on digital technology usage in construction has sought to understand how such technologies may be optimised (Eastman *et al.*, 1997; Eastman, 1999). Advances in computers and CAD technologies have greatly improved the capacity to integrate many functions, coordinate production activities and visualise information.

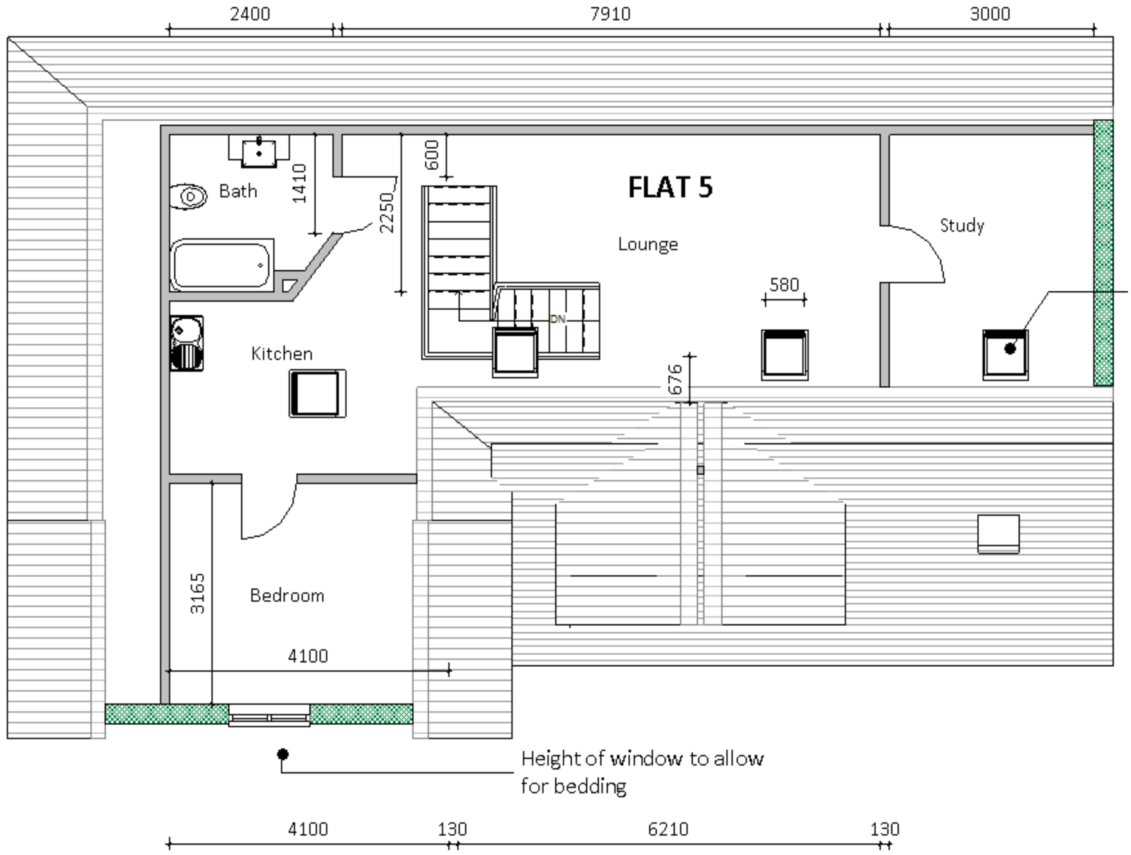

Figure 3:1 2D drawing[18]

Technological advances in CAD have also permitted the production of 3D models that contain digital information about buildings hence the term 'Building information models'. Focusing on the practice of creating 3D models, Eastman *et al.* (2011 p.16) suggests that building information modelling may be characterised by the following:

i. Building components that are represented with digital representations and they contain computable graphic and data attributes. The components include data to

[18] Source: the researcher produced this 2D drawing.

facilitate in-depth analysis of the component e.g. energy consumption, quantity take-off and details of the materials to be used in assembling the component.

ii. Consistent, coordinate and structured data to ensure that changes to the component data are represented in all views of the model, the component and assemblies.

The use of building information models has greatly transformed the ability to procure the built environment (an example of a 3D drawing is shown in Figure 3.2 below) (Eastman, 1980b; Bjork and Wix, 1991; Eastman, 1996). Whilst the term BIM was initially used to refer to building information models (Eastman *et al.*, 2008b; Hardin, 2009), this research argues that BIM is concerned with the collaborative process of creating, controlling and managing the development of all digital information including 3D models using industry BIM standards (Richards, 2010; BIM Task Group, 2013). Section 2.4 will discuss in detail the characteristics and functions of industry BIM standards.

Figure 3:2 Image of a 3D model[19]

Much of the research on the integration of digital tools is practitioner oriented and addresses CAD software compatibility and interoperable uses of data through the use of technical standards, databases and networks for transferring data, and standards for data transfer (Eastman, 1980a; Björk, 1992; Eastman, 1996; Jacobsen and Jeng, 1997; Bjork and Adina, 1998; Kim *et al.*, 2008; Sanguinetti *et al.*, 2012). Within this line of work, researchers have improve the structure and visual graphics of 3D models to allow better quality information to be produced (Eastman, 1980a; Fu *et al.*, 2006). A wide literature now exists on the use of digital tools in construction, including on BIM (Azhar, 2011; Eastman *et al.*,

[19] Source: both the 2D and 3D images were produced by the researcher

2011; Arayici *et al.*, 2012; Eadie *et al.*, 2013; Bevan, 2014). The next subsection examines the different scholarly views on BIM.

3.2.3 Research on BIM

The literature on BIM is vast, and this discussion is not in any way aimed at providing a comprehensive review of the BIM literature. It simply offers a limited account by selecting a few authors to articulate the different views about BIM. The views are generally distributed between practitioner, policy, theoretical and technical perspectives as illustrated in Figure 3.3 below.

Within the policy area, the concern is about the national level factors that influence the implementation (Succar, 2009; Azhar, 2011; Wong *et al.*, 2011). Some researchers that have focused on the technical aspects of BIM address issues to do with digital technology integration, interoperability and optimisation of technologies (Eastman *et al.*, 2008a). Here the concern is on the co-production of information, information storage and communication using digital technologies. For Eastman *et al.* (2011) the problems faced in by the users of the BIM process relate to the understanding of the term ‘Building Information Modelling’ and ‘Building Information Model’. The modelling aspect refers to the process of creating digital 3D models; models are the products of the modelling process (Eastman *et al.*, 2008).

Studies are theorising the implementation of BIM (Dossick and Neff, 2009; Gu and London, 2010; Eadie *et al.*, 2013). The concern here has been on the conception of BIM and the environment where the process is used. Studies highlight the technical requirements; barriers and enablers; benefits as well as problems associated with the implementation of BIM (Dossick and Neff, 2008; Capper *et al.*, 2012; Davies and Harty, 2013). BIM as a collaborative process of creating, managing and exchanging information (Eadie *et al.*, 2013, Azhar, 2011, Arayici *et al.*, 2011).

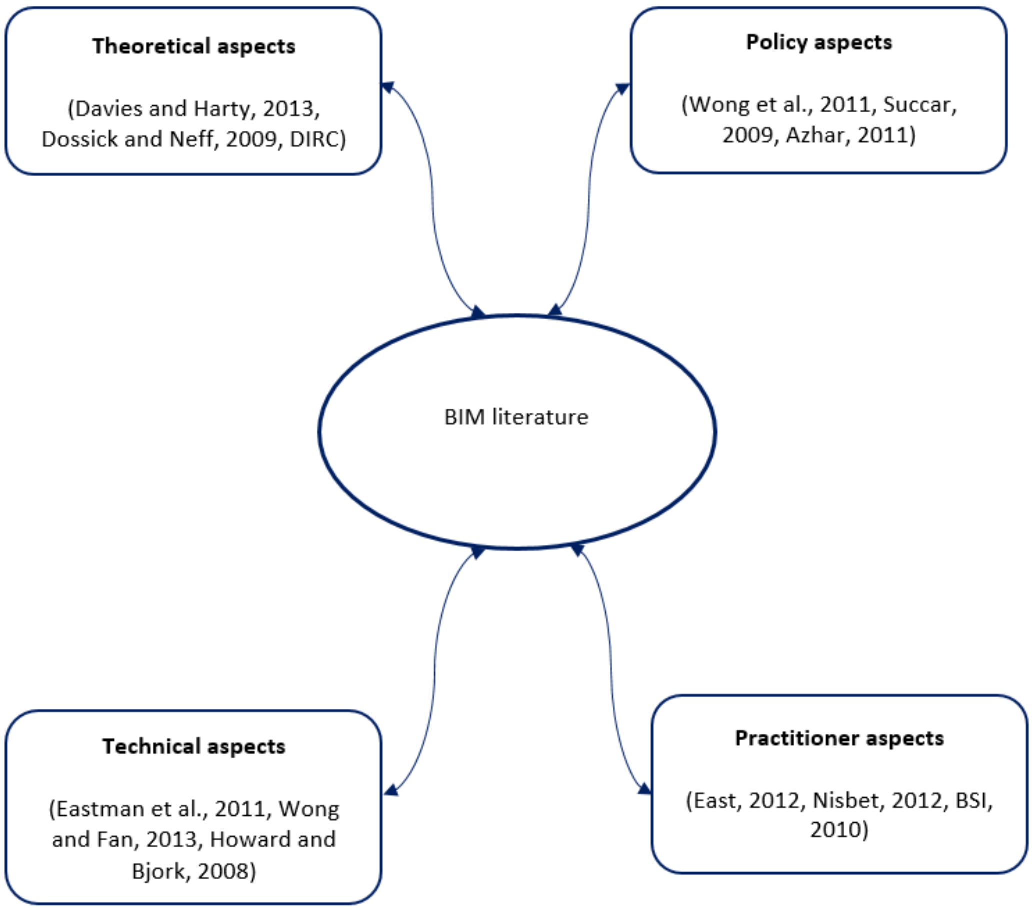

Figure 3:3 Strands of BIM literature

The practitioner view advocates for the use of the process in construction. Groups such as the BIM task group and BIM regional groups have been set up to facilitate the implementation of the process. Such groups argue that BIM creates value and support collaboration throughout the entire life-cycle of a built facility by supporting the creation, collation and exchange of digital information in a collaborative environment (BIM Task Group, 2012). Such groups have also been instrumental in developing BIM standards, and facilitating industry level discussions aimed at addressing implementation problems (Eastman *et al.*, 2010; Richards, 2010; Nisbet, 2012; Nisbet, 2014). The discussion in the next subsection focuses on the UK government's BIM implementation agenda.

3.2.4 The national BIM standards agenda

Attempts to proliferate the BIM process across the UK construction industry have generated intense interest at the policy, practitioners and academic levels. Numerous initiatives have emerged which have seen the creation of industry level groups such as the BIM task group; Regional BIM initiatives and AEC (UK) that seek to enhance the implementation of the new process[20]. Industry groups have successfully lobbied the UK government; and BIM is now core to the UK government's construction strategy (Cabinet office, 2012). The government sees BIM as an important way of addressing inefficiencies in UK construction (Cabinet office, 2015). To facilitate the implementation process the government is not only funding BIM trial projects but has been instrumental is setting up groups such as the BIM task group. As the largest employer of the industry, the government has significant influence over the

[20] For more details about the activities of these groups, the reader is referred to the following websites. (aecuk.wordpress.com); (www.bimtaskgroup.org); www.bimtaskgroup.org/cic-bim-regional-hubs

industry's affairs. In May 2011, the UK government mandated the use of level 2 BIM in all publicly procured contracts starting from January 2016 (Office, 2011). Consequently, large construction firms especially those engaged in large infrastructure projects are beginning to embrace the technology (NBS, 2013). Critiques however argue that the government has thrown caution to the wind, insisting that the implications of BIM are not yet fully known and understood.

Through the Construction Industry Council, which represents the many actors within the industry, the government has channelled funds to support the implementation of the technology. The uptake of BIM has also refuelled national debates on the importance of national standards. Current initiatives are directed the BS 1192: 2007, COBie, Uniclass 2 and the BIM execution plan. Professional bodies such as the Royal Institute of Chartered Surveyors (RICS) are engaged in industry level discussions, and aligning their professional standards as BIM becomes integral to construction processes (RICS, 2012)[21].

The BIM task group has been instrumental in the implementation of BIM across the UK. Its members have collaborated and produced the BIM maturity diagram, shown in Figure 3.4. The diagram illustrates the requirements for implementing the BIM process. The BIM maturity diagram shows the transformation from digital CAD to integrated web based digital collaboration involving the use of 3D modelling technologies, collaboration technologies and industry process and technical standards (BIS, 2013a). The maturity diagram is widely

[21] New Rules of Measurement came into effect on the first of January 2013

referred in conferences and in the literature published by the government. The diagram shows the four different levels (0-3) of BIM competences that are expected of those implementing the process. Most importantly, the diagram shows the BIM technical and process standards that are particularly relevant. The redline between levels 2 and 3 indicates the competences expected by the government of users by the year 2016. The findings of UK government sponsored BIM trial projects indicate that BIM has significant implications for productivity in construction (Cabinet Office, 2012), however the studies do not provide a detailed account of the experiences of firms that adopt this new process.

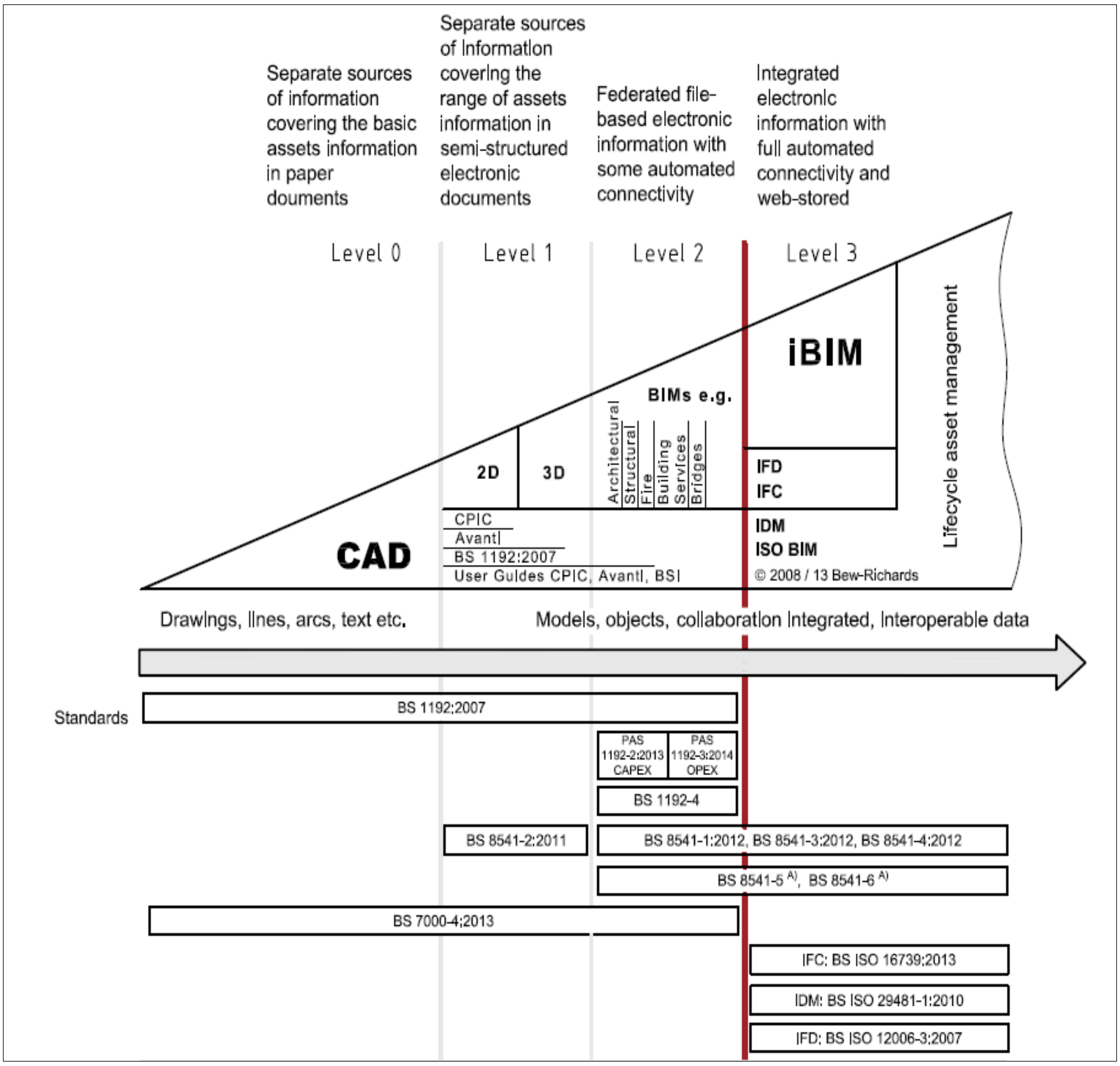

Figure 3:4 BIM maturity diagram[22]

[22] Source BSI (2015 p.iv) – Collaborative production of information Part 4: Fulfilling employer's information exchange requirements using COBie – Code of practice - The Core maturity Model.

3.3 Industry BIM standards

The BIM process involves the use of industry technical and process standards that provide a means of managing the creation, exchange and use of information by project teams. Process management standards include the BS1192:2007 standard, which aims to regulate the collaboration activities involved in BIM environments. Since BIM is underpinned by digital tools that facilitate digital information storage, communication and exchange (Hardin, 2009; Grilo and Jardim-Goncalves, 2010), standards play an important role to collaborate the digital interactions. Research suggests that BIM technical standards ensure interoperability between digital tools (Eastman *et al.*, 2008a; Eadie *et al.*, 2013). This section focuses mostly on the BIM technical and process standards.

The increasing uptake of BIM has refuelled a wider industry and academic debate about the role and implications of national standards in construction (BIM Task Group, 2012; Grilo *et al.*, 2012). The practitioner and academic communities, generally view BIM standards as tools that can improve productivity and quality of information, reduce risks in construction and foster a culture of collaboration by reducing variation (Dossick and Neff, 2009; Nisbet, 2012). The sets of standards associated with the BIM process address the technical and process aspects of creating and collaborating in the production of the built environment. Technical standards such as industry foundation classes (IFC) address interoperability in the production of information, whilst process standards such as Publicly Available Specification (PAS) 1192: 2013 and its predecessor the British Standard (BS) 1192:2007 are aimed at the management of information production, exchange, storage and retrieval processes (Richards, 2010; Blackwell, 2012; NBIMS-US, 2012). Although the Construction Building Information Exchange (COBie) standard is associated with the PAS 1192:2012 standard it is a data schema standard, i.e. it prescribes the structure of information that is shared in the CDE environment. (BSI, 2015). Table 3.1 below explains the differences between the standards.

The use of BIM standards helps to streamline the production, exchange and use of information (Eastman *et al.*, 2008a), this is vital in addressing the problems of fragmentation in the construction process. The standards may improve the construction firm's ability to deliver projects. A number of studies have shown that BIM standards can improve productivity and quality of information, reduce risks and foster a culture of collaboration (Dossick and Neff, 2009; Nisbet, 2012). However, as explained before many of the studies have been directed at technical standards.

Table 3.1 identifies industry BIM standards used in construction practice. It is important to note that there are many other different types of standards used in a BIM environment. Professional standards for instance are regulative in nature; they are used to monitor the performance of professionals. Professional standards include the Rules of Measurement (NRM) developed by the RICS, Civil Engineering Standard Method of measurement by the Institution of Civil Engineers (ICE) and the plan of works developed by the Royal Institution of British Architects (RIBA).

BIM standard	Type of standard	Function
Industry Foundation Class (IFC) - BS ISO 16739 ; BS 854-(1-4); BS ISO 12006 -3:2007 - International Framework for Dictionaries; Model View Definition; Uniclass	Technical	Interoperability and compatibility, 2D and 3D design information production, visualisation, synchronisation and classification of work elements Creation of information
BS ISO 12006-2:2001, Building construction – Uniclass, Omni class, NRM, RIBA plan of works, IFC	Technical	Classification of work elements, collaboration, Organization of digital information
BS 1192:2007, PAS 1192:2012 (2-4) Construction Operations Building information exchange (COBie)	Process management and structure of information	Communication, coordinating, control and management of construction activities

Table 3:1 Functionalities of Industry BIM standards

It is possible that BIM process standards can improve the construction firm's ability to transform the capacity to deliver its business functions. A number of studies have shown that BIM standards can improve productivity and quality of information, reduce risks and foster a culture of collaboration (Dossick and Neff, 2009; Nisbet, 2012). However, as explained before many of the studies have been directed at technical standards. The discussion below examines the differences between these two types of BIM standards.

3.3.1 Industry BIM technical standards

Technical standards facilitate interoperability in the use of digital tools used to produce construction information (Bjork and Wix, 1991). Early research on technical standards was directed at the development of the International Standard for the Exchange of Product Model Data (STEP) (ISO standard 10303) (Wix, 1997; Liebich and Wix, 1998; STEPTools, 2012) and the Industry Foundation Class (IFC) standard. Research has shown that common technical standards enhance communication between CAD technologies (Howard and Björk, 2008). Eastman *et al.* (2008) explains that technical standards can provide the interface between different technologies, which enhances compatibility. Innovation could be enhanced by such standards because the developers of CAD technologies are able to maintain variation as long as a common interface between the technologies is maintained.

Following the successful development of the STEP standard, significant effort was placed in building the IFC standard (Wix, 1998). This led to the formation of the umbrella body the International Alliance for Interoperability (IAI) organisation which would be later renamed to BuildingSmart (BuldingSmart-UK, 2013). The IFC is an open industry technical standard that facilitates the exchange of building information models between CAD technologies (Froese and Yu, 1999; Steel *et al.*, 2012). Research on the open IFC industry standard has provided insights into how communication between CAD technologies is managed (Lu, 2007; Grilo and Jardim-Goncalves, 2010; Laakso and Kiviniemi, 2012; Aram *et al.*, 2013). Technical standards are popular with the producers of CAD technologies (Björk and Laakso, 2010; buildingSmart, 2012; NIBS, 2012) hence such standards have received significant support from the IT sector.

For instance, many of the members of the organisation that coordinates the production of the technical standards associated with BIM - BuildingSmart are IT suppliers.

3.3.2 Industry BIM process standards

More than 20 years ago Bjork (1992) argued that the use of computers in construction did not only involve technical standards, but also standards for managing the networks for information transfer and storage databases. Although these views were pioneering, not much has been done to understand the standards that manage the process of producing information in digital environments. Eastman (1997) comments that information management standards are important for concurrent information production, communication and storage.

The Avanti programme, which was funded by the UK government was an early attempt to develop process management standards that could be used to streamline people's interactions in digital technology based environments (Avanti, 2006). The aim of the Avanti programme was to explore the ways of encouraging construction project teams to work together, apply, and develop the processes required to support collaboration (CPIC, 2014). According to the Construction Project Information Committee (CPIC) the organisation that was part of the Avanti programme, Avanti aimed to "deliver improved project and business performance through the use of ICT to support collaborative working, ….getting people to work together; providing processes to enable collaboration; and applying tools to support collaborative working" (CPIC, 2013 p.01). Work on Avanti culminated in a report that was published by the DTI in 2007 (DTI, 2007). The Avanti programme provided the experience and best practice required to produce the BS 1192:2007 standard and later revisions to the same standard (Richards, 2013).

3.3.2.1 The BS 1192:2007 standard

According to the BSI (2010 p.iv), structured processes are important because they regulate and control the creation and use of information, ensuring its reuse, and reductions in time required to retrieve and maintain documents in construction projects. Developed at the industry level, the BS 1192:2007 and its successor the PAS 1192:2012 (1-3) is an open, collaboration management standard for use by the UK construction industry. The standard aims to improve "the ability to communicate, re-use and share data efficiently without loss, contradiction or misinterpretation" (BSI, 2007 p.01). The BS 1192: 2007 requires all construction projects to implement the following procedures:

- Roles and responsibilities of the project team members
- Digital information file naming conventions
- Project specific codes for managing information
- A common data environment
- An information management hierarchy

The BS 1192: 2007 has since been extensively revised in the latest version of the PAS 1192:2012 (1-3). Figure 3:5 shows an extract of a typical standard information delivery process as set out in the latest version of the standard. The extract shows the different stages of the construction process such as the brief, concept, definition, design, building and commissioning, handover, operation and use stages. During these stages, the project information model (PIM) provides the single source of information. At handover, the PIM is transferred to the facilities management team where an Asset Information Model (AIM) is produced.

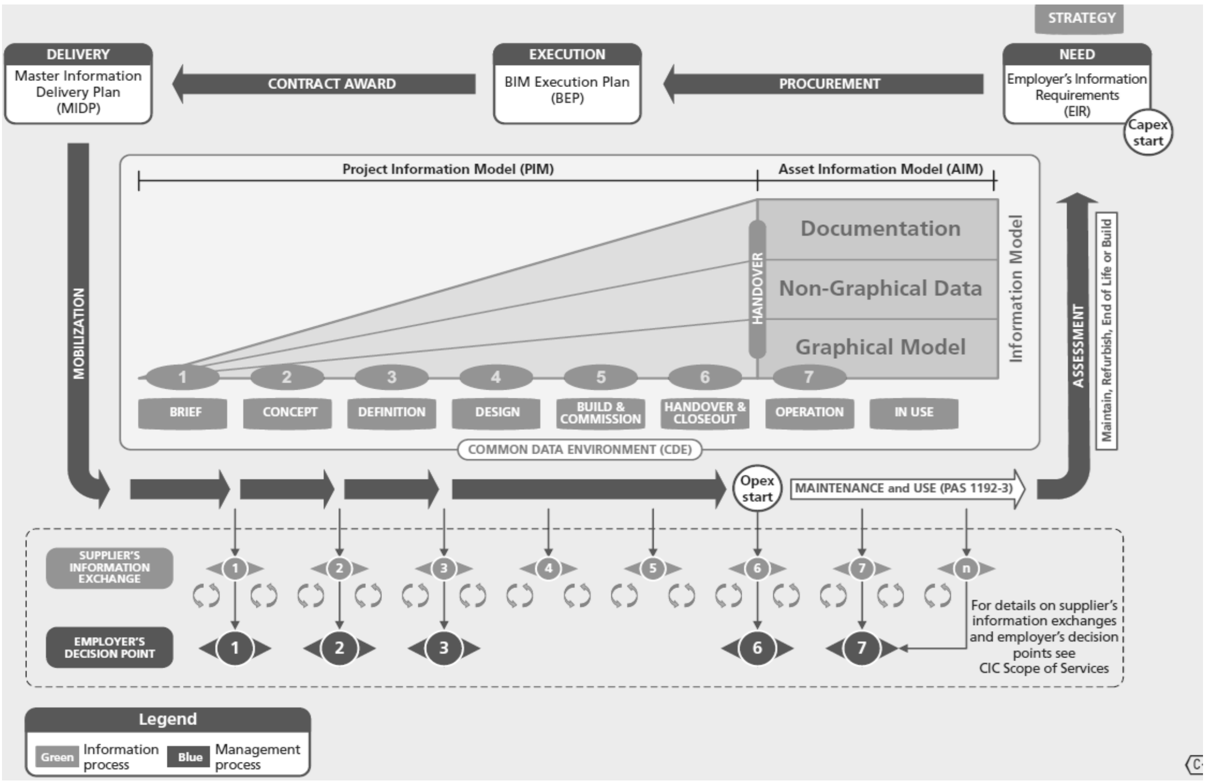

Figure 3:5 PAS 1192 standard construction information delivery cycle[23]

[23] Sourced from Richards, M. 2010. Building Information Management: A Standard Framework and Guide to BS 1192. London: British Standards Institution

3.3.2.2 The BS 1192:2014 – 4 Standard (COBie standard)

COBie is a means of sharing structured built facility information (East and Carrasquillo-Mangual, 2013). COBie provides the procedure and format for information exchange throughout the design, construction and maintenance stages (East, 2012). According to East and Carrasquillo-Mangual (2013 p.10) the COBie process "delivers the subset of the Schematic Design information related to spaces, zoning, and room data sheets." The COBie process standard originated in the United States of America (USA). The COBie process has been illustrated in East and Carrasquillo-Mangual, 2013 p.10 as shown in Figure 3:6 below to show how the COBie is used in exchanging information in the execution of projects.

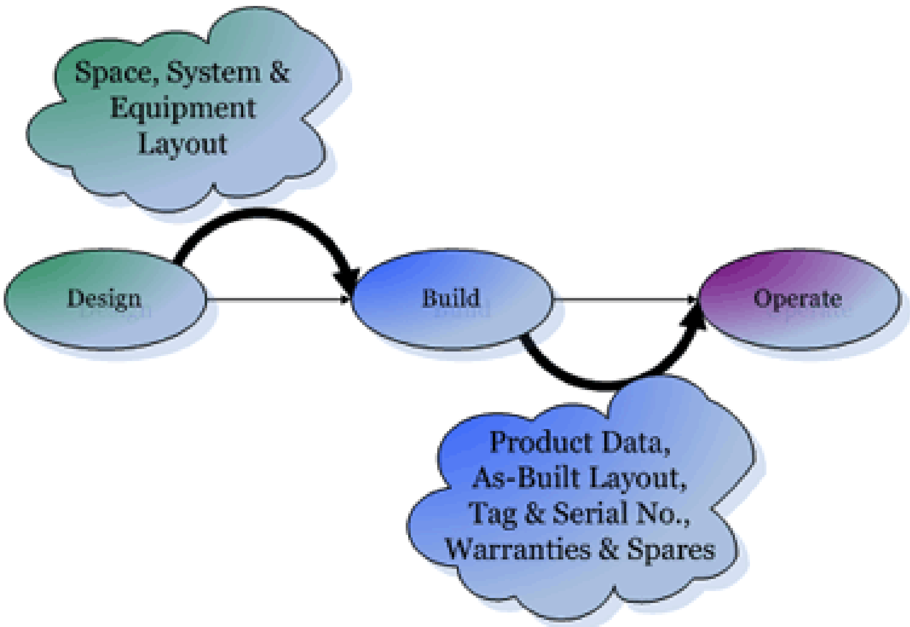

Figure 3:6 An illustration of the COBie process[24]

[24] Sourced from East and Carrasquillo-Mangual, 2013 p.10

In the UK, the standard has been adapted as a schema, with the support of various industry players including BuildingSMART, the BIM task group and the UK government. According to the BSI (2015 p.01), the COBie standard "provides a common structure for the exchange of information about new and existing facilities, including both buildings and infrastructure". The standard provides the schema for information exchange in BIM environments.

The idea behind the COBie standard is that excessive resource wastage is incurred if information-sharing processes do not follow a standard format (East, 2013, Nisbet, 2014, BuildingSMART, 2014). Figure 3:7 shows the different formats of information produced by the COBie standard. Even though the COBie standard is associated with the PAS 1192:2012, because of the expectation that it will be used in the CDE that is provided by PAS 1192 standard (East, 2012; Nisbet, 2012; East *et al.*, 2013). In fact, the links have been identified between the IFC and the COBie standard[25] (BSI, 2015). These links show the systemic nature of standards as explained in Chapter 2, Section 2.3.5 that are interesting to study.

[25] The COBie standard went into public circulation in 2015, this was after the research had been conducted

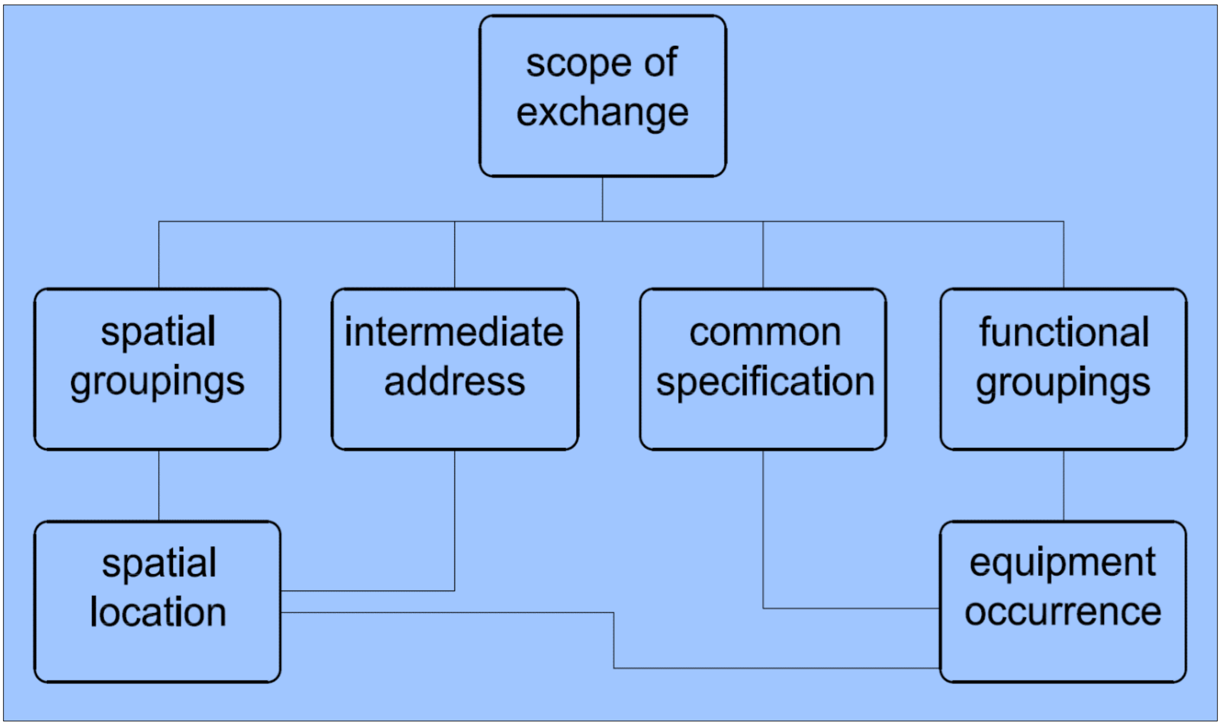

Figure 3:7 The COBie standard process[26]

3.4 The UK construction industry

There are many reasons why construction firms embrace new technologies such as BIM process standards. Harty (2005) explains that technologies are difficult to adapt in construction because of the complicated relationships between actors. This section considers how the landscape of UK construction, the institutional framework, structure of

[26] Source BS 1192-4:2014

the industry and the government may shape the adaptation of industry BIM process standards.

3.4.1 Defining the industry

The construction industry is comprised of professional services, contracting, and facilities management firms (Green, 2011). Arriving at a suitable definition of the construction industry is often problematic because of the nature of construction and the parties involved (Gann and Salter, 2000). For instance, materials suppliers and distributors, contractors, labour only suppliers, plant and equipment manufacturers and distributors, and professional service firms are all involved. These different actors all have varying degrees of influence over the outcome of the construction process. Focusing on the process to define the construction industry is however problematic because the process of construction involves the assembling of physical products manufactured by firms that may be engaged in many different industries. Therefore, the question is whether all these firms might fall within the collective definition of a 'construction industry'? It is important to note that there is little agreement on this problem. The department for Business, Innovation and Skills (BIS) argues that firms that produce, distribute and sell construction related products and materials are not part of the construction industry. This is because they are not directly involved in the designing, constructing and maintenance of built environment.[27]This research adopts the BIS

[27] The UK government adopts this definition of the construction industry. It excludes the industries that produce, distribute and sell construction related products and materials (BIS, 2013).

definition of the construction industry. Accordingly, the UK construction involves only contracting and professional service firms that are directly involved in the design, construction and maintenance of built facilities. The firms in the construction industry, so defined, provide contracting, architectural, project management, engineering design and facility management services. These firms perform various functions in the production of built facilities; therefore, they may have an influence over the adaptation of industry BIM process standards.

3.4.2 The construction innovation issue

Work on innovation in construction discusses innovation in terms of productivity and competitiveness. In January 2011, the UK government published its construction strategy that places BIM at the core of government policy, arguing that innovation is necessary to reduce carbon emissions, construction costs and productivity (Cabinet Office, 2011). This is not the first time when a new initiative has received significant attention from the government. Since the end of the Second World War, successive UK governments have sought to improve the productivity by launching a number of industry level review that have all culminated in various solutions such as Business Process Review and Partnering. The reviews have addressed a variety of topics including research and development, innovation and competivity (Joint Government and Industry Construction Review, 1994; Construction Task Force, 1998). The Emerson report; Banwell report; Latham report and the Egan reports (Ministry of Public Works and Building, 1964; Joint Government and Industry Construction

Review, 1994; Construction Task Force, 1998; Fairclough, 2002), identified problems such as the limited uptake of new technologies, poor procurement systems, and fragmented construction process that breed rivalry between project parties. The absence of knowledge centres for best practice and lack of collaboration are some of the cited problems. Against this background, there is speculation that BIM process standards are receiving an unusually large interest from across the construction industry because of the expectation that they will address the problems cited above (BIM Task Group, 2012). This is despite that many technologies have come and gone with little success in addressing the identified challenges.

Addressing issues raised in the high profile industry reviews is profoundly important for product manufacturers, design and construction firms, facilities management businesses, the government and other users of the BIM standards technology. For the government as a key client the purpose of embracing BIM standards is to reduce costly infrastructure development schemes and improved use of built facilities (Cabinet Office, 2011a). The industry as an important sector of the UK economy develops vital infrastructures such as schools, hospitals, railway lines, bridges and roads. The infrastructure contributes significantly to economic growth and technological advancement, therefore studying the way firms innovate in the production of the built environment is relevant.

The UK construction industry produces the built environment. The industry employs more than 2.1 million people and contributes significantly to the country's gross economic output (ONS, 2013)(ONS, 2013). The use of industry BIM standards for efficient production and exploitation of resources is of prime concern not only for firms, but also for customers both public and private. This may partly explain the current UK government's position on BIM (Office, 2011; BIS, 2013a).

The extant debate on the innovativeness of UK construction has focused on a variety of issues including how new technologies are integrated into production processes (Dossick and Sakagami, 2008; Manley, 2008; Arayici *et al.*, 2011b). Construction is generally presented as a traditional industry that does not embrace new technologies as compared to other industries such as IT and manufacturing (Gann, 2000b; Brandon *et al.*, 2005; Reichstein *et al.*, 2005). However, as argued in Section 3.3 digital tools are rapidly shaping construction practice, meaning that there are significant improvements in the production processes, which are yet to be recognised.

Barely, four years after a review led by Sir Michael Latham, the incoming labour government commissioned Sir John Egan to provide another report on the industry's competitiveness. The Egan report (as its often identified by some), was published in 1998 titled 'Rethinking construction' focused mostly on the building sector (Construction Task Force, 1998). The report underscored the importance of integrated processes in delivering projects. It argued that such processes foster a culture of collaboration in construction practice. It also advocated for the "maximum use of standard components and processes" to complement the collaborative culture (Construction Task Force, 1998 p.04). Despite its reach, like many of its predecessors Egan's review did not examine the use of new technologies in construction production. Even though the Egan and Latham reports were published when significant advances had been made in relation to BIM, the reports say little about how industry BIM process standards shape technological change in construction firms.

In 2002, another review led by Fairclough was published. The review's findings were that there is need for improvements in research and development (R&D) efforts. The review also emphasised the importance of new technologies (Fairclough, 2002). Though the review focused on R&D, the findings had broader implications for innovation in construction. Indeed, in the past decade there has been an increase in research on innovation in the construction industry (see Chapter 3). Whilst other reviews such as the Egan report (1998) had made scant reference to innovation, Fairclough's report concluded that the long term competitiveness and efficiency of the industry lies in the government's ability to support R&D and the adoption of new technologies (Fairclough, 2002). Fairclough's report however did not address innovation from the use of new technologies in UK construction deciding to focus mostly on R&D.

Despite the high profile reviews, there are suggestions that firms in the construction industry continue to face challenges particularly in exploiting new technologies (BERR, 2008; Cabinet Office, 2011; Underwood and Khosrowshahi, 2012). As an example a recent report by the government's department for Business Innovation and Skills notes that the construction industry has a) high levels of fragmentation and limited collaboration; b) procurement processes that do not address low levels of collaboration, and c) reduced learning and knowledge transfer (BIS, 2013b p.vii). The view that the industry does not embrace new technologies appears to be popular in discussions of the UK construction industry (Ofori, 2003; Goulding *et al.*, 2007; Akintoye *et al.*, 2012). Problems with new technology adoption in construction however are in conflict with research on Computer Aided Design (CAD) digital design technologies, which indicates increasing of such technologies in construction production since the 1960 (Björk, 1992; Miyatake and Kangari, 1993; Coles and Reinschmidt, 1994; Eastman, 1999). Dodgson *et al.* (2005), argues that innovation technologies such as CAD are rapidly influencing and contributing significantly to innovation in construction. These differences in perspectives suggest that there may be deeper issues about new technologies and innovation in construction that need to be addressed.

Among the many different studies of new technologies (Gann, 2000b; Whyte, 2003; Boland *et al.*, 2007; Henderson, 2007; Taylor, 2007), the topic of BIM as a technology that intensifies the innovation process is under-represented. Hence, little is known of how firms' adapt and strategize as they begin to integrate BIM into their production processes. Consequently, it has neither been possible to explain the role of the institutional environment, nor fully unpack the implications of industry BIM process standards on the creation of resources and capabilities in construction-based enterprises.

3.4.3 Structure of the industry

In the decade prior to the 2008 economic down turn, the industry experienced rapid growth (See Figure 2.1 below). In 2013 the industry contributed 9% to the UK's annual Gross Domestic Product (GDP) (BIS, 2013b). This makes the industry a key sector of the UK economy. As many of the sectors of the UK economy the construction industry did not escape the devastating effects of the 2008 global economic down turn. The industry shrunk by as much as 13% and 8% in 2009 and 2011 respectively (ONS, 2013) as shown in Figure 3.8 before it began to slowly recover.

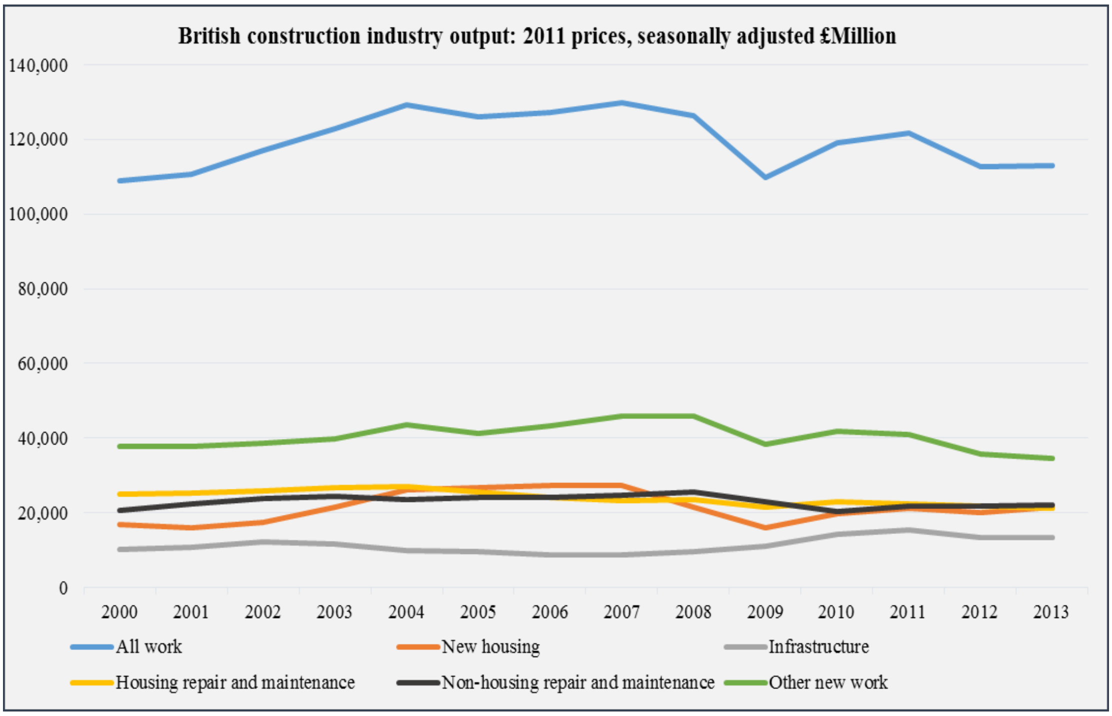

Figure 3:8 British construction industry output (2000 - 2013)[28]

[28] Data sourced from the Office of National Statistics, 2015. Figures do not include specialist service firms

Data from the UK's Office of National Statistics (ONS) shows that construction industry had 266 000 construction firms and in excess of 45 000 professional services firms at the end of December 2013 (ONS, 2013) [29]. As shown in Figure 3.8 less than 2% contracting firms turnover more than £5 million. A significant proportion of the industry's output comes from small and medium size firms. In fact more than 70% of contracting firms turn over less than £250 000. Whilst smaller contracting firms are responsible for the actual assembly, large firms usually, integrate the services of many different suppliers to deliver built assets. This also confirms that industry has low barriers to entry (Ezulike *et al.*, 1997; Morton and Ross, 2008); and has implications to the competitiveness of the industry.

The UK construction industry consists of a few firms (2%) that account for the highest turnover (above £5 000k) as shown in Figure 3.8. The industry has many small enterprises that employ the bulk of the construction work force (See Figure 3.9). The small firms, as measured by turnover below £250k, employ less than five people. This is in the context of an industry that employed around 2.3 million people in 2008, although by mid-2014[30] this had reduced to 2.2 million (ONS, 2014). The large firms typically employ the small firms to carry out a variety of functions. Therefore, the small and large firms are embedded in systemic interdependent relationships.

[29] Data sourced from the Office of National Statistics, 2015. Figures do not include specialist service firms
[30] Non-seasonally adjusted figures of construction industry employment published by the ONS in December 2014

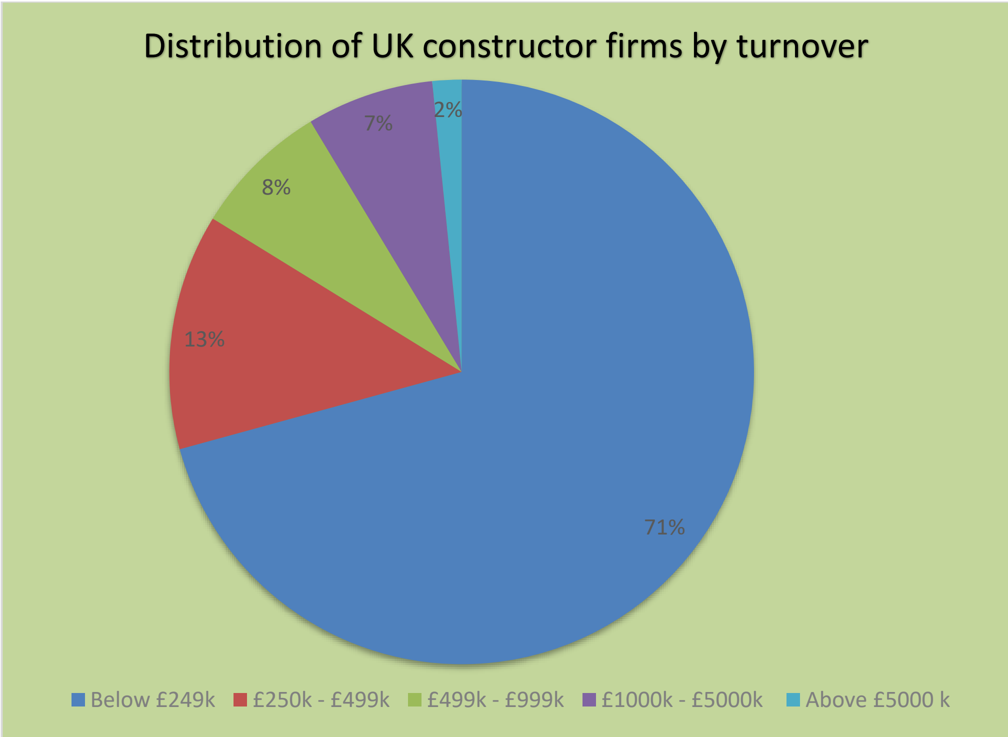

Figure 3:9 UK Contracting firm distribution by turnover[31]

3.4.4 Dominant role of government

The industry relies on the government for the bulk of its employment. The UK government has been instrumental in spearheading the industry's recovery by increasing expenditure in infrastructure projects (ONS, 2014). Notable large-scale infrastructure projects commissioned include High Speed 2 and the Crossrail rail projects. However, this also means the industry remains heavily influenced by the government of the day. This makes

[31] Source ONS, 2014 – Data is for firms in Great Britain only

construction particularly unique. For instance in some sectors the application of industry standards is mostly driven by the market, where is in the UK, the application of industry BIM process has been driven by the UK government.

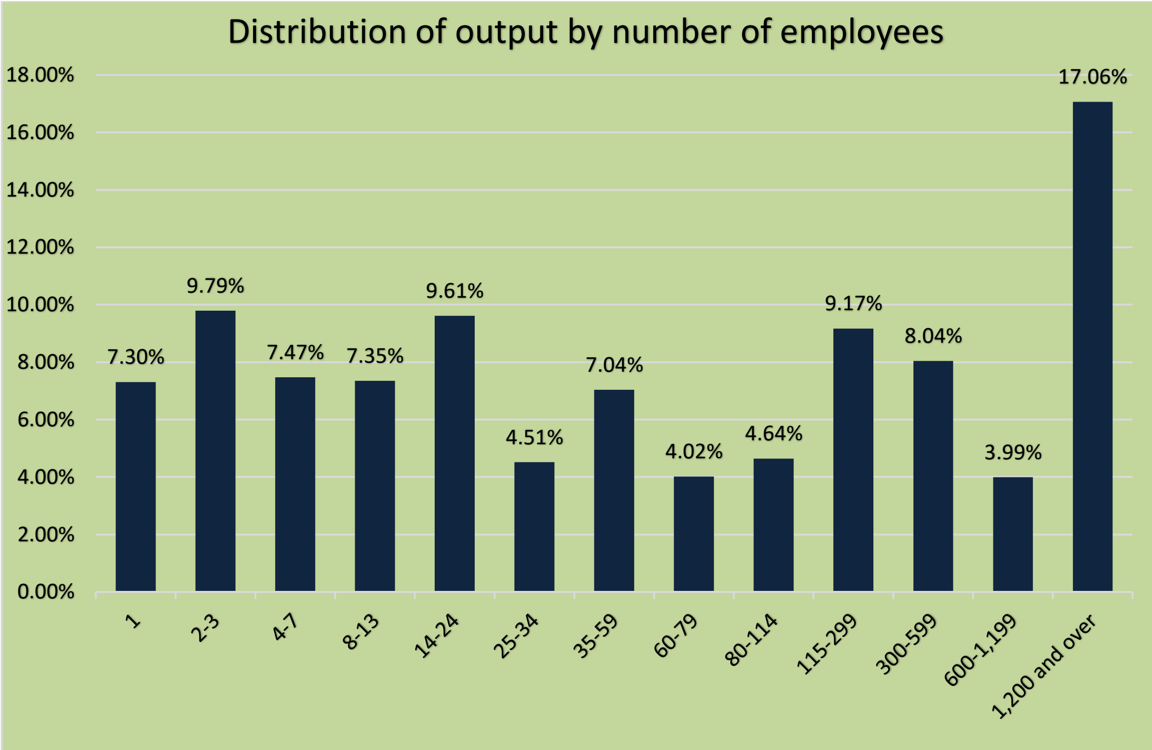

Figure 3:10 Distribution of construction output by number of employees[32]

[32] Source: ONS, 2014 - Data is for firms in Great Britain only

3.5 Summary

This chapter discussed the concept of BIM and associated industry BIM standards. The differences between BIM process and technical standards were identified and discussed. The discussion shows that technical standards are used to manage interoperability between digital technologies, whereas process standards manage the collaborative environment in which digital, construction information is produced and exchanged. The chapter further examined the empirical context of the UK construction industry that may influence the adaptation of industry BIM standards. The next chapter presents and discusses the research methods used to study the adaptation of industry BIM process standards in a large UK construction firm.

Chapter 4: Research methods

4.1 Introduction

This chapter explains the research methods used to investigate the adaptation of industry BIM process standards in a large UK construction firm. The previous chapter proffered an insight into the debate surrounding the BIM initiative. This chapter argues that the application of industry BIM process standards is influenced by the complex nature of construction and that this is better understood using an interpretive philosophy. Therefore, it is necessary for the researcher to embed themselves within the social setting of the participants to understand the meanings they attach to their experiences with industry BIM process standards. This chapter presents and discusses the literature on research paradigms, research designs, data collection methods and analysis techniques used in social science research.

The chapter is organised in sections as follows. Section 4.2 discusses the interpretive research philosophy adopted for the research. Section 4.3 focuses on the data collection methods. Section 4.4 explains the research design. Sections 4.5 and 4.6 explain the interpretive and case study strategies including the data collection techniques used. Section 4.7 focuses on the data analysis techniques whilst section 4.8 concludes the chapter with a review of ethical considerations.

4.2 Adopting an interpretive paradigm

4.2.1 Interpretivism

Saunders *et al.* (2012 p.116) argue that in management research, “not only are business situations complex, they are also unique. They are a function of a particular set of circumstances and individuals coming together at a specific time”. It is important for the researcher to embed within the participant’s world, understand their lived experiences and to know the meanings they attach to those experiences. To do this the researcher must draw upon their own experiences, interpret the meanings of other’s actions and contest those meanings, to understand reality (Yanow and Schwartz-Shea, 2015). The interpretive paradigm is one of the many different philosophical paradigms such as positivism, realism and pragmatism (Merriam, 2014). Interpretivism assumes that reality is concealed in social interactions. Philosophical paradigms are foundational perspectives about reality in social science inquiry (Denzin and Lincoln, 1994). They are “perspectives about research held by a community of researchers that is based on a set of shared assumptions, concepts, values, and practices” (Johnson and Christensen, 2008 p.31). Paradigms cannot be proven or disproven instead they are human constructions and subjective (Guba, 1990b).

The interpretive paradigm is to be distinguished from the positivist who believes that there is a single reality that can be abstracted from its context. The realist argues that a real world exists and there are multiple scientific ways of understanding it (Miles and Huberman, 1994;

Hammersley, 2008). The interpretivist believes that reality is subjective and there are multiple realities in the social world. Reality is seen as inseparable from its contextual setting (Guba and Lincoln, 1994a; Creswell, 2003; Flick, 2014). Interpretivism believes that reality exists only in one's mind and can only be understood in the particular context of occurrence (Denzin and Lincoln). If one removes themselves from the context of occurrence, their interpretation of reality changes. Consequently, one can only understand reality through a window of a specific theoretical and mental enquiry. All research is guided by these fundamental beliefs about reality (Guba and Lincoln, 1994b). The interpretive paradigm is adopted because it is necessary for the researcher to embed themselves within the social setting of the participants to interpret the meanings they attach to the adaptation of industry BIM process standards. This allows the phenomenon to be understood through the particular lenses of the users.

Scholars researching the built environments have grappled with the philosophical paradigms debate. While some argue that research should focus on understanding meanings rather than causality through the use of the interpretive approach (Seymour and Rooke, 1995; Love *et al.*, 2002), others have fiercely defended the positivist paradigm (Wing *et al.*, 1998). Raftery et al, (1997) argues that strict adherence to a single philosophical paradigm is being too narrow minded and unhelpful. Despite differences about which paradigm to assume, there is some consensus in what the paradigms allow the researcher to say and not say (Dainty, 2008). For example scholars agree that the interpretive approach is appropriate for investigating the *how and why*, while the positivist approach is useful in establishing causality i.e. the *what* (Runeson, 1997; Walker, 1997; Seymour and Rooke, 1998; Dainty 2009). The subsections below discuss research ontologies, epistemologies, axiology and methodological positions and their role in social science inquiry.

4.2.2 Ontology

Ontology is the science of the nature of reality. It is concerned with whether reality exists or does not. Dichotomies of ontology exist in positivism, realism and interpretivism. Whereas objective ontology assumes that there is a single reality which can be abstracted and be subjected to universal laws of science, rationality, and be manipulated through logical processes of the mind (Erlandson *et al.*, 1993); realist ontology believes in the existence of both the objective and subjective reality that is shaped by time and history (Miles and Huberman, 1994). The research is aligned to the relative ontology argument that sees reality as subjective and socially constructed (Strauss and Corbin, 1998). Therefore, reality exists in multiple forms and cannot be understood through rational processes of the human mind (Denzin and Lincoln, 1998b). Perceptions of reality as constructed by the mind, are context specific and bound to change as the context changes (Erlandson *et al.*, 1993). Reality is therefore interdependent, contested and only explainable through examining the whole context within which phenomena occurs (Lincoln and Guba, 1985). To understand reality, researchers piece together its different meanings as constructed by the individual in their particular and specific social contexts (Guba, 1990a).

4.2.3 Epistemology

Epistemology is the science of knowledge. It concerns the assumptions about how humans come to know what they know (Silverman, 2006). It involves the validation of knowledge and the relationship between the inquirer and the known (Guba, 1990a). Epistemology seeks to answer the questions: how do we know what we know? What can we know, and how do we acquire and accept what we regard as valid knowledge? Whilst objective epistemology argues for the maintaining of distance between the research and research subjects, subjective epistemology argues that knowledge is socially constructed (constructivism) (Denzin and Lincoln, 2008). It is only possible to understand knowledge through removing distance between the researcher and the researched. In the subjective epistemology tradition, naturalistic methods of collecting data are preferred (Lincoln and Guba, 1985; Silverman, 2006). Field studies and first-hand information are an important way of gaining knowledge (Creswell, 2003).

Table 4:1 below offers an analytical review of the objective, interpretive (constructivist), post positivist and critical theory views. The table addresses some of the practical research issues within the tradition. In sum, constructivist views reality as socially constructed. Research is a way of understanding and reconstructing meanings formed by individuals. Moreover, the researcher's values are woven-in in naturalistic fashion. Researchers act as a platform for multi-voice recognition. In the process of research, the subjective nature of meaning and the multiple meanings constructed through social interactions become clearer.

4.2.4 Axiology

Axiology is the science of values that are a-priori postulated as truths. The values, basics or unquestioned assumptions about reality form the basis for making claims about the nature of knowledge. Whilst positivists maintain objective separation between the researcher and the researched, interpretivists believe that the researcher's values are part of social science inquiry. According to the interpretivist tradition, all research is shaped by and dependent upon the researcher's value systems (Silverman, 2006; Creswell, 2007). Whilst every attempt is made to minimise bias during research, the researcher's values are intertwined with the research.

4.2.5 Methodology

Methodology is the science of research methods or techniques (Patton, 2002a; Creswell, 2003). Methodology addresses the appropriateness of research techniques, sampling strategies and data analysis (Denzin and Lincoln, 1998a). Guided by the fundamental belief systems explained before, research methods yield different research outcomes. There is an argument that there is no accurate research method, instead methods can only be either useful or less useful depending on one's perception of reality (Creswell *et al.*, 2007). Research methods depend on the researcher and the research purpose (Silverman, 2009). The next section 4.3 below discusses the different research approaches, strategies and methods for data collection.

Issue	Positivism	Post positivism	Realism	Interpretivism
Inquiry aim	Explanation, prediction and control		Critique and transformation	Understanding and reconstruction
Nature of knowledge	Verified hypothesis	Non verified hypothesis	Structural and historical insights	Individual reconstructions and consensus seeking
Knowledge accumulation	Generalisations, cause-effect linkages		Generalisation by similarity	More informed and sophisticated reconstructions
Quality criteria	Benchmarks of authenticity established. Testing external and internal validity, reliability and objectivity		Historical situatedness, erosion of ignorance	Trustworthy and authentic
Values	Excluded		Included	
Ethics	Extrinsic – tilting towards deception		Intrinsic, tilting towards revelation	Intrinsic, tilting towards revelation and exposing special problems
Voice	Disinterested, informer of decision makers, policy and change agents		Advocate / Activist	Facilitator of multi voice recognition
Training	Technical and quantitative substantive theories		Resocialisation, qualitative and quantitative	
Accommodation	Commensurable		Incommensurable	
Hegemony	In control of publication, funding and tenure		Seeking recognition and input	

Table 4:1 Practical issues in research paradigms from Guba and Lincoln 1994 p.112

4.3 Research strategies and data collection methods

This section discusses the research strategies and data collection[33]. The discussion contrasts the interpretive and case study strategies adopted for this research with other strategies such as ethnography and grounded theory. Methods for gathering qualitative data such as interviews, observations and secondary publications are examined. This section articulates how interpretive and case study strategies are appropriate in addressing the research phenomena as well as examining the limitations of these strategies.

4.3.1 Quantitative, mixed and qualitative data

Social science inquiry employs different ways of gathering quantitative, mixed and qualitative data. According to Cresswell (2003), the collection of quantitative data is associated with research strategies such as surveys and experiments. Such techniques are associated with establishing causal relationships, confirming and refuting hypothetical statements about the generality of phenomena and establishing strengths in relationships between variables (Denzin and Lincoln, 1994; Kumar and Phrommathed, 2005). The researcher's philosophical beliefs guide the selection of particular approaches. Other

[33] A distinction is made between research techniques, research strategies and data collection methods. Strategies are not linked to any particular data collection method as explained by Yin, R. K. 1981. The case study crisis: some answers. *Administrative science quarterly*, 58-65.

scholars prefer to gather mixed data (Hammersley, 2008) thereby reflecting a rational approach. Ethnography, grounded theory and case studies are popularly used by interpretivists to gain new insights into the phenomenon of interest (Creswell, 1994 ; Fellows and Liu, 1997; Silverman, 1997).

Table 4.2 contrasts between the approaches to collect qualitative and quantitative data. Qualitative data is popular with scholars with interests in explaining how interpretation occurs and the multiple meanings attached to social phenomena (Flyvbjerg, 2006; Neergaard and Ulhøi, 2007; Baxter and Jack, 2008). To build new theoretical understandings, scholars emphasise the ability to reduce separation between the researcher and environment (Miles and Huberman, 1994; Eisenhardt and Graebner, 2007). Silverman (2009) questions the dichotomisation of qualitative and quantitative data arguing that "no method of research, quantitative or qualitative is intrinsically better than any other" (p.6). He (Silverman) argues that the dichotomisation is an affront to research methodology advancement, concluding that the selection of a research technique depends on the research question and not on a-priori fixed predeterminations. Cresswell and Clark (2007) identify the, researcher's background, access to participants and the research problem as important in selecting research techniques.

Assumption	Questions addressed	Research approach	
		Quantitative research	Qualitative research
Ontology	What is the nature of reality?	Reality is objective and singular	Reality is subjective and multiple
Epistemology	What is the relationship between the researcher and the researched?	There is distance between the researcher and researched.	There is no separation between the researcher and the researched.
Axiology	What is the role of values?	Research is value free and unbiased	Value laden and biased
Methodology	What is the process of research?	Deductive process Static design and categories are identified before the study begins Context free Generalisations leading to prediction, explanation and understanding Accuracy through validity and reliability	Inductive process Emerging design – categories are established during the research process Context bound Patterns and theories are developed for understanding Accuracy assessed through verification

Table 4:2 Philosophical assumptions adapted from Cresswell (1994 p.05)

Even though the use of plural research as suggested by Silverman and Punch cited above is important to highlight the different aspects of the research problem (Wing *et al.*, 1998; Pan *et al.*, 2007), there is an argument that the different methods emphasise different aspects of the research problem leading to varied conclusions (Dainty, 2007; Rose and Manley, 2012). Interviews, observations and documentary publications are chosen here as appropriate to understand a user firm's experience of industry BIM process standards from an interpretive perspective.

4.3.1.1 Qualitative data

Denzin and Lincoln (1998a) explain that the collection of qualitative data began as a rival to quantitative data collection which was argued to be too objective and structured. Moreover, the data collection process did not recognise the role of the contextual setting. According to Erlandson (1993), qualitative research emerged in the early 1920s and since then its use has grown exponentially. The qualitative research technique is defined by Denzin and Lincoln (1998) as, "multi method in focus, involving an interpretive, naturalistic approach to its subject matter" (p.3). In the collection of qualitative data the researcher embeds in the participant's contextual environment in order to study things or humans in their natural settings (Denzin and Lincoln, 1998a). As illustrated in Table 4:1 interpretivism seeks to reconstruct social meanings through providing a detailed account of people's interactions and experiences (Guba and Lincoln, 1994b). This is at variance with positivists who emphasise on quantifying through measurement of causal relationships between independent and dependant variables, in order to explain cause and effect (Punch, 1998).

The collection of qualitative data involves the use of multiple methods to suit the context of occurrence. The argument behind qualitative research is that reality exists in multiple forms as explained in Table 4:3, hence multiple methods of collecting data are often necessary to improve the understanding of the phenomenon. Subsection 4.3.3 outlines the multiple methods used to collect data. Interviews, observations and secondary documents capture multiple meanings as constructed by participants (Saunders *et al.*, 2012). Miles and Huberman (1994) note that the qualitative research produces rich and voluminous data, involving thick and vivid descriptions of the context. Merriam (2002 p.5-6) and Punch (2009) explain that the qualitative data is appropriate for:

a) understanding and shedding light on the meanings humans construct about their experiences and environment;
b) making use of the human instrument as a primary means of data collected and analysis;
c) gathering data in an inductive fashion rather than deductively in order to develop theory or advance existing theoretical understandings;
d) providing a rich account of the contextual setting within which the phenomena was investigated; and
e) gaining a holistic overview of the context, its rules and arrangements.

In spite of their wide usage, qualitative research approaches are not without weaknesses. A common critique is that of generalizability of findings. There is a view that the qualitative approach is limited in rigorously examining frequency of occurrence beyond the confines of the particular phenomenon (Silverman, 2006). A similar concern relates to the subjective separation of the phenomenon from the researcher given that the naturalistic nature of data gathering. Proponents however, argue that qualitative data proffers multiple views of the phenomenon. This provides rich meanings about the research problem (Denzin, 2009). Moreover, the qualitative research technique allows for the construction of new value laden meanings about social phenomena (Marshall and Rossman, 1989; Miles and Huberman, 1994; Creswell, 1994 ; Strauss and Corbin, 1998).

This subsection considered the different approaches to collecting quantitative and qualitative data. The discussion shows that the collection of qualitative data is, " characterised by a search for meaning and understanding, the researcher as the primary instrument for data collection and analysis, an inductive investigative strategy and a richly descriptive end product" (Merriam, 2002 p.6). Qualitative data helps to develop an in-depth account of the contextual intricacies and multiple experiences of the phenomenon. The approach also enables the complexities and various meanings as constructed by participants to be established and understood.

4.3.2 Research strategy

The research strategy outlines the rationale for gathering data (Punch, 2009; Saunders *et al.*, 2009a). Table 4:3 illustrates the different strategies that are common in gathering qualitative and quantitative data. Strategies can include interpretive, experiments, surveys, ethnography, grounded theory, and case studies (Denzin and Lincoln, 2000; Merriam, 2002; Saunders *et al.*, 2003). As illustrated in Table 4:3 these strategies serve different purposes and address different issues depending on the research question. For instance, the narrative inquiry strategy is important in developing an understanding of how change occurs over time, grounded theory is useful in examining phased change, whilst case studies provide an in-depth account of the phenomenon (Eisenhardt, 1989b; Stake, 1995).

4.3.2.1 Interpretive strategy

Merriam (2014) explains that the interpretive strategy is appropriate to know more about the phenomenon. They add that it can be used to understand how participants make meaning of a particular situation or phenomenon. The strategy is phenomenological in nature; it is concerned with the lived experiences of those involved. Consequently, naturalistic techniques for collecting data that embed the researcher in the natural context are necessary. The strategy uses the insider's view (emic) rather than the outsider's (etic) perspective to gather knowledge about the phenomenon (Merriam, 2014). Inductive data analysis techniques are used to build common themes that cut across the data (Merriam, 2002).

4.3.2.2 Case study strategies

Positivists and interpretivists can use case studies. This research employs the case study strategy from an interpretivists perspective to provide a contextually bound, rich and in-depth analysis of the phenomenon (Eisenhardt, 1989b; Miles and Huberman, 1994; Stake, 1995; Creswell, 2007). For Yin who follows a positivist philosophy, the case study is “an empirical enquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident” (Yin, 2003 p.13). Eisenhardt (1989b) considers case studies to be, “research strategies which focus on dynamics present within single settings” (p.534). Interpretivists like Creswell et al (2007) argue that case studies are strategies, “in which the investigator explores a bounded system or multiple bounded systems over time through detailed, in-depth data collection involving multiple sources of information (e.g., observations, interviews, audio-visual material, and documents and reports)…” (p.245). Whilst the above definitions emphasise the detailed nature of case studies, differences persist in the definition of a ‘case’.

The above discussion prompts one to inquire about the definition of a case. For Miles and Huberman (1994) a case is “a phenomenon of some sort occurring in a bounded context” (p.25), similar views are shared by Eisenhardt. However scholars like Stake define the case as if it an object with functions and boundaries (Stake, 1995). Stake argues that a case must be a “specific, complex, functioning thing” (Stake, 1995 p.2). For Miles and Huberman (1994), the case can be an event, period of time or process. Following Stake (1995)’s view, the research argues that the firm is the case because the case is a specific functioning thing. Studying the adaptation of BIM process standards by the firm helps to: a) develop understandings through in-depth studies, b) integrate contextual issues into the analysis, c) emphasise the context; and d) focus on the particularities of the phenomenon.

Stake (1995) identifies the intrinsic, instrumental and collective typologies of case studies. The intrinsic case studies focus on the particulars and uniqueness of a single case, whereas the collective case study is comprised of a number of cases. Instrumental case studies focus on the specific issue in order to provide insight into a wider phenomenon. Therefore they are important in building an in-depth understanding of the particular phenomenon (Stake, 1995).

There is an intense scholarly debate concerning the use of case studies in social science inquiry. Yin (1994) argues that case studies should be consigned to testing theories, whilst others (e.g. Eisenhardt and Graebner, 2007) maintain that case studies are useful in developing middle range theories and not grand theories. Contributing to the debate on case study suitability, Flyvbjerg (2006) identifies what he addresses as 'common misconceptions' such as, "1) Theoretical knowledge is more valuable than practical knowledge. (2) One cannot generalize from a single case, therefore the single case study cannot contribute to scientific development. (3) The case study is most useful for generating hypotheses, while other methods are more suitable for hypotheses testing and theory building. (4) The case study contains a bias toward verification; and (5) it is often difficult to summarize specific case studies"(p.03). Case studies can produce "concrete, context-dependent knowledge" (Flyvbjerg, 2006 p.06). Even though this research does not seek to test theory, the prevailing view is that through purpose and theoretical sampling, case studies can be useful in both building and testing theory (Stake, 1978; Silverman, 2009).

As noted in Flyvbjerg (2006), concern has been expressed on the generalizability of findings from case studies given that data collection focuses on the particulars of a single and often unique case that are hardly replicable. Thus, there is a question about the relevance of focusing on particular instances when seeking to understand, predict and interpret general phenomena. There is an important argument in that truth is not to be found in general axioms, but in particulars, and is socially constructed in an individual's mind (Stake, 1978). Therefore, generalization is naturalistic and subjective to the individual's context. It is different from statistical generalization.

4.3.3 Data collection methods

David and Sutton (2004) used the *Camera* metaphor to argue that although useful data collection methods have weaknesses – they are influenced by other factors such as the researcher and the research participants. They explain,

> "… it is nice to imagine that the camera… gives a picture of the world that never lies, how the researcher choses to direct and select will shape the data they collect… what people do and what they say they do are not always the same thing. Similarly what people say and do and what people say and do when they are being observed are not always the same things" (p.27).

To ensure reliability of research findings it is essential to employ multiple data collection methods. Multiple methods are also important in approaching the phenomenon from different angles to build understandings of the breadth and depth of idiosyncratic human experiences in social and natural contexts (Strauss and Corbin, 1998; Seale, 1999; Patton, 2002a; Ritchie and Lewis, 2003; Saunders *et al.*, 2009a). The next subsections offer an in-depth analysis of interviews, observations and secondary publications.

4.3.3.1 Interviews

Interviews are an interaction between the interviewer and the research participant to obtain information about the participant's particular views and experiences (Kvale, 1996). The interviewer aims to understand the world from the participant lived experiences and the meanings they attach to their experiences. According to Kvale (1996), interviews advance understanding of the lived world, human experiences and human constructions of meaning. Ritchie and Lewis (2003) argue that, "… complex systems, processes or experiences are better addressed in, in-depth interviews because of the depth of focus and the opportunity for clarification and detailed understanding" (p.58).

Interviews are classified according to their structure, depth and the degree to which the interview is standardized across different respondents and settings (Punch, 1998). Open-ended, semi-structured and structured interview are popular types. In the open-ended interview, the interviewer explores many facets of the participant's experiences. The participant talks freely while the interviewer regulates the discussion, pursuing interesting leads as they arise. This type of interview is used to gain an understanding of the wider phenomenon (Silverman, 2006). Semi-structured interviews have a sequence; they stipulate the areas covered in the discussion and have specific questions. Semi structured interviews are flexible enough to permit the interviewer to diverge as necessary in order to pursue interesting lines that arise from the conversation (Kvale, 1996). Structured interviews contain standardized questions and multiple choice answers (Silverman, 1997).

A common critique for semi-structured interviews is that they are limited to the context of the discussion. They do not provide an accurate account of social reality because of bias in both the research and the researched. Interview participants use “familiar narrative constructs, rather than providing meaningful insights into their subjective view” (Silverman, 1997 p.127). Moreover, sense making and interpretation is done by the participant (Charmaz, 2003). However, through asking interviewees to recount specific examples of their experiences interview bias is limited.

4.3.3.2 Observation

Observations can be a useful way of gathering qualitative data. They involve the researcher spending time observing human behaviour and interactions in their natural environment (Creswell, 2003). Patton (2002a) explains that observational data, “describe the setting that was observed, the activities that took place in that setting, the people who participated in those activities, and the meanings of what was observed…” (p.264). Observations take different forms. While some researchers might prefer to actively participate (participant observer), others prefer to simply be an observer (Silverman, 2006). Despite the purported differences, Atkinson and Hammersley (1994) argued that social science inquiry involves participant observation because researchers are part of the world they are observing.

Research question type	Qualitative research strategy	Unit of analysis	Data collection method	Data analysis strategy
Questions about life histories and how they unfold over time	Narrative research	One or more individuals	Interviews and documents	Storytelling and chronology
Questions about providing an in depth understanding of a unique case	Case study	Event, program, activity, interaction, process, one or more individuals	Questionnaire, interviews, observations and documents	Description of the case and themes within the case
Process questions about experiences over time or changes that have stages and phases	Grounded theory	Process, action, interaction involving many individuals	Interviews and documents	Open coding, Axial coding and selective coding
Questions about how people make meaning of a particular phenomenon	Interpretive	Situation, phenomenon	Interviews, observations and documents	Descriptive, inductive to identify recurrent themes that cut across data
Essence questions at the core of experiences about a phenomenon	Phenomenology	Several individuals with shared experience	Interviews, observations and documents, artefacts	Bracketing, statements, meaning themes
Questions about how change occurs in communities	Participatory/ Action research	Entire community	Quantitative and qualitative methods	Community involvement in decision about data analysis

Table 4:3 Review of research strategies adapted from (Creswell *et al.*, 2007 pp.239 - 241)

Benefits of observations as a way of collecting data are that the researcher is able to understand the context within which people interact (Denzin and Lincoln; Flick, 2007; Saunders *et al.*, 2009b; Whyte and Lobo, 2010). Moreover, the researcher is free from the shackles of prior conceptualisations. As a result the researcher can observe things that would normally elude interview recollections (Patton, 2002b). However, as presented in Table 4:4 observations are time consuming, intrusive and there is a risk of the researcher going 'native' (Bryman and Teevan, 2005). Moreover, the participant behaviours might change due to the researcher's presence. Despite the weaknesses, when used together with other methods such as interviews and secondary, observations are useful in separating facts from fictional descriptions (Marshall and Rossman, 1989).

4.3.3.3 Documents

Documents are an important source of qualitative data and are often combined with other data collection methods such as interviews and observations (Patton, 2002b). Punch (1998) suggests that documents provide information about the "immediate natural behavior of participants …and the symbolic context and significance of that behavior" (p.62). Documents include diaries, emails, personal notes, reports, drawings, meeting agenda, webpages, meeting minutes, institutional pronouncements, financial reports, video recordings, pictures and internal communiques, but generally these are generated through the research process.

Distinctions exist between the classifications of documentary evidence. For instance Prior (2003) argues that documents should be classified according to the original intentions of the creator, the uses, and the settings in which the documents evolved. There is also an important argument that documents should be distinguished as either primary, secondary, direct or indirect sources of evidence (Punch, 2009). The primary and secondary document categorization has been used in this research. The analysis of documents can be cumbersome due to their vastness and voluminous nature of the data. Secondary documents are advantageous in that they cannot be affected by hindsight bias or retrospective synthesis as might occur for instance in an interview discussion (Orton, 1997; Gibbs, 2008)

Data collection method		Advantage	Disadvantage
Interviews	Structured interview	Useful in ensuring consistency	Information is filtered through the views of the participant and the researcher
	Semi structured interview	The researcher has control over the line of questioning Useful in maintaining some consistency	Some participants are not good at articulating their experiences
	Open ended interview	Explores many facets of the interviewee's experiences Participants can choose their own themes Useful in obtaining large amounts of data quickly	Some participants are not good at articulating their experiences Unstructured interviews do not provide a framework for guiding the discussion
	Focus group	Useful in stimulating people to make explicit their views Less expensive, flexible, data rich and elaborative	Particular skills are required in the researcher which if not possessed might affect the research
	Participant observation	Researcher has first-hand interaction with the participant Information can be recorded in-situ	Researcher may be seen as intrusive Private information might be obtained which is not useful to the researcher

Observations	Observer	Ability to stand back from the discussion so that groups dynamics emerge Unusual aspects can be noticed during observation Is unobtrusive when conducted inconspicuously	Researcher may be seen as intrusive Private information might be obtained which is not useful
Documents	Secondary publications	Enable the researcher to obtain language and words of the participants Researcher can access the information at times convenient to them	Documents may be protected information which is not available to the researcher Accuracy is limited
Audio visual		Can be an unobtrusive way of gathering information It captures attention visually	Information can be difficult to interpret The presence of an observer may affect the behavior of the participant

Table 4:4 Advantages and disadvantages of qualitative data collection methods[34]

[34] Adapted from Creswell, J. W. 2003. *Research design : qualitative, quantitative, and mixed methods approaches,* Thousand Oaks, Calif. ; London, Sage. and Silverman, D. 2006. *Interpreting qualitative data : methods for analysing talk, text and interaction,* London, SAGE.

4.3.4 Sampling strategy

Sampling in qualitative research involves making decisions about which individuals, events, organisations, processes or settings to study (Punch, 1998). Scholars use different types of sampling techniques. Miles and Huberman (1994) for instance have identified 16 different sampling techniques. However, common sampling techniques fall within the theme of "purposive sampling". According to Punch (1998), this means that sampling is focused. Purposive sampling techniques include typical case, theoretical, criterion, snowballing and opportunistic sampling. Miles and Huberman (1994) suggested that purposive sampling and theoretical sampling are prevalent in most studies because they are driven by the uniqueness of the research. Theoretical sampling is driven by some conceptual question and therefore the primary concern, "is with the conditions under which the construct or theory operates, not the generalisation of the findings to other settings" (Miles and Huberman, 1994 p.29).

This section 4.3 discussed the research approaches, strategies, and methods for collecting qualitative data. Strategies linked to the collection of qualitative data include grounded theory, case studies and ethnography. Data collection methods popular with the collection of qualitative data are interviews, observations and secondary documentary evidence. The next section explains the research design.

4.4 The Research design

The aim of the research is to investigate how large construction firms adapt new industry process standards. The purpose of a research design is to link the research strategy to the research outcomes (Creswell, 2003). Dainty (2007) explains that a research design situates the research into an empirical context and connects the research aim to the data. The research design encompasses the researcher's philosophical beliefs and perceptions about the acquisition and advancement of knowledge. Punch (2009) argues that the research design should contain:

- the chosen theoretical framework,
- the research strategy,
- the unit and level of analysis (i.e. what is to be studied), and
- the tools and procedures to be used for collecting and analyzing data.

Silverman (2006) notes that in setting the research design, the researcher has to make early fundamental decisions about a) identifying an appropriate research strategy, b) selecting a theoretical conceptualisation, c) identifying a unit of analysis, d) choosing appropriate data collection and analysis methods; e) explaining how reliability credibility and validity issues will be managed, and f) managing ethical issues. These different suggestions have been incorporated into the designing of this research. The next subsections explain how the research addresses the issues raised by different scholars highlighted above.

Research process overview

Figure 4:1 below illustrates the research process. It shows that the research involves the use of an interpretive pilot study in the first stage that has been identified in this research as the initial phase of the research. The lessons from a preliminary interpretive study are presented in subsection 4.5 below. The lessons helped to inform the designing of the case study as illustrated in Figure 4:1. The second stage of the research involved a detailed study of the use of BIM in a large UK construction firm using a case study strategy. The purpose of this research design is to provide an in-depth understanding of meanings as socially constructed by those involved in the use of industry BIM standards. This is important in developing knowledge of how industry standards influence the capabilities of the large construction firm.

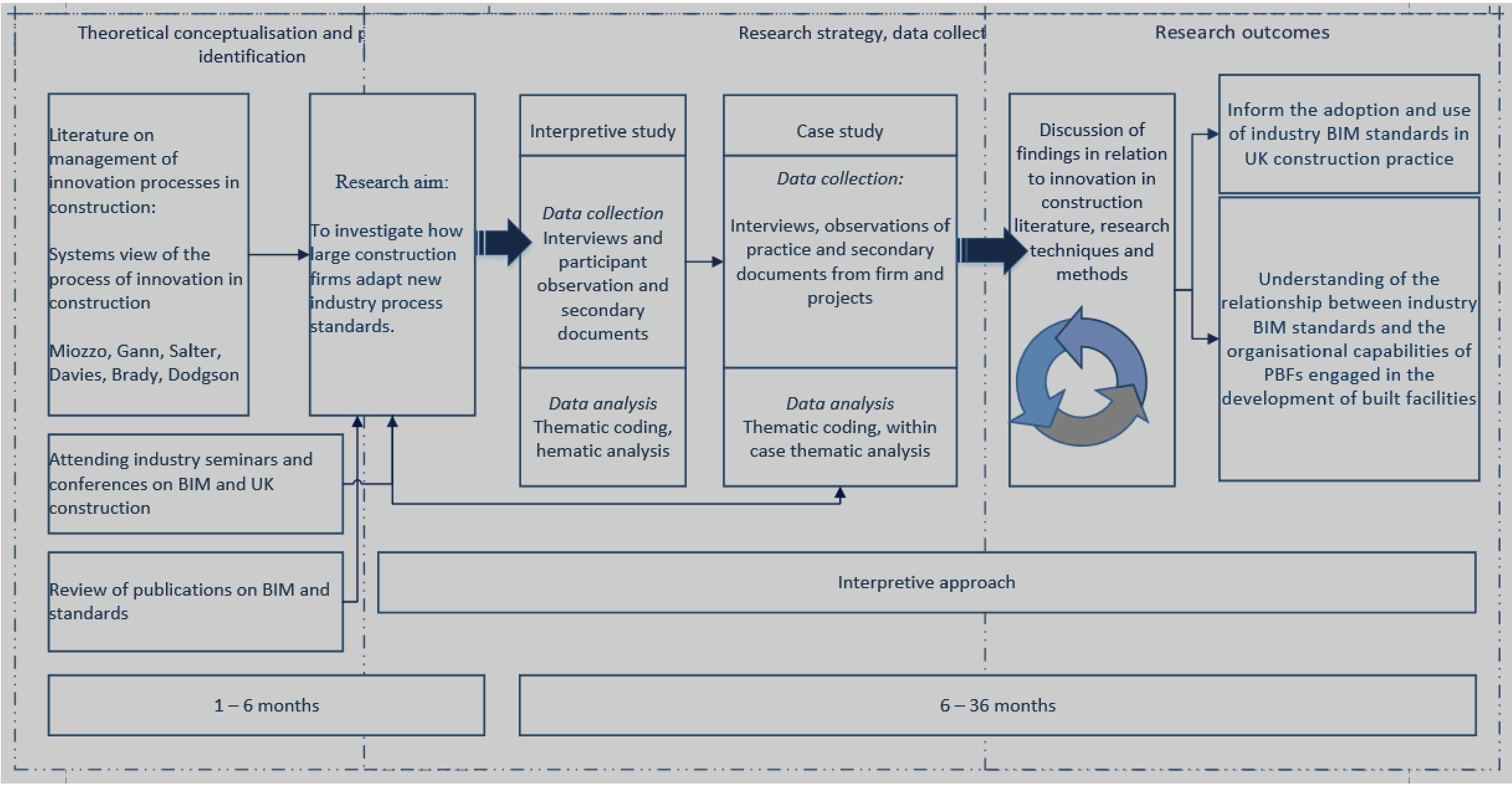

Figure 4:1 The research process

4.4.1 Recap of the theoretical framework

The research adopts the modified organisational capabilities theoretical framework advanced in Davies and Brady (2000) as explained in detail in Chapter 3 to make sense of the research findings. Adopting a prior theoretical framework in theory building is useful in a) shaping the research question, b) designing the research, and c) it improves the cumulative advancement and robustness of the emerging theory (Eisenhardt, 1989b). Orton (1997) explains that a theoretical perspective is useful in explaining the different parts of the phenomenon of interest. The adopted theoretical framework is important to explain the findings of the research. As argued before it is inadequate an attempt to understand the adaptation of industry BIM process standards without acknowledging the systemic nature of interactions between firms and the institutional environment (Gann, 2000a; Seaden *et al.*, 2003; Miozzo and Dewick, 2004). Therefore, the system of innovation concept is relevant in making sense of the findings.

4.5 The preliminary interpretive study of BIM in UK construction

This section explains the preliminary interpretive study adopted for the initial phase of the study including the data collection methods and data analysis techniques preferred. The interpretive study used helps to appraise the research instruments and to gain an in-depth understanding of the use of BIM in UK construction. Preliminary investigations are useful in developing an understanding of the phenomenon, assessing the suitability of research methods, assessing the suitability of selected research methods and gaining familiarity with the research context (Teddlie and Tashakkori, 2009). The interpretive study was particularly useful in understanding the multiple meanings attached to the BIM standards by the key individuals involved. More still, the approach enabled the researcher to understand how BIM standards are employed in construction practice, the actors involved in its development and the activities in which BIM is used.

4.5.1 Unit of analysis

The unit of analysis is the central phenomenon explored in the research. The unit of analysis for the preliminary interpretive study was the implementation of industry BIM process standards in the UK construction industry.

4.5.2 Sampling of key informants for interviews

Key informants are individuals with a deeper knowledge of the field the researcher is interested in (Tremblay, 1957). Apart from providing a historical account, key informants can direct the researcher to situations or events that yield more and useful data for the research (Bryman and Teevan, 2005). Miles and Huberman (1994) argue that researchers cannot study everyone and everything even though they might want to. Hence researchers “usually work with small samples of people nested in their context and studied in-depth” (Miles and Huberman, 1994 p.27). Selecting an appropriate sample is influenced by cost, time and access (Kvale, 1996; Creswell, 2003). Tremblay (1957 p.96) explains, "when we use key informants, we are not randomly sampling from the universe of characteristics under study. Rather, we are selectively sampling specialized knowledge of the characteristics."

Following a desk study and attendance of BIM conferences held in the UK, the researcher identified individuals that are involved in the development and use of industry standards in the UK construction industry. The purposive sampling technique is used to select key informants based on the following criteria:

- History of involvement in the development and use of industry standards for the construction industry.
- Participation in the current BIM standardisation initiative and,
- Participation in some of the BIM implementation groups highlighted in Chapter 2, and willingness to participate in the research.

The snowballing technique is used to identify additional participants. References from colleagues within the researcher's university were also useful.

The key informants provided vital information about the state of BIM use in UK construction in a very short period of time, thus reducing time and cost. However, the use of key informants has weaknesses in that the informant might only express views that are politically correct and acceptable to the society. As a result the researcher might end up with a biased opinion (Tremblay, 1957). Based on the criteria explained above, nine participants were sampled. The profiles of the key informants are included in the Appendix D[35].

4.5.3 Data collection methods

Data is collection relied on the use of unstructured interviews, observations and documents. Organising access for interviews was particularly challenging. Most informants approached were worried about revealing too much information about their firm's BIM programme. As a result, there was a general reluctance from participants to engage. Software providers were particularly concerned about the exposure of their technologies to rival firms. Some standards consultants were equally concerned that their views could be misrepresented thus jeopardising their chances of winning future government work and reputation in the industry. It took lengthy negotiations to establish a relationship with the informants before data collection began.

4.5.3.1 Interviews

Using unstructured interviews in the first stage provided useful way of gaining knowledge about the individual's interpretations, understanding their culture, as well as the practices of a community of those that are involved in the use of BIM standards. Interviews participants

[35] Names have been anonymised in accordance with the agreement with the participants

were drawn from construction firms, IT suppliers, standards consultants and the government.

The interviews took place either on site or over the internet. In contrast to online interviews, face-to-face discussions were particularly helpful for the researcher to understanding the participant's environment. In addition, the researcher had an opportunity to mingle with some of the key informant's colleagues. Although the discussions with the participant colleagues were informal, in some instances the colleagues volunteered useful information to corroborate the informant's account.

Participants had an average of 30 years of experience in the industry. Five of the nine interviews had been involved in the government's BIM policy formulation. Some participants had published a number of articles on BIM and had been keynote speakers at BIM conferences attended by the researcher. Even though the interview were unstructured to allow participants to respond freely, the researcher to maintain focus used an *aide memoire,* (an example is included in Appendix E). Themes of interest that emerged from the discussions were probed further. Participants were encouraged to cite specific examples of their experiences. The interviews lasted for an hour on average. All the interviews were recorded and transcribed by the researcher.

4.5.3.2 Observations

An IT supplying firm invited the researcher to observe a training session for construction professional on the use of industry BIM standards. The training session lasted the whole day. The researcher ended up also participating in the training. Notes were taken of the discussions and experiences, the setting, participants and the context in which the observations occurred. Participation enabled the researcher to gain hands on experience as well as appreciate the complex relationship between industry standards and the digital collaboration technology.

4.5.3.3 Documents

Research participants often provided the research with important documents about industry BIM standards. Some of the documents were sourced off the internet. The documents included unclassified publications on BIM from various private and public organisations. Organisations that provided important BIM related material included professional bodies such as the RICS, ICE and RIBA, private firms, industry groups, standards development organisations such as the BSI and BuildingSmart, universities and standards development consultants. The documents reviewed were useful in corroborating interview and observation evidence.

4.5.4 Data analysis

To identify cross cutting themes, the thematic data analysis technique is used. Braun and Clarke (2006), define thematic analysis as “a method for identifying, analysing, and reporting patterns (themes) within data. It minimally organizes and describes your data set in (rich) detail” (p.6). Qualitative data analysis is often iterative, emergent and flexible enough to suit the voluminous data gathered. Data analysis helps to reduce data to manageable chunks, for interpretation and in raising new research issues to be explored (Gibbs, 2008). Kvale (1996) explains that ultimately interpretation of qualitative data requires that one removes themselves and recontextualise using a specific theoretical orientation.

Thematic data analysis can be inductive or deductive. Inductive analysis involves deriving themes from the data set rather than deductive analysis where a priori theoretical concepts influence data analysis. Integrating an inductive and deductive approach means data are coded to themes from the theoretical framework while new themes can be clearly identified. Gibb (2008) argues that it is impossible for one to be free from some prior theoretical conceptualisation. New themes emerge from reading and rereading of data set. The guiding theoretical framework provides the theoretical grounding as well as positioning of the research within the ruling theory (Eisenhardt, 1989a; Flyvbjerg, 2006). Thematic data analysis allows the researcher to be free from prior theoretical conceptions, but at the same time acknowledge that data can only be made sense by existing theoretical postulations.

4.5.4.1 Lessons from preliminary study relating to research design

Table 4.5 presents some of the lessons from the preliminary study relating to the designing of the case study.

Finding	Implication for the case study
Access issues and privacy concerns pose a challenge to data collection	Approach and negotiate access with the firm the researcher was working for
The use of open interviews opened the research to a wider discussion which at times was not necessary to the research	Semi structured interviews would be used in the case study
It was difficult to draw boundaries around the unit of analysis	The firm was identified as suitable for the study
To understand BIM implementation better, the sample needed to include firms engaged in trial projects	Firms sampled were those only involved in BIM trial projects and they were the large construction firms.

Table 4:5 Lessons from preliminary study

4.6 The case study strategy

This section explains the case study strategy used in the second stage of the research. The section addresses the unit of analysis, sampling technique and data collection methods used in the case study of interactions using BIM standards within a large construction firm. Details of the level of analysis, unit of analysis, data collection methods and interview participants are summarised in Table 4:6 below and discussed in detail in the sections that follow. The need to integrate the contextual setting, cultural and organisational issues is paramount. The case study ensures that a vivid illustration of the use of BIM standards is presented.

Case study designs are common in construction research (Fellows and Liu, 1997; Liu *et al.*, 2012; Shi *et al.*, 2012). Larsen and Whyte (2013) employed the case study approach to explore perspectives about safe construction through design. Salter and Gann (2003) used the strategy to investigate communication patterns in between design engineers in Arup. Gann and Salter (2001) adopted a case study design to examine technology management practices in design and construction firms. Davies and Brady (2000) used a case study approach to explain the organisational capabilities of PBFs.

4.6.1 Unit of analysis

The unit of analyses is the central phenomenon of interest (Creswell, 2003) or the unit under study (Gibbs, 2008). The unit of analysis is the adaptation of industry BIM process standards by the large UK construction firm. This is considered important to provide a detailed and consistent picture of the interactions, challenges, barriers and enablers.

4.6.2 Level of analysis

The level of analysis is the level at which the researcher is operating. The level of analysis guides the data collection process. According to Langley (1999) qualitative data are fluid, they spread out beyond the confines of contextual boundaries, necessitating the use of multiple levels of analysis. Confining one to a single level is thus unhelpful. Langley argues that through rich and detailed descriptions researchers can integrate multiple anchor points. This allows the reader to generalise the findings to their own contextual settings. Drawing upon the discussion in Chapter 2, Section 2.2 that shows that the construction PBFs is embedded on the business and project environments, this research assumes that the firm and the project are the anchor points. Thick descriptions allow readers to draw their own conclusions by moving vicariously through the business and operational levels. Table 4:6 below shows that the research strategy, level and unit of analysis, data collection methods and sampling technique for the study.

4.6.3 Sampling strategy

The research employs the purposive sampling technique in identifying and filtering construction firms. Theoretical sampling, typical case sampling and snowballing techniques were all useful in identifying suitable projects, and participants for interviews and observations. To aid the selection process data was sourced from the ONS.

Research strategy	Unit of analysis	Level of analysis	Data collection method	Sample of participants
Interpretive study	Implementation of BIM in UK construction	Multiple levels (industry, system, firm and projects)	Unstructured interviews, participant observation, documents	Key informants involved in the development of construction industry BIM process standards
Case study	Adaptation of industry BIM process standards	The firm	Semi-structured interviews, observation, secondary publications from the case study firm and industry	Directors, BIM managers, project managers, design managers, site engineers, BIM modellers, surveyors, architects, engineering designers, site operatives

Table 4:6 Research strategy, level and unit of analysis

The data in Table 4:8 shows that only eight large construction firms (employing more than 1200 people) are engaged in major civil engineering projects. The eight firms were subjected to a sampling criteria outlined in Table 4:7.

Parameter	Criteria
Size by number of people employed and/or turnover	1200 people and/or annual turnover greater than £1 billion
Activities	Civil engineering contracts
Engagement in BIM implementation trial	The firm should be involved in the development and use of industry BIM process standards in its projects The firm should be participating in government sponsored BIM trial projects
Location	The firm must be conveniently accessible and be willing to participate in the research.
Data collection	The firm should be prepared to provide access for qualitative data collection

Table 4:7 Sampling for case study firm

The data presented in Table 4.8 shows that there are eight large construction firms in the UK construction industry. Following the application of the criteria set out in Table 4:7 only three met the selection criteria. Five of the eight potential candidate firms were excluded at this stage because they were not involved in BIM standards initiatives. The next stage was to approach the three remaining firms that met the criteria to negotiate access for qualitative data collection. One of the firm had initially participated in the pilot study and expressed an interest in the research, however at the time of the case study they could not commit. Another firm was already participating in a similar research and politely declined to participate. Hence, both firms were immediately excluded. After lengthy and protracted negotiations with the remaining firm, access was granted and data collection began immediately.

Size of firm (by number employed)	Property developers	Commercial	Residential	Civil Eng
0 (sole proprietors)	3456	1881	2975	2887
1	14201	4012	9573	5973
2-3	6354	2853	7275	4686
4-7	2537	1300	3294	2600
8-13	800	474	1229	1183
14-24	326	266	734	740
25-34	38	91	235	300
35-59	46	98	285	282
60-79	20	35	91	100
80-114	9	21	72	89
115-299	17	23	125	92
300-599	7	10	34	47
600-1,199		8	11	12
1,200+			13	8
All firms	27811	11072	25946	18999

Table 4:8 UK construction firms and sectors[36]

[36] Data sourced from Ons 2013. Construction Statistics - No. 14, 2013 Edition.

4.6.4 Data collection

Data collection was conducted in three of the firm's ongoing projects and the head office. The projects were selected with the support of the firm's BIM manager. A decision was made at the outset to focus only on the projects that were using BIM. This was considered important to study interactions using BIM standards. At the time of data collection, the firm was in the midst of developing an organisation wide policy for BIM. Efforts were being made by senior management to support project managers in that regard. Coincidentally, one of the projects selected was a trial project funded by the government. The firm had specifically won the project because it would be a pilot for use in improving industry BIM process standards development. Effectively, the three projects resembled best practice within the firm. Data was collected from the firm's senior managers and the core BIM team, which is charged with the strategic role of facilitating BIM introduction and use across the firm. Details of the selected projects are covered in Table 4:9.

In order to capture the lived experiences of working with BIM process standards, the researcher decided to spend time observing practice within the sampled projects. The projects employed a wide range of professionals - some were directly engaged in national BIM implementation groups, while others followed the discussions closely but did not actively participate. Data was collected over a period of seven months from the firm's core team and ongoing projects. The subsections below focus on the specific methods used in data collection.

	Docklands Cross rail station	Central London Cross rail station	Manchester hospital expansion[37]
Scope	Redevelopment of existing rail station to accommodate Crossrail underground trains	Redevelopment of existing rail station to accommodate Crossrail underground trains	The project was procured as a preliminary BIM trial project. It involves the construction of a new wing of an existing hospital
Procurement route	Design and build contract	Design and build joint venture contract	Design and build joint venture contract
Start date	Jan 2013		June 2014
Duration	Phased works (Total duration 25 months)	Phased works (Total duration 48 months)	17 months
Project cost	£27 million	£110 million	£18 million
Number of people employed on the project[38]	110	200	87
Client	Government/ Cross rail	Government/ Cross Rail	National Health Service

Table 4:9 Details of projects selected

[37] Project names have been altered
[38] Not all those employed on the projects were direct employees of the firm.

4.6.4.1 Interviews

28 semi-structured interviews were conducted. Details of the interview participants are shown in Appendix C. The interview protocol used is included in Appendix F. The snow balling technique was used to sample additional participants within the project and firm. Due to their detailed nature of the interviews, only a limited group of individuals participated. The interviews lasted for an hour. The discussions covered primarily the role played by industry BIM process standards in the creation and exploitation of skills, resources, knowledge required to accomplish the firm’s business functions. The discussions also covered learning and problem solving in BIM environments; nature of interactions with clients, suppliers, the government, universities, and research and organisations. Participants were also encouraged to cite specific examples of their day-to-day experiences. Figure 4:2 illustrates the interview and observation process. The researcher knew the participant better by spending the first few minutes of the interview discussions asking questions about their working environment. This helped to diffuse ‘tensions’ and ally fears and concerns the participants might have preconceived. The researcher at all times aimed to cultivate free environment in which the participant could air their views freely. For instance one of the participants was worried that the researcher might have been sent by the head office to spy on them. It took a bit of time before they could open up and the researcher was careful to allow them time to feel at ease. Interviews and observations were conducted on the same day whenever possible.

4.6.4.2 Observations

Interviews proceeded observations. Observations lasted half a working day on average. The interview and observations followed a semi-structured format. The format for observations involved the participant explaining what they do on a day to day basis. They would show some of their work on their computer, following which the researcher would ask specific questions about their experience with BIM standards. At times this would generate interesting new discussions and highlights of specific examples which were important for the researcher to immerse himself in the participant's environment. On some occasions the researcher was invited to attend project meetings were discussions centred on BIM standards and how they were being used. Observations were useful in corroborating the interview discussion.

Observations were particularly useful to corroborate evidence provided by others as well as evidence from documents provided by the firm. They were held at participants' desks and/or in site or design review meetings. Some observations were organised as demonstrations so that the researcher could gain knowledge particularly of some of BIM's functions. The researcher strenuously took notes while observing. At times he recorded the discussions. Observations typically involved the researcher and the participant sitting side by side as the participant carried out their normal day job. In some cases a phone call or colleague asking about some clarification, some document, or something else interrupted the observations. The interruptions were helpful in that the researcher would pick on them, try to inquire about what they were looking for, as a result detailed information about experiences was obtained. On one particular occasion, the observations had to be to be postponed because the senior engineer participant was urgently required on site.

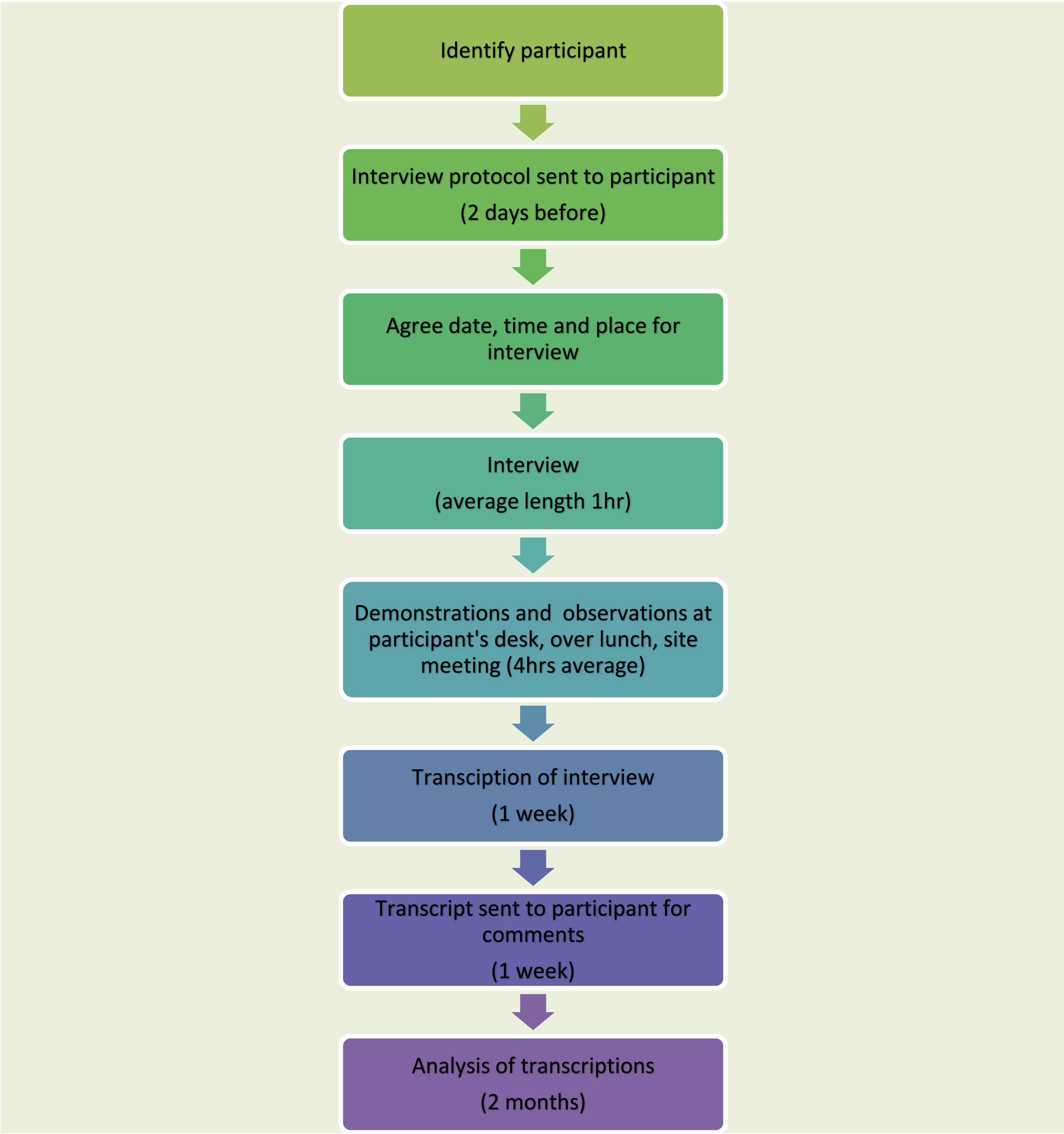

Figure 4:2 Stages in the interviews and observation data collection process

Observations were also conducted on site during toolbox talks with site operatives in the canteen or over breakfast with site engineers on site. The researcher participated in a lunch and learn session where participants were involved in a discussion about the implications of BIM standards use on their site duties.

4.6.4.3 Observations in workshops

Data was collected from two workshops organized by the firm's BIM manager as a lead in the BIM standards user group. The workshops were organised to facilitate the dissemination of feedback from BIM trial projects. Presenters were drawn from the government, the firm and other firms that participated in the trial project. The firm's presenters were drawn mainly from the core BIM team. More than 60 professionals drawn from participating construction firms, 2 material suppliers, 5 IT suppliers, 3 universities, representations from the government and BuildingSmart attended the workshops. Workshops lasted on average for 4 hours and they were recorded at the request of the researcher. Video footage was obtained of the workshop proceedings; however, the discussions therein were not transcribed. Instead, the evidence was consulted during the data analysis process. The data was important to corroborate the interview and observation data.

4.6.4.4 Publications from the firm and other data

The participants supplied most of the secondary evidence used in the research. While most of the data was public information about the firm, some of it was sensitive and this data was securely provided to the researcher. Publications on the firm's website were also used. The next section discusses the data analysis techniques used.

4.7 Data analysis

This section explains the thematic data analysis technique used to make sense of the qualitative data collected. The process is seen as an iteration between the data and the theoretical framework set out in Chapter 3. Computers were useful to manage the data and to facilitate the generation of different kinds of reports to aid analysis. Techniques used to manage validity, reliability, and generalizability are discussed.

Qualitative data can be analysed discourse analysis (Glaser and Strauss, 1967), conversation analysis, narrative analysis and thematic analysis techniques (Creswell, 2007). Discourse analysis (Strauss and Corbin, 1998), "produces a model that would make sense of the discourse structure in a whole range of different settings" (p.201). Conversation analysis sees meanings as manifests of social interaction and can only be understood through examining turn taking, asymmetry, turn design, sequence organisation and overall structure organisation of conversation (Silverman, 1997). This research uses the thematic analysis technique where rich details of the data set relating to the themes associated with the chosen theoretical framework are generated. Braun and Clarke (2006) explain that themes are identified at semantic or latent levels. Semantic levels relate to the surface meanings;

latent themes go beyond the surface to develop deep interpretations. The advantages and disadvantages of thematic analysis are as outlined in Table 4:10 below.

Advantages of thematic data analysis	Disadvantages of thematic data analysis
Useful in summarizing large pieces of qualitative data sets	There is a lack of clarity on how to generate themes
Similarities and differences across data	Difficult to link different pieces of data in creating a story about the differences and similarities across data
Useful in generating new insights from data	Iterating between constructs to develop new insights is demanding and requires a lot of time
Flexible and relatively easy method to learn and implement	Although flexible, there is a lack of clarity on how themes are generated
It is possible to integrate other forms of analysis within the broader thematic analysis	Combining too many methods might dilute the effectiveness of the method, rendering it less effective

Table 4:10 Advantages and disadvantages of thematic data analysis[39]

Data analysis in the research utilizes the Nvivo computer software. The use of computers in qualitative data analysis helped into improve rigour, develop a consistent coding scheme and manage the large volumes of qualitative. Indeed Nvivo speeded the analysis process and its multiple features enabled different kinds of reports to be produced. This was particularly

[39] Developed by the researcher from reviewing scholarly publications especially that of Braun, V. & Clarke, V. 2006. Using thematic analysis in psychology. *Qualitative research in psychology,* 3**,** 77-101.

useful to improve the analysis. Nvivo was particularly useful in thematic coding, categorization of themes and linking different themes.

The analysis process involved uploading of: a) actual recordings from interviews and workshops, b) the transcriptions, together with other forms of evidence from observations, workshops, and c) documents from the firm into the Nvivo software. Loading actual recordings and transcriptions enabled the researcher to correct potential errors in the transcriptions and to listen to the interviews while coding data. Listening to the raw interviews recordings prompted the researcher to recollect and visualize the interview setting, participant's actions and interview context in ways different from simply reading a transcript. An iterative process then followed this within the different phases as illustrated in Figure 4:3 below. The process involved preparing the data through transcription, reading secondary documents and reviewing notes taken during coding. This is followed by generating initial codes using the organisational capabilities theoretical framework, searching for themes that did not fit the established theme, reviewing the emerging themes to identify interesting emerging ideas, defining and naming the respective themes and reporting.

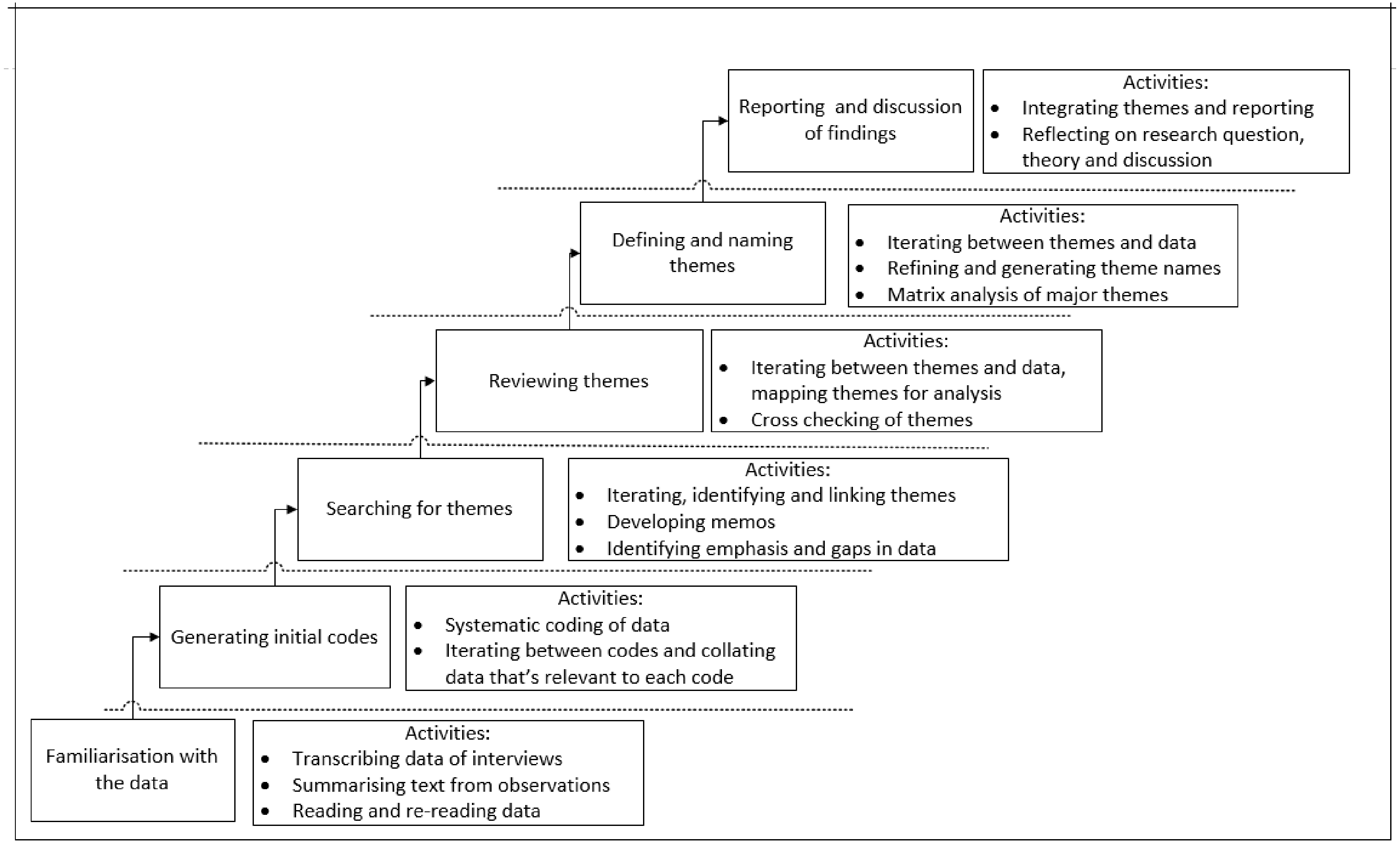

Figure 4:3 Phases in the thematic analysis adapted from Carney (1990)

4.7.1 Validity

Validity involves assessing the plausibility of findings from research. Validity is about "choosing among competing falsifiable explanations" (Miles and Huberman, 1994 p.279) to determine the accuracy of the findings from the perspectives of the researcher, participants and research community (Creswell, 2003). In qualitative research, Gibb (2008) explains that validity checking techniques are important to eliminate mistakes and generate rich explanations.

Distinctions between internal and external validity are outlined in Table 4:11 and 4:12 below. Whilst internal validity is concerned with whether findings make sense, external validity is about the applicability or importance of findings to other contexts (Kvale, 1989). Creswell (2003) identifies triangulation, respondent validation, thick descriptions, external auditing and generalizability as important ways of ensuring validity. Validity issues have been addressed in the research design.

Internal validity	How this is managed
Data and methodological triangulation	Methodological fit is discussed in sections above. The research uses multiple methods for collecting data. These include interviews, observations, workshops and publications available from the industry and the firm. The sampling technique has been maintained throughout the research process.
Respondent validation	Research participants were offered an opportunity to review the transcriptions. Feedback was provided in two meetings. The feedback process also enabled participants to contribute and/ or clarify their statements.
Self-bias	The researchers values have been articulated, his experiences and his beliefs have also been explained

Table 4:11 Managing internal validity

External validity	How this is managed
Rich and thick descriptions	Thick and detailed descriptions have been used to allow readers to construct their own disparate meanings about the data and the interpretations made.
External scrutiny	The researcher and his supervisors reviewed the research protocol and design at length. The protocol was reviewed with fellow doctoral students and research fellows within the researcher's university.
Generalisability	Rather than seeking statistical generalization, the research focuses on theoretical generalization as explained in Section 4.3 above.

Table 4:12 Managing external validity

4.8 Ethical considerations and summary

The research involved interactions with human subjects. The university has a strict policy on research ethics, which has been followed throughout the research. Prior to data collection, the researcher sought approval from the University of Reading's Ethics Committee. During data collection, all participants were requested to indicate their consent to the use of the tape recorder as shown in Appendix B. Participants were free to withdraw at any time during the discussions. All participants were given a written guarantee that their personal identity, information or submissions in whatever form, would remain confidential to the researcher.

This chapter has explained the research design, data collection methods, and data analysis including how research ethics were maintained throughout the research. Literature on philosophical beliefs, values and experiences was presented and discussed. The next Chapter discusses the research findings.

Chapter 5: Findings of the empirical research on the adaptation of BIM process standards

5.1 Introduction

This chapter presents findings of the investigation into the adaptation to industry BIM process standards by a in a large UK construction firm. The previous Chapter 4 argued that the interpretivist philosophical paradigm is useful to gain in-depth understanding of the multiple; context dependant meanings attached to the application of BIM process standards. The chapter presents findings of the research. The chapter is structured to explain the experiences of the firm at the business, project and construction innovation system levels. The next section 5.2 provides a brief analysis of the construction firm's structure, context and processes of delivering projects. Section 5.3 presents findings relating to the firm's relationship with the external business environment and interactions with the construction innovation system in which its business activities are executed. Section 5.4 focuses on the large construction firm's relationship with industry BIM process standards at the business level. The findings illustrate how the firm's strategic capabilities are transformed and complexities faced by the firm at this level. Section 5.5 addresses the application of BIM process standards at the project level. Here, attention is directed at the user experiences of using the new industry-wide process management technologies. The findings show the challenges faced by the firm as it seeks to gather momentum around the standards and the implications on its ability to improve the execution of projects. The section explains how the firm is able to develop integrated project delivery capabilities. Section 5.6 concludes the chapter with a synthesis of the findings.

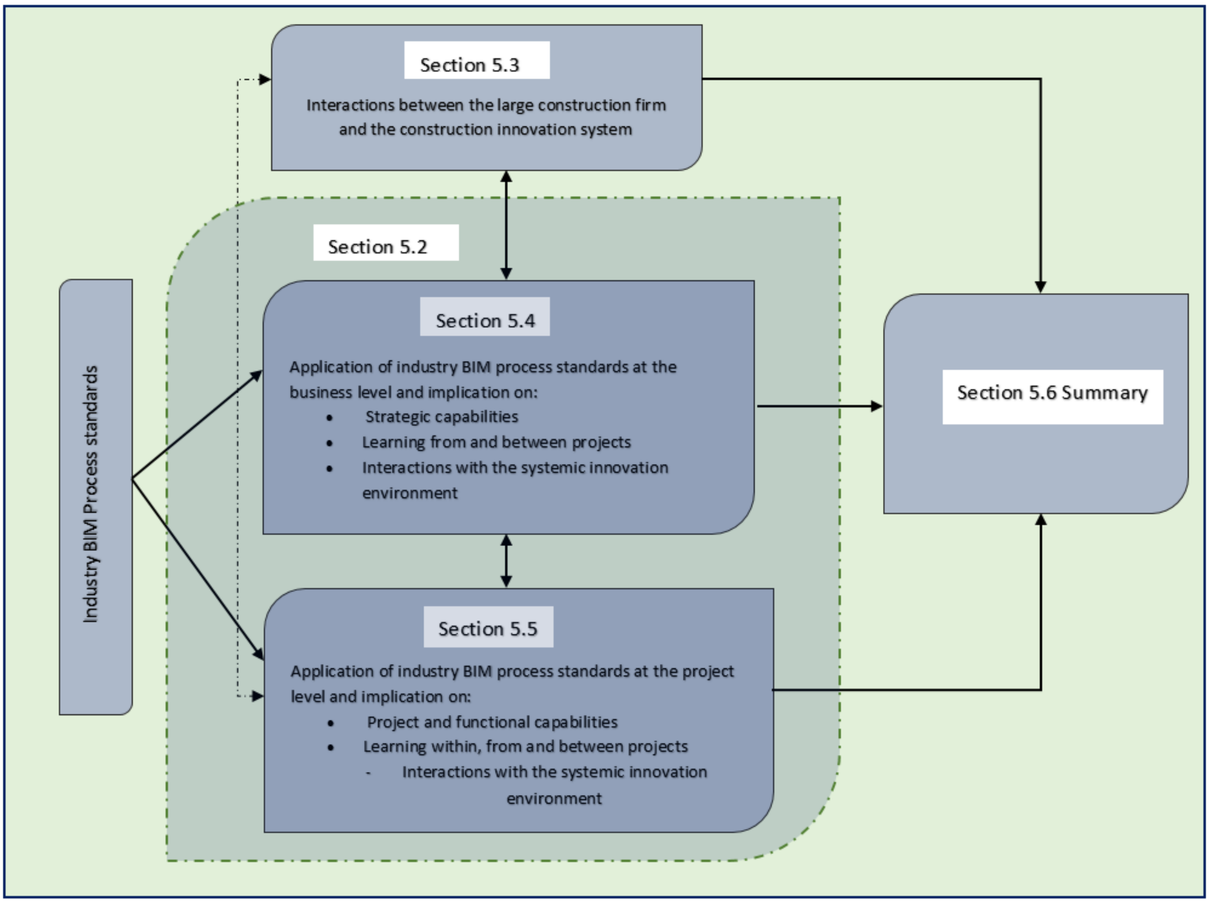

Figure 5:1 Findings chapter layout[40]

[40] Developed by Researcher to illustrate the findings on the experiences of the large UK construction firm with industry BIM process standards at the business, project and innovation system level.

5.2 The research setting

The research is conducted in a large UK construction firm involved in civil engineering, housing, hospitals, commercial buildings, nuclear, rail, waste management and utilities projects. The firm involved in the research is identified as Conco UK[41]. The construction firm is a subsidiary of Conco Plc[42], an international business whose headquarters are located in France. The UK business, which is the focus of this research, contributes an average of 4% to the group's annual turnover.

Conco UK's entry into the UK construction market dates back to 1918. Since its formation, the business has undergone significant changes including a merger in the 1970s and an acquisition by Conco Plc in the late 1990s. In its formative years in the UK, the firm specialized in the design and construction of reinforced concrete structures. At the time of data collection (April 2013), the firm was involved in more than 300 construction projects in the UK.

Conco UK acquired a reputable civil engineering firm in 2008. Since the acquisition, the firm has undergone significant restructuring. Senior management have created a new structure to support the integration of staff. The senior management team leads the transformed organisation. Although the new management structure shows clear distinctions between

[41] Names have been changed to ensure anonymity in line with agreements between the researcher and the firm involved

[42] Names have been anonymised in line with confidentiality agreements with the firm.

divisions, in reality the Chairman is pursuing an integrative approach that blurs the boundaries between divisions. The chair explains,

> *"By combining the experience and expertise of our teams, both locally and globally, we will improve our collective performance, bringing innovative approaches to projects and improving productivity…" (Chairman's comment, 2011)*[43]

As the largest division, the civil engineering business unit contributes 60% of the UK business's turnover. The division was the focus of data collection for the research. The division employs circa 3500 people in the UK. The division's directors and a handful of support staff work from the firm's headquarters in South East, England. The division is mostly involved in design and build contracts. This means the division is responsible for managing design, specification and construction activities. Most of the staff such as the project managers, design managers, quantity surveyors, civil, structural, electrical engineers, and site supervisors are employed directly by the division. These professionals coordinate, supervise and manage project execution activities.

At the time of data collection (April 2013), the division was engaged in 14 projects which were at different stages of completion. The largest of the projects was valued at £240 million, and the smallest had a value of £27 million. The division has gained expertise and reputation of executing some of the complex and large infrastructure projects in the UK. Its

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[43] Internal publications from the firm

major clients include the central UK government, local authorities and private firms. The division has been awarded contracts in the £16 billion London Crossrail project. The civils division is an amalgamation of the now defunct but reputable civil engineering firm that was acquired by the firm in 2008 and employees from the firm's civils department. By acquiring, the civil engineering business, the firm inherited experience in cutting edge digital technology development. As a former employee recollects,

> *"…we were doing advanced things … we were a very advanced company, that ethos followed through the company ...." (X02.13)*[44]

The acquisition however was not as smooth as described by the former employee. A current employee explained of the challenges of moving from the now defunct innovative firm.

> *It was difficult because … (acquired firm) were quite pioneering and cutting edge in what they did, in the whole of the industry whereas, well Conco were very dated in the methodology and their processes. So a lot of the innovation we did was, we took a step back and we had to start again really and … its taken quite a long time (X12.13)*[45]

Whilst the challenges reported by participants are many, the firm identifies the improved ability to use innovative digital tools such as BIM to deliver construction projects and the reputation for managing complex projects as the key benefits. Two large UK airport projects,

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[44] Interview with key informant - Pilot
[45] Interview with BIM modeller

in which the firm was involved were completed in 2013. The projects partially utilised the BIM process. Discussions with the BIM strategy manager show that very little lessons were drawn from these two projects because of the limited BIM support from senior management.

5.2.1 Project procurement and execution procedures

Conco UK is moving to integrate services of designers, material suppliers, specialist subcontractors and labour-only contractors using digital tools at the business and project levels. Centrally located teams that serve across the firm coordinate interactions with suppliers, clients, and they work with internal project teams as part of the project delivery process. The central teams coordinate bidding activities, temporary works design, and BIM implementation. Figure 5:2 below illustrates some of the pre-contract activities that are performed by the business level team. Figure 5:1 shows the project functions, i.e. the project level operations. They include, some design work, material and subcontractor procurement, assembly, planning, project management and 3D modelling.

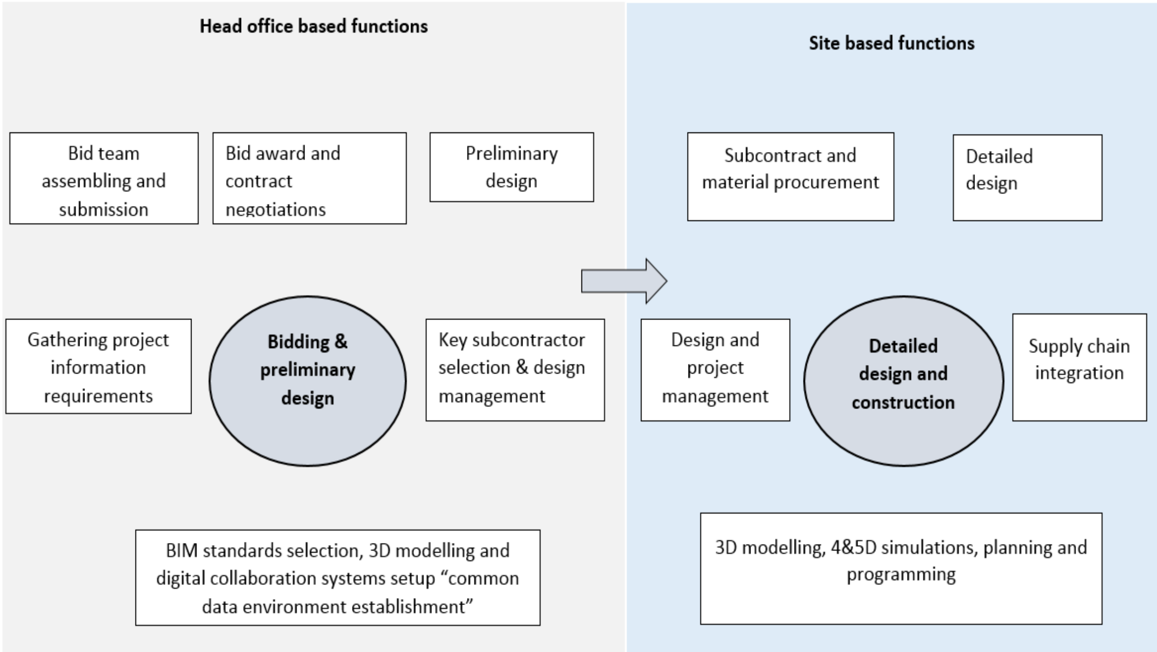

Figure 5:2 Distribution of business and project functions

Conco UK follows a structured process of procuring and delivering contracts. Figure 5.2 illustrates the delivery of projects. As shown, the process starts with a decision to bid usually made by senior management. Following the bid decision-making, senior management assemble the project team. Although the central team as explained above performs some functions, the project manager is usually responsible for managing all aspects of the project from design to handover. This includes the design, bid preparation, bid negotiation, construction and handover. The design management process has been configured in order to meet the requirements of the PAS 1192 and COBie standards. Project management manuals such as the design management plan, the project execution plan, the design execution plan, construction execution plan, the operations and handover execution plan have been revised to produce a new Design management protocol[46].

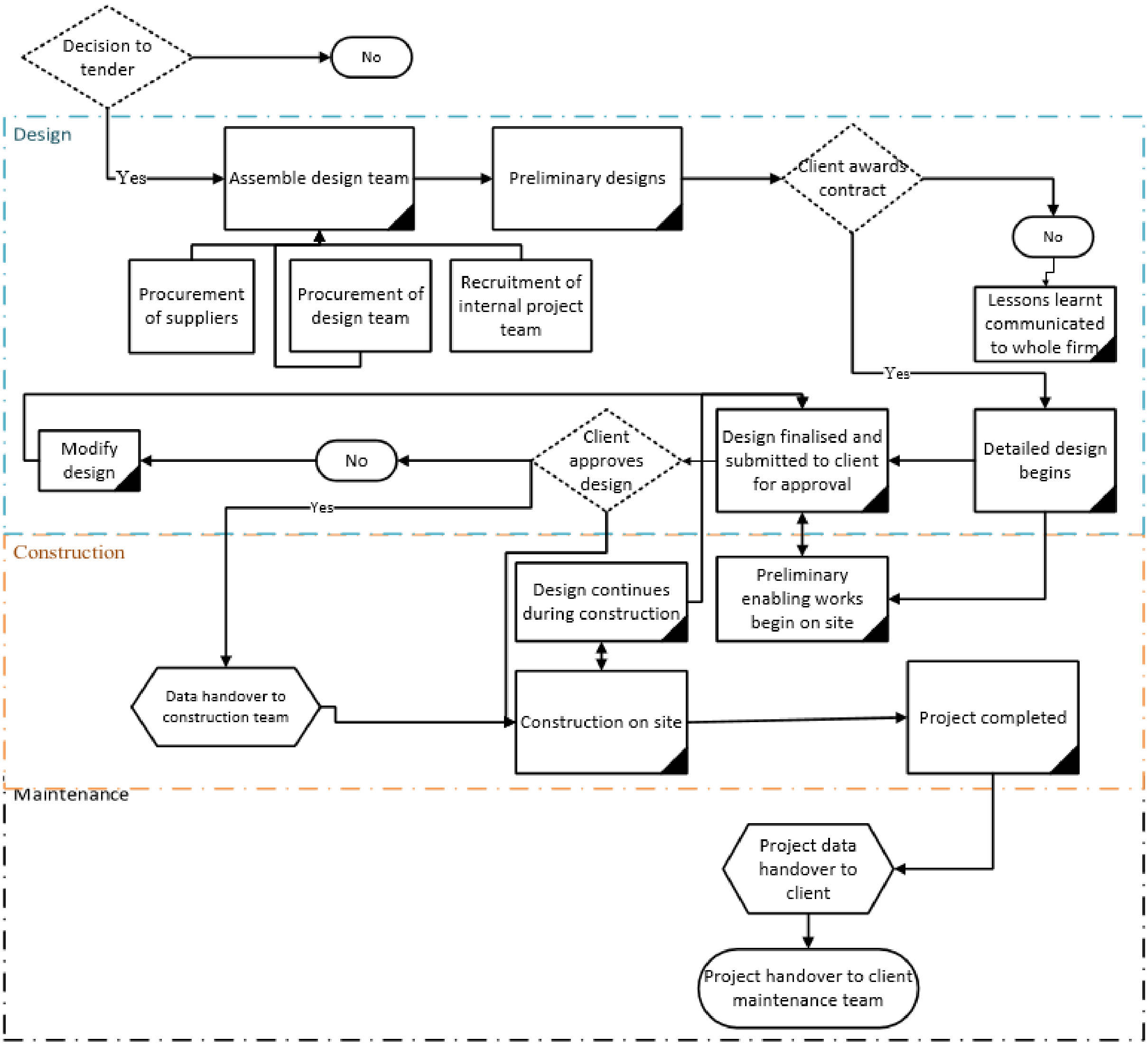

Figure 5:3 The project delivery process in Conco UK[47]

[46] BIM standards and support procedure section of Conco UK's Design management protocol
[47] Developed by researcher using data from the research

5.2.2 The functional role of project managers

Project managers (PM) are in charge of the design and delivery of projects. The project manager is the firm's senior representative on the project. The project manager reports to the engineering director. All other personnel on site report to the project manager. The project manager operates with autonomy in making decisions on site, although in some instances the engineering director's approval is required. The PM makes key decisions about the resources to use, planning, programming, change, cost management. With support from senior managers such as the engineering director, the PM assembles a suitable project delivery team involving supervisors, site agents, design manager, section engineers, construction managers, commercial managers and site engineers. The design manager manages the day-to-day activities of external design consultants. In practice, the PM decides on the digital tools to be used on the project, including whether or not BIM process standards are used. This is in spite of the existence of a company-wide BIM implementation protocol that mandates the use of BIM standards in projects.

The PM has responsibility for planning, programming and procurement of subcontractors. They have to ensure that projects are delivered using the firm's procedures. However, this is not often the case in joint venture contracts. The PM wields influence over the selection and use of industry BIM process standards, design and collaboration technologies. This becomes complicated when the firm is involved in joint venture contracts as explained by a project manager.

"… One of the issues which we're still struggling with is the relative importance of the outputs of BIM to certain people in certain parts of the construction process … it's going to be very, very difficult to have a standard (industry) that suits all projects or all requirements." (X19.14)[48]

This section has examined the procurement of projects in Conco UK and the functional role of the project manager within the firm. It has been explained that the PM has influence over the BIM standards that are used in the project. There is however, some ambiguity in that the firm mandates the use of BIM standards, however the PM maintains influence over the application of the standards within the projects they manage. Some of the possible explanations of this behaviour are examined in Section 5.4. The next section addresses the firm's interactions with other actors in the complex systemic construction environment.

5.3 Systemic interactions using industry BIM process standards

Conco executes a large number of projects each year. Typically, projects last for two years, however some projects may last longer. In the three projects selected for the data collection, Conco was the principal contractor in two of them, whereas in the other project was a joint venture with another large construction firm. When Conco is a principal

[48] Interview with project manager – Central London rail station project

contractor, it assumes the full responsibility to deliver the project to the client's goal. In joint venture contracts the situation becomes complex as responsibility is jointly shared.

The model presented in Gann and Salter (2000 p.960), reproduced in Chapter 2, Figure 2.1, was used to guide the discussions with participants about learning processes and knowledge flows between project parties. The research findings show that interactions occur mostly with the client, product suppliers and subcontractors. Interactions with industry stakeholders such as regulators, professional bodies, universities and R&D organisations often occur at the business level and less formally within projects.

In Conco, data analyses show that the introduction of the BIM process standards stimulated the need to interact with competitors, the government, universities, standards developers and IT suppliers in forums such as the COBie trial project (Section 5.3.2). For example, the BIM strategy manager is involved in the industry level BIM initiatives such as the BIM task group. The industry groups, addressed in Chapter 3, section 3.2.4 are facilitating the application of BIM standards in UK construction. The BIM strategy manager is also engaged in initiatives aimed at BIM standards development in standards development organisations (SDOs) such as BuildingSmart. His engagement in industry level discussions has contributed to the firm being selected to participate in some of the early BIM implementation projects, and virtual trial projects. Virtual BIM trial projects such as the COBie project, involved collaborations with 10 competitor firms, government agencies, IT suppliers and universities. Conco has since transformed its interactive processes with IT suppliers, because they have become important in the development of BIM standards and digital tools that are used together with the process standards. These findings are discussed in depth in the next subsections.

5.3.1 Involvement of BIM strategy manager

Recognising the strategic importance of BIM to the business, senior management have appointed a BIM strategy manager to act as the champion of BIM within the firm. The BIM manager is in charge of the introduction and use of BIM across the business's divisions. The BIM strategy manager has participated in a number of industry level initiatives aimed at developing technical standards for the UK construction industry over the past 20 years. He participated in the consultations associated with the development of the government's BIM policy[49]. The BIM manager and his subordinates in the BIM core team are involved in some of the industry groups such as the BIM forum, BuildingSmart user group and the BIM taskgroup (the activities of these groups were discussed in Chapter 2) that are spearheading BIM implementation in the UK construction industry. The firm's BIM strategy manager leads a user group within BuildingSmart. His involvement in national groups is strategic because the firm can influence the standards development process, influence IT suppliers that align standards with digital technologies, as well as keeping the firm abreast with national BIM process standardisation discussions. The engagement was instrumental in winning a pilot construction project sponsored by the government to test and improve industry BIM process standards use in construction.

[49] Interview with BIM strategy manager

The BIM manager works closely with IT suppliers to provide feedback and negotiate the customization of industry BIM process standards to address the firm's unique interests.

> *"We have quite a big influence over Collabtec UK because we're quite a big user of them and they're, they are beginning, they are saying the right sort of things." (X10.13)*[50]

The engagement of the BIM strategy manager has also contributed significantly to the development of the civil engineering division's BIM execution plan. The execution plan defines the integration of industry BIM process standards and digital tools into the firm's project execution process.

5.3.2 Participating in the COBie standard trial project

The firm is participating in trial projects aimed at improving the use of the COBie standard across the UK. The trial projects are receiving funding from the UK government. A new group – the BIM core team has been created to facilitate the use of the BIM standards within the firm. The core team is participating in the COBie trial project. The core team is comprised of highly experienced professionals with IT and engineering skills. The COBie trial project is a digital virtual simulation of the BIM environment in which the PAS 1192:2012 and the COBie standard are utilised. The project involved 10 large construction firms, 4 IT supplier firms, 1 government agency, 1 standards development organisation and a university. The project

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[50] Interview with BIM strategy manager

involved the production and exchange of digital information shown in Figure 5.1 below using the COBie and PAS 1192:2012 standard. The project, which was partly funded by the government was important to gain knowledge of the experience of and complexities surrounding the use of new industry BIM standards.

> *"… It's the risk of using that methodology when it's not been trialled by anybody else. You never want to do it on your own projects for the first time because of the risk." (X10.13)*[51]

Figure 5:4 Extract from COBie trial project[52]

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[51] Interview with BIM strategy manager
[52] Source: The IFC/COBie report in which the firm was involved. The report is published by the NBS (2012). The image shows the 3D model together with the COBie data in the form of an excel spreadsheet on the bottom of the image.

Apart from gaining knowledge about how to use of the COBie standard, collaborating with others to reduce risks associated with the use of new standards. This also helps the BIM core team to provide meaningful feedback to the development of the standard. The challenge however is that there is no single approach to COBie within the firm. Whilst the government's view is that COBie is a means of sharing information as explained in Chapter 3 Section 3.3.2, the view by some participants is that COBie is a spreadsheet containing information about the built facility. For one modeller,

> *"… COBie is a dumbed down IFC… My understanding and thoughts on COBie is that, again, BIM pioneers say here is IFC and the industry goes, what the hell is that, we don't understand it. OK you don't understand IFC, will dumb it down to a flat spreadsheet" (X13.13)*[53]

The challenges around the use of the COBie process became apparent in one of the projects were the client had their own information exchange standard that they wanted to use. This meant that a unified approach to the standard within the firm was hard to achieve because the firm's clients use different technologies and maintained varied approaches to standards. Hence a site engineer explains that,

[53] Interview with BIM modeller

"They are not going through the COBie process. They're going for Asset. The client decided that this is their standard and we have to use their standards. They are not using COBie, they just said not COBie" (X16.13)[54]

Involvement in projects where clients have different preferences to standards means that it is often difficult for the firm to develop and implement a consistent and coherent approach to BIM process standards. Even though there may be different understandings of the COBie standard, some of the BIM core team members noted participation in the trial project was useful to learn about the implementation of the process. Through the trial project, the firm accessed a diverse source of ideas involving IT suppliers, government and other construction firms. The development of the standard was also improved as involved offered the firm with a collective unique voice to strategically influence IT suppliers and standards developers. An engineer in the BIM team explains,

"… It's at the end when we found something, for example we said to the IT suppliers; okay this software has an issue … It's a unique voice you (the team) have to influence…" (X13.13)[55]

Participation in the COBie trial project funded by the government, standards development organisations and IT firms enabled the firm to reduce its research and development expenditure. However, participation in the trial project could be a sign of the desire to

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[54] Interview with site engineer
[55] Interview with BIM modeller

reduce risks associated to the use of new technologies. The BIM strategy manager explains that the risks associated to using new technologies in live projects are many.

5.3.3 Interactions between project actors

The use of industry BIM process standards is influencing the firm's interactions with material suppliers, the government, Standard Development Organisations (SDOs) and IT suppliers as explained in Table 5.1. The table explains how the division is transforming interactive relations with IT providers and SDOs to acquire knowledge required to use standards. To use industry BIM process standards effectively, the firm interacts with and sources knowledge from universities, IT suppliers, standards developers, government agencies, material suppliers and professional bodies. Findings suggest that much of the learning that goes on at the firm level is not technology specific but is concerned with knowing where to find knowledge. Participating in standards development for instance allows the firm to know which IT suppliers are providing what technology. The knowledge is not directed at improving specific skills in projects but is aimed at keeping the firm abreast with the national and international level discussions of industry BIM process standards.

Source of learning	How are they interacting?
Material suppliers	Interactions occur through the national BIM library where material suppliers file product information for use as specifications by designers. The library is an important source of information for digital object modelling activities by the BIM core team. However, knowledge sharing is influenced because the supply chain is less knowledgeable. *"At the minute the suppliers are even less educated in BIM and one of our tasks is to educate them into, some of them have never even working in 3D before, so the first step is to get them working in 3D" (X13.13)*
Government and professional bodies	The firm participates in industry conferences and workshops organised by national bodies and professional organisations such as the ICE, RICS and the BIMtask group. The government mandated BIM in public contracts. *"… Well first of all the big announcement about 2016 is fantastic, people started talking about it, it wasn't mad scientists locked up in a basement shouting, BIM, BIM, and nobody understanding what it is, it's actually on the spotlight and whether it's correctly interpreted or not we're going to get there but at least people are talking about it, thinking about it and it's not only techies that's working on it. This up here has a very important function obviously in that in driving the private sector. So if we divide these three flows into government, private and academia, again dynamics of relationship are important equally. Regulatory bodies cannot say something that's not going to work, it's again a bit of a back and forth." (X14.13)* … *"… We cannot prequalify on current projects now without demonstrating that we understand these principles and know how we're going to adopt them." (X11.13)*

Standards Development Organisations	The firm's BIM strategy manager is involved in, and participates in SDOs such as BuildingSmart. This allows the firm to access information on latest information on industry process standards such as PAS 1192:2012 and COBie.
Universities and other research organisations	The firm participates in the COBie standard trial project involving universities and research and development organisations. *"… Because many of the things in BIM, how it will work, it does not know. We need to have, like for example we are working with (x)*[56] *University quite a lot, Professor (xx), he certainly offers a lot of help. They have developed some tools that we can use…" (X12.13)*
Other project based firms	The firm engages other competitor firms in the COBie trial project. The firm participates in workshops organised to address BIM standards related issues.
IT suppliers	The firm participates in the COBie trial project and providing feedbacks for solving day-to-day problems in integrating COBie with other digital design tools. *"Yeah, we have quite a big influence over 4Projects because we are quite a big user of them and they are, they are beginning, they are saying the right sort of things that they want to be best of breed in everything they do. So they're throwing a little more money at it"*[57]*(X23.14)*

Table 5:1 Interactions between the firm and some of the systemic innovation actors

[56] Names withheld
[57] Extracts from interviews

5.3.3.1 Interactions with clients

Clients play an important role in the adaptation of industry BIM process standards. For instance, some clients such as the government are specifically requesting the firm to use BIM standards. However, the analyses also show that there is no consistency in the client requirements. The researcher noted that in two of the projects studied, the BIM standards implementation policy was different even though the project shared the same public sector client. There is a view within the firm that clients are less informed, hence the inconsistencies in their demands. For instance, in one of the projects the client would request that projects team deliver information using the COBie standard even though they did not have the skills and technology to manage the information.

> *"We have had a couple of tenders recently which the information we were supposed to tender on was within a BIM model issued by the client, but when we started entering information, we found that it (BIM model) was inconsistent … we understand the clients are not using the information anyway" (X26.14)*[58]

In addition, clients have limited technical abilities to manage the digital information produced from using the COBie standards. There is a view in some of the projects studied that developing competencies to address client specific requirements using industry BIM

[58] Interview with the division's Engineering director – Main

process standards is important however, clients lacked an appreciation of the benefits of using the standards.

5.3.3.2 Interactions with IT suppliers

The introduction and use of industry BIM process standards requires the firm to possess competences and skills to manage information production in a highly digitalized environment. The construction firm requires capabilities to manage the changing and dynamic relationship with IT suppliers that increasingly serve important functions. IT suppliers have traditionally supplied the firm with IT hardware and software and associated maintenance. However, the use of industry BIM process standards means they have expanded responsibilities due to the limited technical knowledge to understand the digital technologies and process standards. The relationship is shifting from an arm's length market based relationship to one in which the IT supplier is providing an integrated solution to the construction firm. IT suppliers provide consultancy services to establish the firm's IT requirements following which they integrate BIM process standards and customise their proprietary digital collaboration technologies to suit project specific requirements. This ensures that the IT supplier tailors the digital collaboration technology to suit requirements.

To address its limitation in applying BIM process standards the firm has established a long-term relationship with an IT supplier. They also act as a "launch pad" for the development of the Collabtec technology, which is embedded with BIM process standards. Since 2003, the civil engineering division has been involved in the development of Collabtec[59]. The construction firm uses the Collabtec technology to store, exchange and facilitate multiple communication between individuals involved in the production and use of information during the development of a built facility. A BIM modeler explains,

> *"Collabtec actually started out from two guys that worked for civils and they developed a system internally for managing data, but the division didn't have the resources to carry on with the research that was required. So the (employees) left and formed Collabtec Inc" (X12.13)*[60]

The research shows that the Collabtec technology is aligned to the PAS 1192:2012 standard. Since the standard is embedded in the digital technology, it has been necessary for the business to transform its relationship with IT suppliers. In use, the PAS 1192:2012 standard has become inviable because it is embedded within the digital collaboration technology the user interacts with in the performance of information management functions. IT suppliers occupy a central role in the use of industry BIM process standards because they embed the standards in their digital collaboration technologies and the firm does not possess all the skills required to use proprietary technology. The Collabtec technology is a digital document management and communication system that regulates information exchange and communication by all the project parties. The collaboration technology provides the digital

[59] Names have been changed for confidentiality reasons
[60] Interview with BIM modeler Core team – Main

common data environment in which digital information sharing interactions occur within the project environment.

The qualitative data indicates that the use of the industry standard has radically altered the firm's interaction with IT supplier meaning that the firm has transformed its interactive relations with the developers of technologies that become embedded with industry BIM process standards. Occasionally the civils division in collaboration with the BIM core team acts as a test-bed for testing updates to the Collabtec technology. As noted by the BIM strategy manager,

> *"We have quite a big influence over Colltec because we're quite a big user of them and they're, they are beginning to say the right sort of things" (X10.13[61])*

The BIM core team is comprised of skilled professionals with competences in IT and engineering, to facilitate the use of BIM process standards. Due to the nature of their work, BIM core team members regularly interact with IT suppliers who provide highly technical information. The professionals within the team supply IT suppliers and standards developers with vital feedback that is channelled into the development of the PAS 1192:2012 standard and the Collabtec technology.

Further to the requirements of the BIM process standards, the firm has introduced the roles of the information manager and BIM modeller within its operating procedures. The BIM

[61] Interview with BIM strategy manager

modeller is a technical function that involves the production of 3D models and checking the quality of models supplied by external designers and the in-house temporary works teams. The information manager is responsible for setting up information management protocols and ensuring compliance with industry BIM standards. The BIM modeller creates digital information using BIM standards and ensures that project teams create and exchange information in accordance with the industry BIM standards. The information manager also works closely with the IT suppliers to ensure that the digital information management systems used in projects are customised to the firm's idiosyncratic requirements.

5.3.3.3 Interactions with SDOs, professional bodies and industry groups

Engagement in standards development initiatives is of strategic importance to the firm because the firm improves its ability to access knowledge and influence the development of the standard. Typically, the firm has to create and improve its ability to interact and source knowledge from a diverse environment comprised of competitor firms, clients, standards developers and IT suppliers. Participation in standards development ensures that experiences from BIM standards trial projects are included in future versions of the standards. This helps to address resistance to the use of the new technology because the standard resembles best practice of the firm. A typical process of developing the PAS 1192 standard is outlined Figure 5:5. As illustrated the process is one in which the standard emerges from complex negotiations, iterations and feedback. By strategically projecting its influence and possessing the skills and competences required to engage with SDOs, the firm is able to influence the development of the standards. This also helps to simplify implementation within the firm because the output (the industry BIM process standard) resembles the firm's experiences. The firm's BIM manager and modellers participate in workshops and conferences organized to develop the PAS 1192 standard. Due to engagement of the BIM core team in the national discussions of standards development, best practices from the business are included into the final standard.

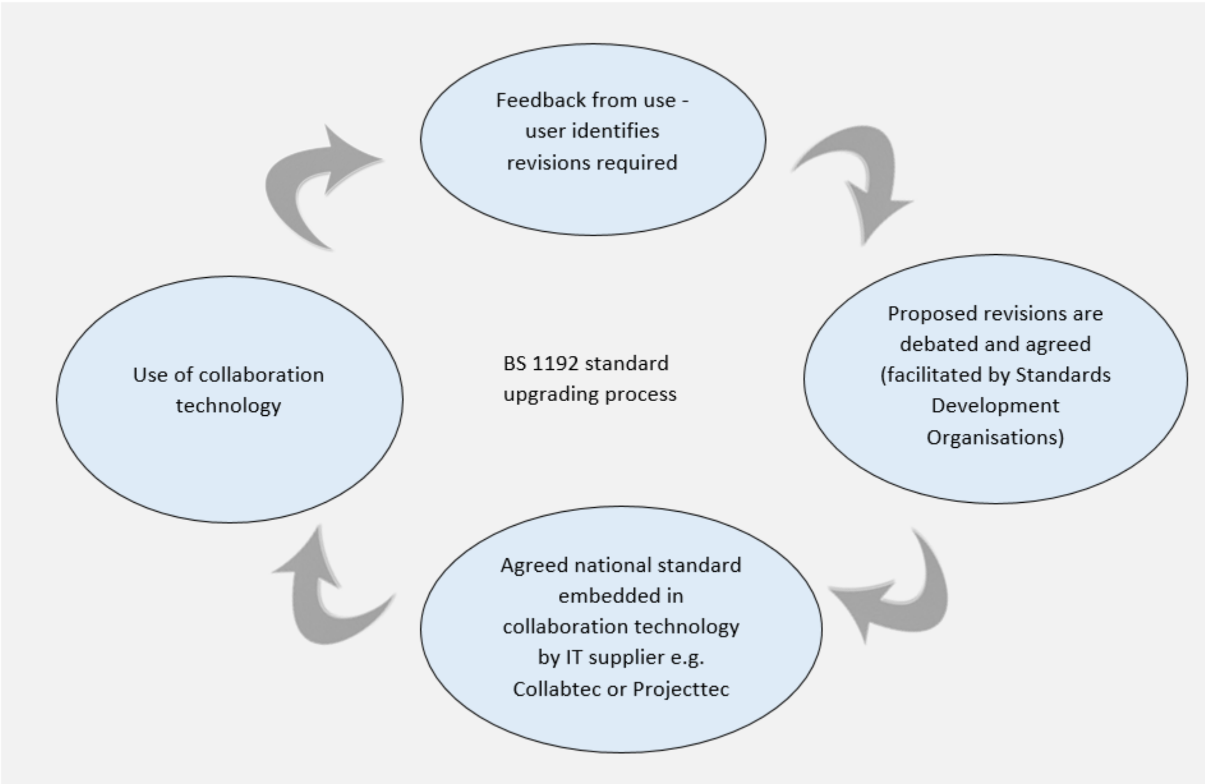

Figure 5:5 Engagement in in PAS 1192 standard development process

Interactive relations with systemic innovation actors however are affected by the multiple meanings that are attached to BIM. The absence of a common definition means that the actors perceive BIM process standards differently. The civil engineering division director explains,

> *"… the problem is disconnect and lack of understanding perhaps. … Somebody working in graphics would see BIM as pretty pictures, somebody in planning department would see BIM as 4D simulation, somebody in cost estimation would see BIM as quantity take offs or a 5D simulation." (X26.14[62])*

Whilst the different understandings have benefits in that a stronger and widely acceptable standard might emerge, challenges are that it is heavily resisted within the firm. This creates complexities in the use of an industry standard in the project as shall be shown in Section 5.4. construction firm as it seeks to use an industry lack of clarity on the definition is unhelpful to the development of capabilities required to consistently deliver built facilities given the numerous construction industry actors involved.

The above findings indicate that the use of industry standards influences the construction firm's ability to source knowledge, research and develop through participation in standards implementation trial projects, and collaborate with other actors to sense, seize and enhance its competitive advantage. The construction firm also alters its interactive relations with IT suppliers and standards developers. These transformations enhance the firm's ability to create and exploit resources to improve performance and competitive advantage.

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[62] Interview with Engineering Director

5.4 The firm's business level interactions with BIM process standards

Conco UK is using industry BIM process standards to deliver projects of different sizes. This research examined use patterns in three ongoing projects. This subsection presents findings showing the business level issues that arise as the firm attempts to adapt industry BIM process standards. The following themes are addressed in this subsection. a) Managing perceptions about the technology within the firm. b) The introduction of facilitating teams, and c) the strategic positioning of the technology as a way of winning new contracts. Many issues that will be addressed in within the subsections. They include organisational inertia, the autonomy of project managers and involvement of the firm in joint venture contracts. Some of the challenges manifested in limited appreciation of the benefits especially within the top management hierarchy of the civil engineering division.

5.4.1 Challenging senior management perception of BIM process standards

The data analyses show that there is limited appreciation of the benefits of industry BIM process standards. This is despite that BIM is rapidly being introduced in many of the firm's divisions including in the civil engineering division. There results show that there is lack of support from senior managers. Despite that steps have been taken such as the creation of the BIM core team and the BIM strategy team. The high costs of training and excessive influence by some project managers are cited as the reasons behind limited engagement with BIM process standards. For the BIM manager however, the main issue is not about management support but,

> *"It's still down to does the project need it? … We have to turn it on its head that the business will say; all projects will work this way. We'll all work from a BIM, according to the BIM policy we'll be dealing, we'll take a model approach rather than the, a drawing approach, which is turning it, everything on its head." (X10.13)*[63]

In defence of their position, senior managers argue that the implementation of the new technology is risky and costly. According to an engineering director, the benefits take long to realise, moreover the competitive nature of construction means that they have to make a decision on whether or not to participate on the likelihood of winning the bid.

> *"We have had a couple of tenders recently which the information we were supposed to tender on was within a BIM model issued by the client, but when we started entering information, we found that it (BIM model) was inconsistent. So we spent a lot of time and effort to get it into a standard we needed. We were then unsuccessful." (X26.14)*[64]

Therefore, management has to consider the financial implications of participating in the use of BIM and the business's capacity to sustain such a process given the risks that they may not recover the investment. The fact that industry BIM process standards are still in their

[63] Interview with BIM strategy manager
[64] Interview with the division's Engineering director – Main

infancy means that participation is highly risky. Middle management and site engineers did often not appreciate this.

5.4.2 Forming the new BIM core and steering team

The data analysis shows that some of the senior managers within the civils division believed that industry BIM process standards constituted a significant change that could yield benefits to the business. However, there were doubts about the capacity within the firm to exploit the new technology, especially that some of the standards such as COBie require technical expertise and were still being developed. To address the risks and uncertainties involved two new teams were created. Management considered that adapting industry BIM process standards required significant oversight until such time that the process had stabilised. They creating the BIM steering team comprised of senior managers, divisional directors, project managers and engineers drawn from projects in the firm's different divisions. The BIM strategy manager is a member of the steering team. The BIM steering team leads the implementation process assisted by a newly created BIM core team that provides technical functions. Many interview participants reported that they did not know such a team existed.

Management also created the BIM core team, which is comprised mostly of personnel with IT and engineering skills. These professional skills meant that they could make sense of technical information provided by IT suppliers, SDOs and standards development consultants that were working with the firm. A member of the BIM core team explains the functions of the team,

> *"Well we're the mother ship and we have regional BIM specialists who would sit with us for several weeks and be trained on the processes and the tools on the best practice" (X13.13)*[65].

The BIM team acts as a 'knowledge silo' or the 'mother ship'[66] as the above interviewee commented. The team consolidates knowledge about how to use BIM standards from the external environment and adapts it to suit the firm's context. From the experience of using industry BIM standards, the core team influences the development of industry by channelling specific information to SDOs. This is important in reducing the time required to learn the emerging BIM process standards. The BIM core team acts as a receptor and facilitator of knowledge transfer between the firm's internal and external environment. It senses the developments in the external environment, obtains and adapts knowledge to improve the technical capabilities of the firm. The team sources knowledge and latest developments about BIM standards from the industry, IT suppliers, universities and standards developers and keeps project teams abreast. This explains the resourcing of the BIM team with specialists with skills in both ICT and construction engineering making it easier to synthesize and apply construction knowledge.

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[65] Interview with BIM modeler Core team – Main
[66] Interview with X12.13 BIM modeler Core team – Main

For one BIM modeler, the work of the team is challenging because the many different projects the division is involved in have different understandings of the BIM process. They explain,

> *"It will always be like this because one project has different elements and different facilities management team, they might want different things at the end." (X12.13)*[67]*.*

The business is creating new roles in line with the requirements of the PAS 1192 standard. The roles of the information manager and the BIM modeller are set out in the PAS 1192:2012 standard. The PAS 1192:2012 standard requires the design lead to be separate from the information manager as show in Figure 5:6. However, there was no evidence of this separation. The design manager performs the information manager's role. BIM core team members are integrated into the project team to provide the day-to-day project technical IT support requirements.

[67] Interview with BIM modeler Core team – Main

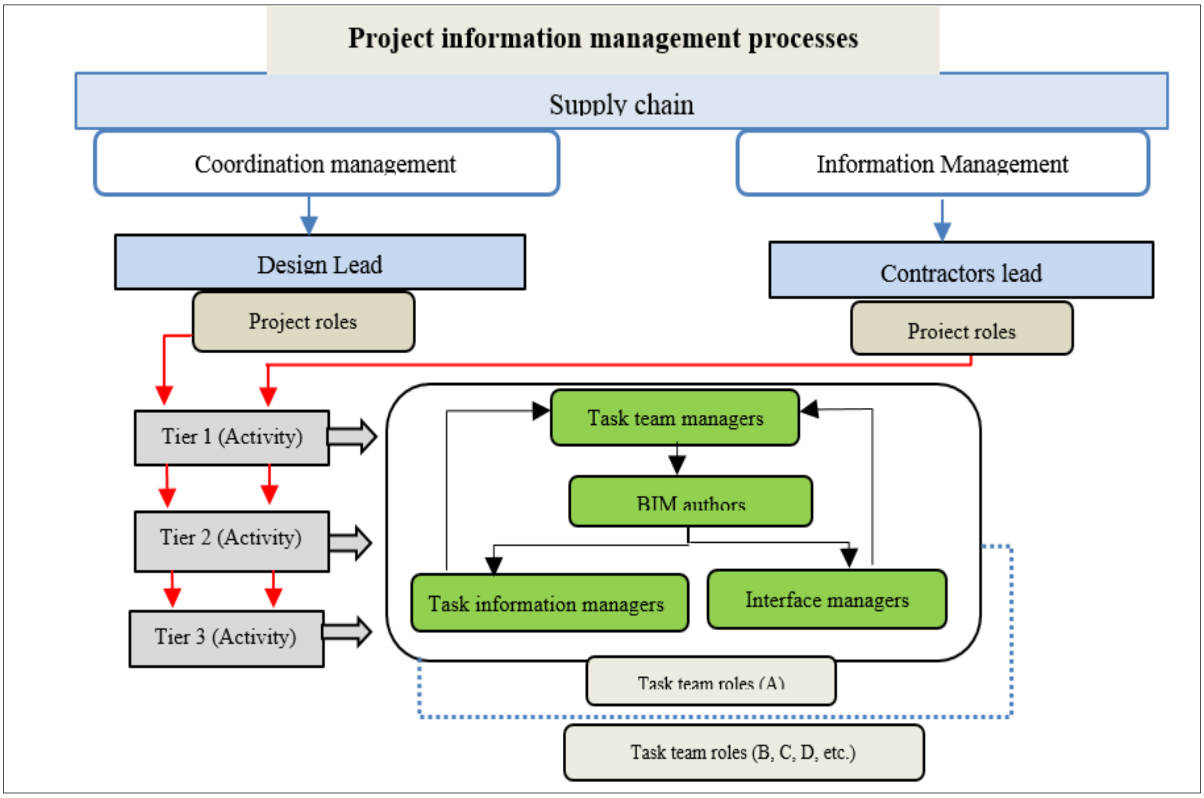

Figure 5:6 Extract from BS1192 showing the role of information manager[68]

Professionals in the BIM core team help to train and help address technical problems relating to the introduction and use of BIM standards. By solving problems faced by the project team, the BIM core team is positioned to channel knowledge from and between projects, and from the firm to SDOs, IT suppliers and standards consultants. The BIM core team also interacts with centrally located teams such as the tendering and temporary works design teams that serve not only the civil division but also other divisions of the firm.

[68] Source: PAS 1192-2:2013

5.4.3 BIM: a tool for winning new contracts

Conco's civil engineering division has realised that utilising industry BIM process standards has strategic importance especially in the public contracts market. Since the government has mandated the use of industry BIM process standards, the ability to use BIM standards qualifies the firm to bid for public contracts. This also means the business is able to retain a key employer in the government. Moreover, many of the firm's private clients are demanding the use of BIM process standards. A BIM modeller explains that most of the projects the firm bids for in both the private and public sectors are introducing specific questions about the firm's competence in BIM standards.

> *"…when you go into a tender there are some prequalification questions you need to answer normally. And those questions usually have a BIM section. You need to let them know what experience you have in BIM…you need to let them know that you have worked in BIM and these are the experiences that you have…"(X11.13)[69].*

Questions about the use of digital 3D objects, 4D, 5D simulations and digital collaborative technologies feature prominently in new tenders. Presentations of the firm's use of industry BIM process standards are now part of the bidding process. According to the Engineering director, the use of industry BIM process standards together with digital collaboration technologies has significantly improved the firm's ability to realise benefits of its investment

[69] Interview with BIM modeler Core team

in BIM. However, the challenge is that integrating BIM standards into the bidding process is expensive and time consuming. Failure to win a project after considerable investment usually leaves the senior managers pondering whether to use the new technology or not to.

> *"So we spent a lot of time and effort to get it into a standard we needed. We were then unsuccessful. So having put so much effort ... That was a waste of time and investment … if this keeps happening our attitudes to BIM may change." (X26.14)*[70]

A centrally organised bidding team with the support of the respective division, design firms and senior management usually accomplishes the bidding functions. Individuals from projects are at times temporarily co-opted to the bidding team so that knowledge from projects informs the bidding process. The bid preparation process can be chaotic if activities of the different personnel are not managed efficiently. Here BIM standards have been beneficial in regulating the activities of the bidding team members. For instance synchronization of information production activities, filing, communicating and updating the bid team on tender information. According to the temporary works and design manager, industry BIM process standards provide a common digital environment for interaction, reduce time wasted in searching for information, enhance the integration of work and improve the ability to monitor the activities and control design firms engaged in the bidding process. Working in a shared information environment has facilitated the sharing of knowledge required to improve digital 3D modelling, 4D and 5D simulations skills. According

[70] Interview with the division's Engineering director – Main

to the design manager, the use of industry BIM process standards has improved the ability to simultaneously manage a number of bids than before.

5.5 Using the PAS 1192:2012 (1-3) and COBie process standards in projects

5.5.1 The PAS 1192: 2012 (1-3) standard

The PAS 1192:2012 succeeds the BS 1192:2007 standard. Analysis of the research data shows that the PAS 1192:2012 is embedded with the Collabtec and Projecttec technologies used in the firm's projects. The standards are used to provide a common data environment (CDE) where users digitally interact. Within Conco UK's civil division, there are different views about the different digital collaboration platforms. There are complex issues that arise as people begin to interact with standards embedded in the collaborative digital platforms. Participants reported that using the PAS 1192:2012 moulds expectations of behaviour, which improves the ability to develop repetitive ways of synchronizing information creation activities, regulate information exchange and reduce time wastage in searching for project information. According to a BIM modeller,

> *"The PAS 1192:2012 is a collaboration standard, it says you need to use a common data environment and what's the structure of that common data environment, and then it gives you recommendations on naming conventions,*

etc. How you manage files … and it also gives the documents you need..." (X13.13)[71]

These views appear to be far from what is happening within the firm. The division has produced a BIM execution document that is supposed to be used in all projects. However, this not always followed. The document explains how project teams are required to collaborate in a digital environment using standard processes and procedures set out in the PAS 1192 standard. The CDE is a common platform where all digital interactions between project members occur. It is where all the project design information, product specifications, manuals, programmes and records of project communication are stored. The CDE is used to monitor and control information communication activities.

"Yeah, I think as a single source of the truth, I like to think that if you wanted to find the latest version of the model or the drawing or the specification or anything, that email, you would go into this so called common data environment." (X13.13)[72]

By using a CDE, the project team are able to coordinate, control and regulate information exchange and communication between the different firms engaged in the production of the built facility. In practice, enacting a CDE involves identifying project information requirements, configuring the digital collaboration technology to the different access rights and responsibilities of project parties, outlining the file naming convention, creating the

[71] Interview with BIM modeller – BIM core team
[72] Interview with BIM modeller – BIM core team

filing structure and enabling project communication functions as illustrated in Figure 5.3 below. All projects in the civil engineering division are supposed to follow the requirements of the PAS 1192:2012 standard. According to the firm's BIM implementation protocol, failure to enact a CDE as required by the PAS 1192 standard is a risk that must be referred to the engineering director[73].

In practice, the PAS 1192:2007 is embedded in a collaborative internet based proprietary IT technology such as Collabtec and Projecttec to be used in construction practice. The digital collaborative technology provides a common platform to which all project parties refer for information management requirements. The embedding of the industry process standards within collaborative platforms is a source of many challenges. In one project, the design manager uses Collabtec, in another joint venture contract the project team uses Projecttec, yet in the other project, the team used both Collabtec and Projecttec.

> *"… The problem is we, although we have a corporate agreement with them, whether we use (Collabtec) on a project depends on the project manager. So it is not like, oh it is a Conco UK project so we will use (Collabtec), it depends on the project manager. So, if the project manager says, OK we'll use (Collabtec), I think, yeah …, and then if the project manager says, OK, I'm not going to use it, I have other things I can use, for example if there's a joint venture then they can choose whether they, which system they apply." (X18.14)*[74]

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[73] Civil's BIM execution protocol
[74] Interview with site engineer

The use of the PAS 1192:2012 standard combined with the collaborative technology is improving the capability to: a) Create, exchange and store information in 3D models, b) communicate project information, c) maintain and archive digital project information and d) monitor changes in project information. Moreover, using a common collaborative technology aligned with the PAS 1192 standard enables project teams to accesses constant support from IT suppliers thus improving their ability to perform their functions efficiently and improve their interactive relations with IT suppliers.

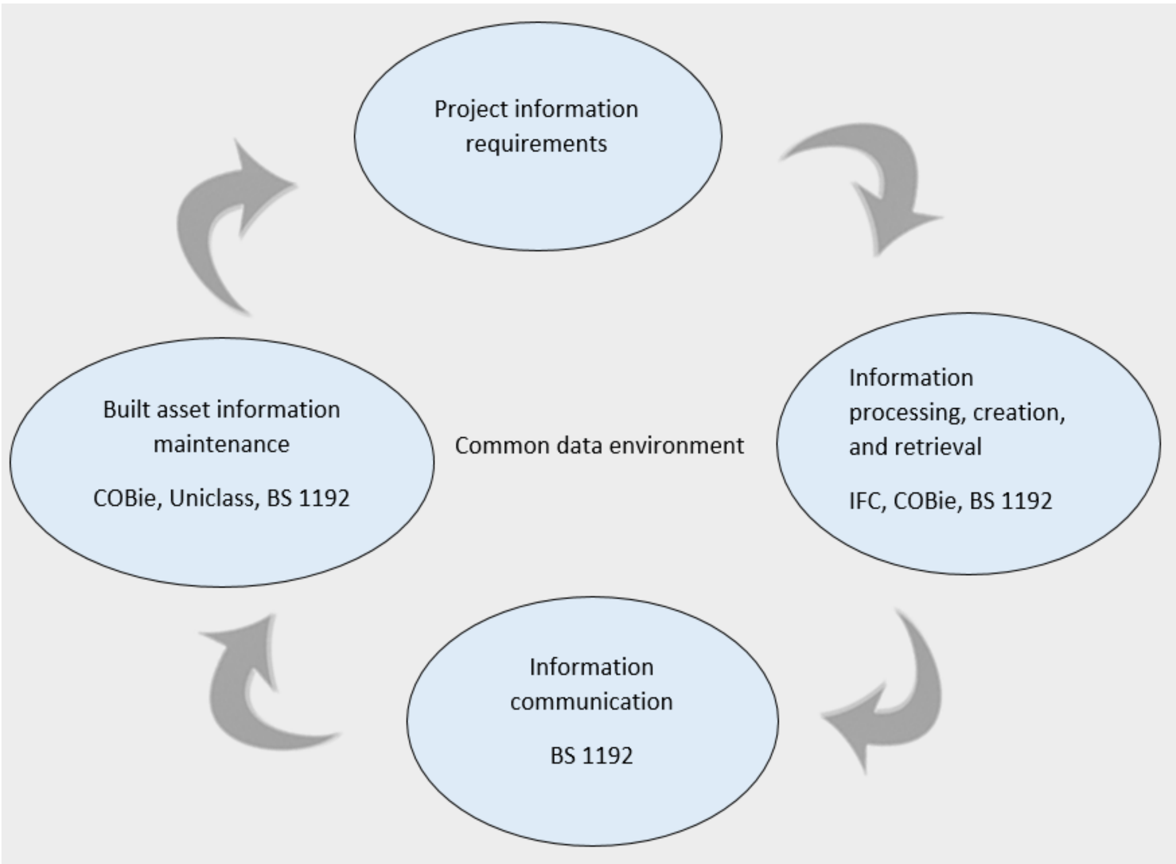

Figure 5:7 Information processing & management in common data environment[75]

[75] Created by researcher from analysis of research data

5.5.1.1 A shared digital data environment

Although the CDE as required by the PAS 1192 is considered useful in providing a common source of information, the data shows that users also view the digital 3D model as a common platform for interaction. There were suggestions for all the project parties to produce and store all the information in 3D models. The use of a single 3D model by the project team members such as designers, engineers, subcontractors and facility managers facilitates concurrent working.

> *"So it's (3D model) a big data base, … it literally takes all info you have in Revit for example you might have several names, numbers, systems and some sort of fire rating, what phase it's in whether it's a new build or some kind of info coming in from Revit, Tekla, AutoCAD, Microstation or something like Archicad, I know it sounds a little magical..." (X11.13)*[76]

Synchronized information production enhances the ability to integrate and manage information. Even though the 3D model serves as a common storage for information for some, data analysis shows that users still rely on the digital collaboration platform provided by the use of the PAS 1192 standard. The digital collaboration technology is often used to store, exchange and access 3D models. With the support from IT suppliers, project participants were able to access and retrieve 3D models easily. They were also able to utilise the communication tools within the collaboration platform to communicate changes. This

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[76] Interview with BIM modeler Core team – Main

meant that individuals could perform multiple functions thus reducing inefficiencies, maximizing resource usage and reducing the production of unnecessary information.

The PAS 1192:2012 is embedded in digital collaboration technologies such as Collabtec. This means that user interaction with the standard becomes invisible to the extent that some users were not aware of the PAS 1192:2012 standard even though they were in daily use of the technology. This is noted by a site manager,

> *"… We use Collabtec[77] to run our projects and to comment and then we extract all the design or the information out of Collabtec from our system … when you read the standard, … certainly at face value everything we do complies with the PAS 1192 standard because it's just a pretty straight forward common sense way of handling collaboration process. But certainly we don't have a rubber stamp which says you are compliant with PAS 1192…" (X26.14)*[78]

The challenge is often that users are unable to explain the difference between the standard and the digital collaboration platform. Moreover, there are varieties of collaboration technologies available off the shelf. The Projecttec technology that was used in one of the projects was aligned to the PAS 1192 standard, however it did not perform as required by the standard. Some of the standard procedures such as the file naming conventions have not

[77] Collabtec is a proprietary technology developed to support the management of digital information in construction projects. Latest revisions to the technology have been aligned with the PAS 1192 standard.
[78] Interview with Project manager – Main

been setup correctly; other sections of the standard have been totally left out. At times, this left some of the users frustrated.

> *"… Because they are not organised, so I also have, Projecttec[79], if you do one thing wrong in Projecttec you affect everybody. If you grab a drawing from Projecttec and you want to save it, I can show it to you, you can create a lot of problems in Projecttec. Let's say I want a plan. Yeah. I've got a plan, I've got this drawing. Yeah? Oh, wonderful. I want to export it. Yeah? Look at this document, it's very, very old and the export option shouldn't be used for files, it'll be anything, externally, a letter returned or inputting a map so, if you don't send to folder and you have instead exported normally, that drawing will be locked" (X13.13)*[80]

The variety of digital collaboration technologies available and the client's autonomy in selecting the technology that is used on the project means that project members have to possess the skills to use different technologies. This means that many professionals have to constantly learn and build skills each time they move from one project to the other. This together with the invisibility of the standard diminishes the appeal to embrace the PAS 1192 standard process to many in the projects. Invisibility of interaction with the standards limits the ability to provide the relevant feedback required to further improve the best practice

[79] Name altered
[80] Interview with BIM modeller

contained by the standard. This may contribute to the rejection of the standard by some users, if they perceive that the standard does not relate with their experiences.

> *"…the biggest amount of problems, coming from subcontractors who generally don't want to know about the BIM that we are doing. All they want to know is providing their information and off we go!" (X20.14)*[81]

The data analysis shows that the absence of an industry wide certification system for compliance to the PAS 1192:2012 does not help attempts to enforce the standard. Due to this, users are not immediately acquainted with the benefits of changing to the new processes. Moreover, a PAS by its nature is not a full standard; this may also explain the reluctance by some to use it, arguing that the PAS 1192:2012 standard is in development. Therefore, it is immature and not best practice for them.

5.5.1.2 Project information communication

A standard communication protocol enhances the ability to regulate the communication of project information. In a project environment, involving many individuals performing a variety of functions, controlling information can greatly reduce inefficiencies that might result from poor communication or inability to communicate design information change. Project professionals communicate using collaboration technologies. The many different alternative forms of communication available such as emails, telephones and face-to-face

[81] Interview with Head of temporary works – Main

conversations affect the use of a single digital platform for communication. This significantly affects the firm's capacity to regulate and control information communication activities. Although the benefits of communicating using collaborative technologies such as improvement of the ability to monitor and maintain a record of project communication for use in the event of contractual disputes, there is significant resistance from project team members. Usually conversations in person or through emails are used in conjunction with formal communication using the collaborative communication technological system. A senior engineer explains,

> *"… communication usually happens either by face to face or email communication when the person's not in the office. I prefer to go directly to the person because we have the client upstairs, we have the designer upstairs, I can easily take the information directly to them, talk them through it. Then I will send them the formal communication on our communication system, on Cross rail's one that would be EB" (X22.14)*[82]

The duplication of communication activities could be contributing to inefficiencies. The multiple processes of communication that persists affect the firm's information management capabilities. Another engineer observed that there are two systems of communication. 'Real communication' conducted in person and formal communication that involves using collaboration technologies.

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[82] Interview with section engineer– Main

"Obviously we have communication in the office, we talk to each other and tell them exactly what needs to happen and we have emails but, in order to make it formal and accepted and contractually apparent, the communication system needs to be used" (X18.13)[83].

The use of different means of communication may affect the management of information using industry BIM process. The head of temporary works[84] bemoaned the frustrations of communicating with a supply chain that does not have knowledge of BIM process standards. Even though there is a view by many participants that the use of BIM standards improves the capacity to communicate information effectively in projects, there different communication systems and lack of consistent enforcement means that adaptation is challenged.

This subsection has examined how information management capabilities are influenced by the use of industry BIM standards. Particularly the complexities of using standards together with cutting edge digital design tools because of the many proprietary collaboration technologies in the market and the client can influence the project team to use a different technology from the one the firm is used. Moreover, IT suppliers might customise the collaboration technology and embed different aspects of the PAS 1192 standard. For instance in one of the projects the client requested Projecttec to be used which is considerably different from the Collabtec technology the project team members have

[83] Interview with Engineer – Main
[84] Interview with head of temporary works - Main

familiarity. Even though both technologies are aligned to the common industry standard, IT suppliers have configured them differently. This greatly challenges the development of information management capabilities.

The data show significant problems arise due to the inconsistent use of standards especially by IT suppliers who embedded digital collaboration technologies with particular aspects of the standard they prefer. This practice by IT suppliers disjoints information production processes. This makes it difficult for some participants to collaborate and use of digital design technologies. Therefore, waste is incurred as people search for documents. The BIM strategy manager noted that this was creating challenges to the firm's ability to perfect digital project information management. As result, it is proving difficult to achieve efficiencies in the creation, storage, exchange and retrieval of information.

5.5.2 The COBie information exchange standard (BS 1192:2012-4)[85]

The COBie standard developed out of the need to improve the process of capturing built facility information during design and construction to reduce costs of post-hoc data capturing and maintenance. The COBie standard is embraced in the firm as part of the BIM process standardisation. However, the analysis of the data shows that the use of the COBie standards is having limited effects on the development of the firm's project management capabilities. Whilst clients such as the government frequently ask for the standard, its use

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[85] When this research was conducted, the COBie standard was referred as the PAS 1192:2012 (4). The COBie standard became a full standard in May 2015 and is now referred as the BS 1192-4:2014 standard and has been published by the BSI. The PAS 1192:2012 (1-3) is yet a full standard.

remains mediocre because the standard is not yet agreed at the national level, it is not viewed as best practice for managing information exchange activities and clients are unclear about their information requirements. A BIM modeller explains,

> *"… one of the biggest problems we're finding … is the client isn't saying these are the assets we need information on, so at the minute we just produce COBie for everything. So we'll get a spreadsheet with everything in it, structural members, everything." (X11.13)*[86]

Whilst the engineering director is keen to promote the COBie standard, there was a limited understanding of the standard in projects. For one project manager on the Docklands station project, the COBie standard is not best practice and is not formally agreed at the industry level[87]. For a BIM modeller the new technology simply is not working. He explains,

> *"You have attributes that's too many and the work sheet is not manageable and I am giving you a conservative estimate. I am a technologist; I can't get my head around why they have chosen a technology that does work..." (X13.13)*[88]

Project team members frequently argued that the COBie standard did not meaningfully improve the ability to manage information because not many of the firms engaged in the

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[86] BIM modeler Core team – Main
[87] Interview with Docklands station project manager
[88] Interview with BIM modeler Core team – Main

project understood it nor did they have the technology or investment to make use of the standard.

The client's information requirements that are set out and agreed in advance govern information exchange. Setting the information requirements in advance improves the ability to structure information production and enhance the quality of information.

> *"Key to the success of information management is clear definition of requirements as defined by the information exchanges and including COBie and geometry. It is wasteful for the supply chain to deliver a greater level of detail than is needed which may also overload the IT systems and networks available."*[89]

The COBie standard is an information exchange standard used to structure and define common attributes of the information transferred to the client. The COBie process standard is configured to work with technical standards such as the IFC standard. Members of the BIM core team have been exploring the production of an IFC based 3D model from COBie data. The setting of project information requirements involves outlining the type of information required by the client, the standard format, process of exchange, and the stages of information delivery. Typically, the 'COBie data drops' as they are called in practice are handed over to the client in a structured format progressively until project completion. The use of a standard COBie improves built facility management and reduces inefficiencies faced

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[89] Comment from a project manager in an internal publication about the lessons learnt from a Bristol building project completed in December 2012

by the division in information transfer by the project team. However, in the research the COBie standard is rarely adhered to because the users argued that the standard was not fully developed - there is no clear and consistent approach to its use.

> *"COBie on its own produces a lot of information, it's very hard to manipulate that information, then you need third party tools and skills to generate reports from that really" (X12.13)*[90]

The challenges faced in using COBie means difficulties for the project team and the client to make meaningful use of project information. Moreover, the division's clients that are not clear about the information they require exacerbate the problems associated with the COBie standard. Consequently, a lot of information is produced and transferred to the client even though it may not be required. This prompted the BIM strategy manager to comment not only about the COBie standard but also about the clients whom he believed were unable to provide clear instructions about their information requirements. For one site engineer,

> *"the dangers faced by the firms are in leaping into BIM technology solutions without really knowing what information you need, what format you need it in, when you actually need it and why you actually need it." (X17.13)*[91]

Although the PAS 1192:2012 standard was considered to be useful in providing a broader framework for managing consistency in information production and exchange, it also

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[90] BIM modeler Core team – Main
[91] Interview with site engineer– Main

created complexities for the clients who did not have the appropriate technology and skills to manage the information. On the contractor's side, it increased resistance to the COBie standard, thus limiting the ability to develop capabilities in managing information. There is also resistance for instance towards the use of a standard file naming convention as outlined in the PAS 1192:2012 standard. The purpose of the naming convention is to ensure a consistent language is used in naming files for ease in referencing, change control and reduce time required to search for documents. However, some suppliers are not concerned to adhere to the standard. A BIM modeller explains,

> *"Yeah there are some files that go up there that are not named correctly, quite often… And then there are others that argue that the way the file is named isn't important, so there are blockers there, we'll tell a company this is how you name it and they'll come back and say, it doesn't matter how we name it as long as we know what sort of thing it is." (X16.13)*[92]

Recognising the challenges faced in attempting to use the industry BIM process standards the BIM strategy manager organised an industry BIM feedback workshop. A number of firms made presentations on their experiences with BIM standards. There was an overwhelming resolution to advocate for an industry wide project information requirements standard, separate from the COBie standard.

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[92] Interview with site engineer

5.5.3 Integrated project delivery using BIM process standards

The integration of project activities is being influenced by the use of BIM process standards. Table 5.2 below shows some of the activities involved in integration of project delivery. The use of digital collaboration technologies embedded with BIM process standards for instance, facilitate early involvement of project professionals and collaborative decision making in addressing project issues. Even as BIM process standards provide the means to integrate the activities of engineers, operatives, subcontractors and material suppliers, the findings show significant complexities. For instance, integrating the activities of the project parties becomes an issue, when the parties maintain different approaches to the application of the BS 1192:2007, PAS 1192:2012 and the COBie standards.

Activity	Emerging capability
Integrating the services of external designers and suppliers	Integrated project delivery
Early supply chain in design activities	
Collaborative problem solving	
Negotiating the systems of standards	
3D visualisation and digital simulation	

Table 5:2 Activities involved in integrating project delivery activities

Data analysis shows that industry BIM process standards are influencing project management activities by transforming the ability to integrate services performed by project professionals and suppliers engaged in the production. In utilising a common process of working, coordination and control of information production activities in the project environment is simplified. For instance, the design and project managers reported that working in a collaborative BIM environment enabled them to anticipate the behaviours of various professionals making it easy to integrate the services offered by design firms, product suppliers and tradesmen. Consequently, using industry BIM process standards makes it possible to manage design activities, plan and programme activities effectively. The services offered by the firm are enhanced by improved collaboration in design problems solving, synchronizing information production and early involvement of parties in the design process. Despite improvements in the ability to coordinate the activities of those involved in the project, industry BIM process standards present challenges that require localized solutions. The discussion below addresses the issues surrounding the application of industry BIM process standards on the coordination of project delivery activities.

5.5.3.1 Integrating the services of external designers and suppliers

Conco UK integrates services supplied by specialist contractors, designers, material suppliers and labour supply contractors to provide design, construction and maintenance functions. The construction firm outsources design functions to external engineering design firms. Managing the different design firms is usually the responsibility of an in-house design manager, who frequently communicates with them and provides updates on design changes particularly client originating changes. Collabtec as an internet based digital collaboration technology platform accessible from any geographic location, facilitates the sharing of information and communication of key design decisions. The use of the PAS 1192 standard embedded in Collabtec provides a common way of controlling and regulating interactions between designers. It also provides a common process by which the design manager monitors and controls the activities of designers. This makes it easy for instance for the design manage to intervene as necessary, communicate change, facilitate collaboration between firms and provide a source of information usable by all project parties.

The use of a common digital platform embedded with the PAS 1192:2012 standard facilitates collaboration with product suppliers. In the process of developing specifications for use in tendering and material procurement activities, designers rely on structured data sets supplied by product manufacturers. The product specific information is stored in way as to support ease access and manipulation by the project design team. The design manager explained how designers have offered material suppliers exclusive access into dedicated sections of the collaboration technology to file product information.

Embedding industry BIM process standards into collaboration technologies however does not mean that there are no challenges to the construction firm's improvement of project management capabilities. A BIM modeller explained that some design firms lack the technical expertise to navigate their way in collaboration technologies. Moreover, some of them do not use digital design tools such as CAD, Revit and Tekla.

> *"Well it's the capabilities of them to supply for example, if you require a model from your subcontractor, it's usually very difficult for them to do it. Because*

> *unlike some of the designers that have a 3D team they can rely on; the suppliers … but most of them, they don't have. So you cannot say to your suppliers, OK, give me a 3D model, it doesn't make sense to them." (X17.13)*[93]

The lack of skills by some of the team members means that the firm has to invest in training the supply chain. However some supply chain partners are not prepared to learn because they do not identify with the benefits of using the standards. A subcontractor argued that the BIM standards do not address their specifics requirements and hence have less relevance. A frustrated subcontractor explains,

> *"So this is why these guys got so angry with me the other day in the meeting because I was telling them it does not work. Only because they have used it on architectural and structural. It does not work on me so they keep on defining their standard around a small part of the industry, which is the architectural and structural design. And they fail to realise that there is a part of the industry that the standard is not working for" (X13.13)*[94]

Some of the labour-only suppliers do not have sufficient financial resources to invest in the training that accompanies the change in the way they perform their functions. Due to the challenges, product and service suppliers are not prepared to commit resources to implementing a standard, which they argue changes rapidly. The different positions on

[93] Interview with BIM modeler Core team – Main
[94] Interview with subcontractor on Docklands Project

industry standards taken by the firm's suppliers significantly limit the construction firm's ability to integrate services in the delivery of built facilities.

5.5.3.2 Collaborating in project problem solving

Using the PAS 1192:2012 standard to facilitate collaboration improves the capacity to identify and address problems in project designs. Analysis of the research findings shows that the use of industry BIM process standards enhances the project team's ability to use a common process for making decisions, which enables early involvement of project team members in the design process. The use of industry BIM process standards also enhanced the communication of change, improved the ability to address emergent project design problems, and to manage the use of design information. However, the standards are not customised to specific project requirements.

Collaborative decision making typically involves the project team collectively participating in resolving design problems. Data analysis shows that design problems solving activities do not only occur at the project level but also occur at the business level. At the business level, design problem solving is not directed at an individual project but at multi projects. Problem solving activities are characterized by multi stakeholder engagement involving clients, product suppliers and design firms. Facilitated by the BIM strategy manager, a collaborative project environment is created where a common language was enacted to coordinate problem-solving activities with the support of IT suppliers. In the COBie trial project for instance, the firm had an opportunity to learn new solutions, assess the applicability of BIM standards, experiment with new technological solutions and address design problems.

> *"…so the best practices of how to export IFC from Revit for example so that we can get as much information out of these models as we possibly can, are also being using the Manchester project,." (X14.13)*[95]

5.5.3.3 Involvement of skilled operatives in design

The use of industry standards to facilitate collaboration between project parties is transforming the sharing of information in project design. Data analysis shows that by pursuing a collaborative project environment, BIM standards are rapidly transforming adversarial attitudes. In the Central London Cross station project, the use of a collaborative digital project environment facilitated the engagement of the client's facilities management team, skilled operatives and the site management team to exchange ideas to address buildability issues.

> *"What you do is you just get people into the canteen, show them the video and they perfectly understand what's going on …they knew exactly what had to be done. People don't just go around, oh I didn't know,… they were able not only to make it their own, understand the operation, but also put forward some options of, yes, perhaps we should do this …" (X16.13)*[96]

The information obtained was vital to inform design decisions because of their experience. In the Docklands Cross rail station for instance, the designer inadequately designed steel

[95] Interview with BIM modeller
[96] Interview with BIM modeller – BIM core team

reinforcement for the headwall because of limited appreciation of buildability issues. Integrating the steel fixing subcontractor into the design process enabled the project team to address the problem in advance.

> *"Can you imagine the consequence …; there was one bar too many in here, one line of bars here. Which shouldn't actually be here because it cannot work the height. It will clash and clash again. You can see this bar cannot exist because it clashes with the ring. … And the steel fixer was here with me…. he said can we get a decision from the structural engineer because I know the problems. Please, Joe he said, put them in and just get them rectified now before it's too late…" (X16.13)*[97]

Despite the perceived benefits in terms of early involvement, use of innovative digital tools and reduced defragmentation of the construction, the ability to perform and manage project designs is affected by the numerous collaboration technologies available in the market. Moreover, the construction firm's project managers and its clients had autonomy over technologies to use. In addition, project team members frequently moved between projects making it difficult for them to exploit the knowledge they gained. This creates an environment in which individuals have to constantly learn and unlearn skills.

> *"Within the organisation …how many people know how to use Projecttec? Not many. To get in it, it's almost like going through Fort Knox, you go an hour, say,*

[97] Interview with site engineer

> *encryption it generates every minute. Then you have a support basis of Citrix access which it requires another password. It's almost like going through Fort Knox. And then once you're in there you can see stuff or you cannot see stuff …" (X13.13)*[98]

Gaining technical mastery in all the available collaboration technologies available in the market is almost futile. Even if an attempt was made, it would be impossible to know which technology the next client or project manager will chose. As a result, project team members are often resistant to change from their established way of working.

> *"The client wants to use EB, and that's what we've got to use. But we don't have EB platform in that project, so we use Collabtec in other jobs. So we use Collabtec with our subcontractors." (X19.14)*[99]

5.5.3.4 Addressing the systemic nature of standards

Industry BIM process standards are not used in isolation of other standards such as the Omni class and Uniclass standards. Although the Omni class and Uniclass standards are classification standards, data analysis shows that such standards play an important role in the use of BIM process standards. The IFC also has a complicated but relevant relationship with the COBie standard. Analysis of the data shows that these standards operate as a suite of standards that help to create an integrated project delivery environment. However, their

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[98] Interview with BIM modeller – BIM core team
[99] Interview with site engineer Docklands Cross rail station

use becomes a challenge for the construction firm due to limited interoperability between some of the digital design technologies, and the digital collaboration technologies used in projects. Interoperability concerns the ability of the different digital design tools to exchange information. Interoperability enhanced collective participation and addressing clashes in design information. In one of the projects, more than six proprietary digital design software were in use. For the BIM strategy manager, improving the ability to work in a collaborative BIM environment is underpinned not only by the use of process standards, but also by the technical standards that support the creation digital design information as shown in Figure 5.4 below.

> *"If you bought Revit you haven't bought BIM, you're not doing BIM if you just use one software supplier's solutions you're almost doing lonely BIM. I think interoperability is the name of the game." (X10.13)*[100]

[100] Interview with BIM strategy manager

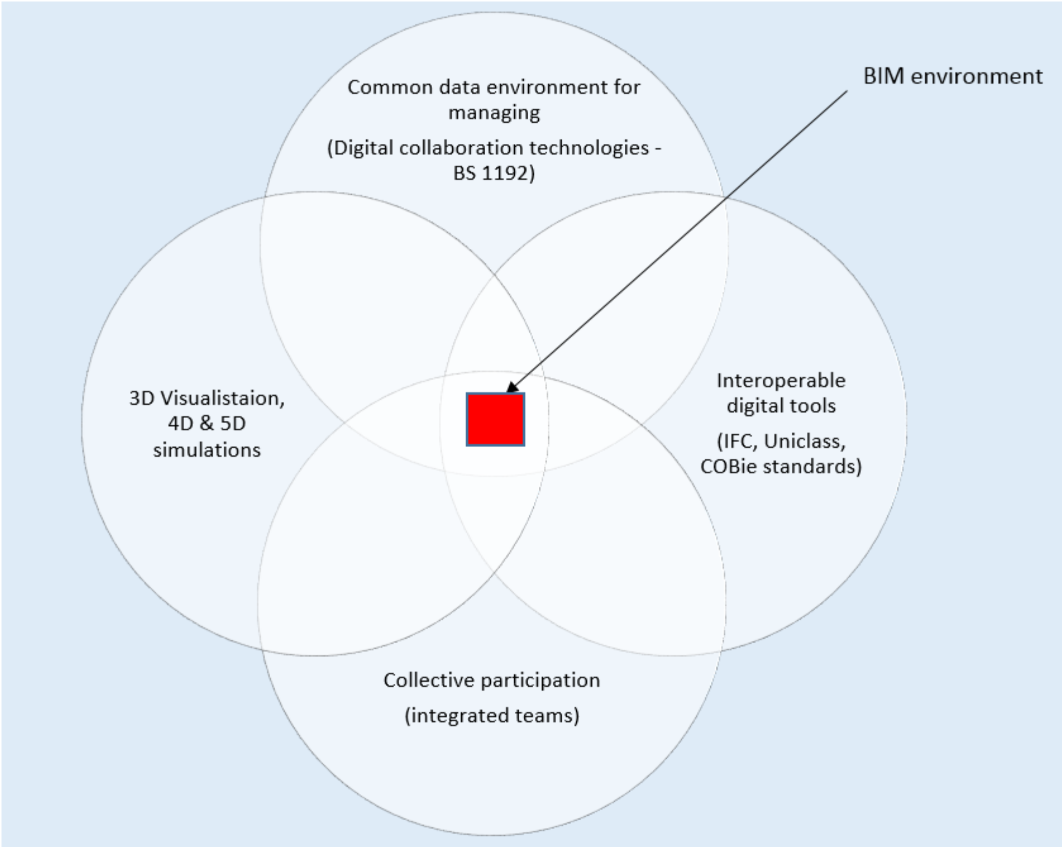

Figure 5:8 System of standards in a BIM environment[101]

Interoperability between digital tools is achieved through technically mapping the internal structures of proprietary digital design tools to agreed standards. Most of the digital tools used by the construction firm were procured from the open market. This means the technologies are hardly suitable to address individual project requirements. Coordination became a considerable challenge where the construction firm did not have the requisite technical IT skills to manipulate the inner functions of technologies to suit contextual requirements.

[101] Developed by research following a detailed analysis of the collected data

"Mapping everything together is much harder and when it comes to pure tech, the issue of interoperability becomes quite tedious, for example a client has specified a certain format … but perhaps they haven't understood that they have to specify it at the very early stage or see that designer capable of delivering that at the beginning stages of the project"

A lack of interoperability between some technologies means that designers had to customise digital design technologies. Sometimes this was impossible because of strict proprietary conditions imposed on the digital design technology and limited support from IT suppliers.

"It's, it is challenging because they want to do the minimum and they might not even understand the common data environment because if you ask Collabtec you get a different answer as to what they think it should look like in their product."

Whilst interoperability mainly focuses on technical standards, data analysis points out that the PAS 1192: 2012 standard is configured to operate in an environment involving industry standards such as the RIBA plan of works, the RICS New Rules of Measurement 2, Associate of Project Managers project stages and Employers Information Requirements. A common challenge in developing capabilities to manage projects is that project teams did not have the skills and competences to work in an environment involving the different standards. Due to differential development processes adopted by standards developers, the standards were incompatible. Even though IT suppliers were at times cooperative by offering user tool kits, customised solutions were hardly achievable due to project specific complexities. An engineer explains,

> *"The thing with this (BIM standards) is every problem is different and there isn't a standard place you can go to learn how to deal with it, or there isn't one answer either, there are many ways." (X18.13)*[102]

Consequently, there was a reluctance to embrace the new technology. The systemic nature of standards means that there is limited interoperability in both the technologies used to design and produce information, and the standard processes that regulate information production. These complexities considerably affected the business's ability to improve integrated project delivery skills.

5.5.3.5 Developing the technical expertise

The use of the PAS 1192:2012 and COBie process standards is influencing the technical skills of the professionals that use them within the firm. There is perception by some within the firm that use of standards allows one to benefit from the best practice of the industry. In practice, it was noted that as professionals attempt to use the standards, they face some problems that require new solutions and improvements in technical skills.

> *"…your skill comes, you want to do, work a lot faster. Sometimes I keep saying to colleagues, here, that is my workflow, it is almost like a sinusoidal function,*

[102] Interview with site engineer – Main

> *you just go up and down, up and down. You have these lulls where you just …, you just concentrate on training, getting your skills. So marrying, also taking notes that this is to be an investment for how to marry each software with everything." (X14.13)*[103]

The standard provides the knowledge to perform general project design and management functions. The use of industry standards provides the bedrock for technical capability advancement. However, the knowledge encoded in the standard at times is not enough to address distinct requirements. Attempts to create workarounds on the standard often proved to be the frontier for technical capability improvement.

5.5.3.6 Technical skills for information coordination and control

In a collaborative project delivery environment, technical skills are required to control, monitor and coordinate the production and use of digital information. Components of digital tools created independent of other project parties and then integrated into the project 3D model using innovative digital design technologies. Coordinating and integrating the independently created 3D model components was a complex task that relied on extensive technical skills and knowledge enshrined in industry BIM standards. For instance, the COBie standard provides knowledge to facilitate information capture from IFC models. Although the industry standards provides basic knowledge to perform general functions the BIM strategy manager observed that project activities are often specific, rendering the standard

[103] Interview with site engineer

at times to be irrelevant. As a result, the project team spends a significant amount of time creating plug-ins or additional technologies that facilitate communication between different digital technologies.

> *"I think I'm the only one in this team that can do this, Well, I don't do too much of these plug-ins and development because it's, well it's not our main role, because we are not software vendors. So we try to use the software that's existing but if something is really needed, we have to do something" (X12.13)*[104]

In addition, the construction firm recruited technical experts, and transformed its relationship with IT suppliers and standards developers. This helped to facilitate learning as well as provide day to day IT related project support. Interactions with the BIM core team, IT suppliers and standards consultants proved beneficial for project teams to develop technical skills.

> *"Yeah to be honest as a team if there's a bit of software out there we'll learn it if we need to" (X12.13)*[105]

The research also shows that the use of industry standards has contributed to the improvement of technical skills in processing digital information and conducting toolbox talks. 4D and 5D simulations that are associated with industry BIM process standards are

[104] Interview with BIM modeler Core team – Main
[105] Interview with BIM modeler Core team – Main

employed to explain pertinent design details and production activities. In some project design review meetings attended by the researcher, improved technical skills in the use of collaboration and design technologies enhanced the ability to detect design clashes. Figure 5:5 shows how technical skills in 3D modelling and planning helped to identify a clash between a crane and overhead power cables.

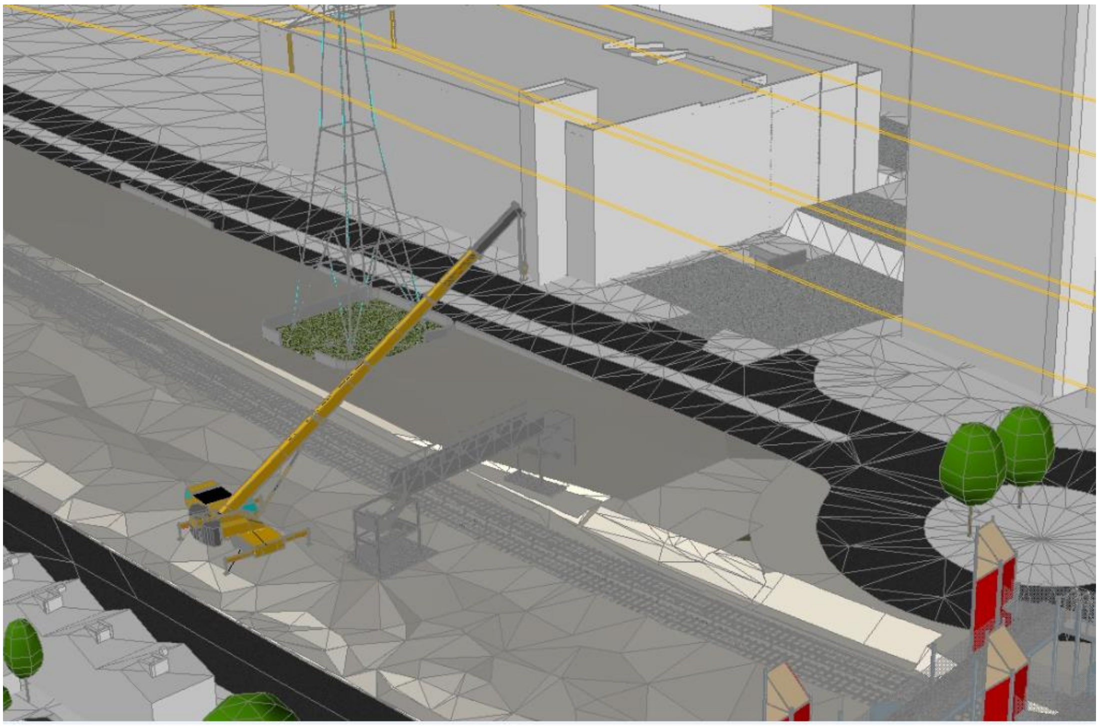

Figure 5:5 Identify clashes using digital design technologies[106]

For the head of temporary works, the use of industry BIM process standards has considerably transformed technical skills however, traditional ways of constructing are still important. He argued that the practicalities of construction mean that techniques for producing 2D drawings are still relevant.

[106] Image supplied by research participant

"… even if the model is done in 3D there needs to be a facility to put that on a piece of paper... We have always worked that way and I think the practicalities of construction are like that… that's how it should be" (X20.14)[107]

5.6 Summary

The data analysis presented in this chapter shows that the process of adapting BIM process standards is complex and uneven. There are significant changes that occur to the firm's interactions with systemic innovation actors. Section 5.4 explained that firm level interactions with BIM process standards necessitated structural changes that seek to enhance the use of the standards. To acquire knowledge about the standards, the firm participates in BIM trial projects, industry groups and in addition transforms its interactive relations with IT suppliers and standards developers. Internally, the use of industry standards contributes to the formation of a new organisational structure, recruitment of professionals with IT skills and improvement of marketing skills. The implications of these research findings to the literature on innovation in construction, PBFs organisational capabilities and standards are the focus of the next chapter.

[107] Interview with Head of temporary works – Main

Chapter 6: Discussion

6.1 Introduction

This Chapter discusses the research findings to draw implications to research on industry process standards, PBF organisational capabilities and innovation in construction. The Chapter is structured in sections as follows. Section 6.2 summarizes the research findings. Section 6.3 discusses the research findings in relation to the strategic capabilities of the PBF. Section 6.4 draws upon research on project capabilities to argue that the adaptation of industry BIM process standards shapes the firm's ability to integrate, control and coordinate project management activities. Section 6.5 draws insights from research on the systemic nature of innovation in construction to argue that the framework of knowledge flows proposed in Gann and Salter (2000 p.960) should be modified to include IT suppliers and SDOs. Section 6.6 summarizes the Chapter.

6.2 Summary of research findings

The PBF organisational capabilities theoretical framework advanced by Davies and Brady (2000) is used to make sense of the empirical findings about the adaptation of industry BIM process standards in Conco UK. The findings show that BIM process standards provide a common language that facilitates collaboration, coordination and control of information production, exchange and storage activities, and digital interactions between designers (Chapter 5, section 5.5). These functions of BIM process standards improve Conco's project execution capabilities. At the business level, strategic management functions are directed at developing interactive relations with influential suppliers such as IT suppliers and SDOs (Chapter 5, Section 5.3). Conco UK's involvement in industry level initiatives helps to channel feedback from internal adaptation experiences to the process standards development initiatives. Organisational structure changes result in the creation of the BIM core team and steering committee (Chapter 5, Section 5.4.2). The recruitment of new professionals proves important to absorb knowledge from the external environment, and to manage interactions with IT suppliers and SDOs. The research articulates how a rapid change to industry process standards and systemic linkages between standards (Chapter 5, Section 5.5.3.4) frustrate the development of project capabilities in Conco UK.

6.3 Building strategic capabilities using BIM process standards

Gann and Salter (2000)'s view that PBF are involved in business and project process is confirmed in Conco. Indeed, the view that the PBF's distributes its business between project and business processes is consistent with the research findings outlined in Chapter 5 Section 5.2.1, Figure 5.1. In Conco UK, senior management perform strategic management functions as explain in Chapter 5, Section 5.2, including deciding to use BIM process standards. The activities of core teams such as the BIM team, bidding and temporary works design teams span between business and project operations. This means that adaptation of process standards occurs at the business and project processes. This section focuses on the business level activities to understand how the adaptation of process standards shapes Conco's strategic management activities. Discussing this is relevant to make sense of the research findings in relation to the Conco's strategic capabilities transformation as industry BIM process standards are integrated into the digital delivery of construction projects.

Chapter 2, section 2.5 explained that strategic capabilities include the PBF firm's absorptive capacity (Gann, 2001) and integrated solutions capabilities (Davies and Hobday, 2005 p.215). Chapter 2, Section 2.4.3 discussed that dynamic capabilities are a strategic management function required by the business to transform project capabilities, and adapt the business to changes in the business environment. The idea of dynamic capabilities assumes that senior management have influence over all aspects of business, however in construction Gann and Salter (2000) argued that the firm has less influence over project activities. Contrary to these views, Davies and Brady (2015) argue that for the PBF to know when and how to transform project capabilities, it requires the dynamic capabilities. Hence, dynamic capabilities are relevant to explain the implications of BIM process standards on the construction firm.

The idea of integrated solutions capability is useful to understand the PBF strategic management function of providing customers with a single solution for business and operational requirements. This entails the provision of pre and post contract functions including performing activities such as finance and maintenance as required by clients

(Davies and Hobday, 2005 p.216). In Conco, data analyses did not confirm a connection between the adaptation of BIM process standards and integrated solutions capabilities. Instead, the data shows a strong connection between BIM process standards adaptation and the project level activities of integrated project delivery activities. Section 6.2.2 examines the idea of project delivery capabilities in-depth.

In Conco, data analyses show that the use of industry process standards is associated with attempts to enhance Conco UK's absorptive capacity. The notion of absorptive capacity according to Gann (2001) is the construction firm's ability to absorb and make sense of knowledge from *R&D*. Subsequently, Blayse and Manley (2004) argued that construction firms must employ a critical mass of skilled professionals that are able to make sense of knowledge from R&D activities. Tatum (1987) makes the same point, emphasizing that construction firms can improve the adaptation of new technologies by recruiting professionals with the ability to interact with lead suppliers. In Conco, knowledge required to adapt the BIM process standards does not come from R&D activities. Contrary to the view that absorptive capacity is directed at knowledge from R&D activities, empirical evidence shows that Conco UK relies on industry initiatives, interactions with IT suppliers and SDOs and participation in virtual projects as sources of knowledge. The assimilation of the knowledge is enhanced by the recruitment of multi-skilled professionals into the BIM core team (see Chapter 5, Section 5.4.2).

Four elements associated with building the absorptive capability include Conco UK's are discussed below. They include the ability to: i) engage in industry level initiatives, ii) manage resistance to change (inertia), iii) manage external and internal perceptions of the industry-wide process standards, and finally iv) participate in virtual BIM standards implementation projects. These elements are discussed in turn below.

6.3.1 Engaging in industry level initiatives

In Conco, the adaptation of industry BIM process standards requires engagement in industry level initiatives to gain knowledge about the new technology, and to influence the development of the process standards. Cohen and Levinthal (1990) argue that the firm's ability to adapt to the changing business environment is important to achieve and sustain competitive advantage. In strategic management (Eisenhardt and Martin, 2000; Pearson *et al.*, 2000; Teece, 2007; Le Masson *et al.*, 2010), forming alliances is a strategic management function that enhances the firm's ability to achieve competitiveness. This view is consistent with the pattern of behavior witnessed in Conco UK. Empirical evidence shows that Conco is engaged in industry groups such as the BIM forum, and the BIM task group (which is a key group in the implementation of BIM in UK construction). Its BIM strategy manager is involved in BuildingSmart, a leading SDO. As shown in Chapter 5, Section 5.3.1, engagement in such industry level discussions is important for Conco UK to source knowledge about BIM process standards, make sense of it and assimilate the knowledge to meet its commercial ends. Interestingly, the findings also show a move by Conco UK to influence the development of BIM process standards. This is subject of discussion in the next paragraph.

Focusing on the user-innovation in the IT sector standardisation, Jakob (2006) argues participating in the development of the standards is important to shape the trajectory of the standard as well as to support local adaptations. In studies of technology implementation in construction (Tatum, 1987, Slaughter, 1993), there is a view that local adaptations are often necessary because construction activities are conducted in unique contexts. Industry process standards do not contain knowledge from Conco perse; hence, it is important for the firm to participate in the development of the standard. This can reduce resistance to standardisation because Conco's own experiences would have been included in the standard.

Tassey (2000) argues that those that adopt a standard promise to work within the jurisdiction of the standard. The research refutes the suggestion that users obediently keep within the jurisdiction of the standard. In Conco, data analyses show that the BIM core team is comprised of technically skilled engineers with skills to adapt industry process standards to meet unique project needs. Moreover, the research findings also show that the first tier of standards users (see Chapter 2, figure 2.4) such as Collabtec and Projecttec embed only the sections of the standards they have interest. This pattern of behavior is peculiar but important to make sense of Conco's activities as well as the environment it operates. The observed patterns of behaviour could be linked to the following. a) The process standards are still being developed and thus do not sufficiently address all project requirements; b) IT suppliers selectively integrate components of the process standards that suite their needs and finally; c) clients such as in the two London projects decided to use a different digital collaboration technology (Projecttec) which Conco UK did not use. These findings shed light into the complexities of adapting industry process standards. Crucially, they show that engaging in industry level initiatives is an essential strategic management function required to adapt industry process standards in Conco UK.

Gann (2001) has argued that even though construction firms interact with many industry stakeholders, they lack the absorptive capacity. This research shows that Conco UK improved its absorptive capacity through recruiting five multi-skilled engineering professionals into the BIM core team that is led by the BIM strategy manager (Chapter 5, Section 5.3.1). Such professionals can engage in industry level discussions and interact with IT suppliers to facilitate the adaptation of industry process standards. This finding confirms the view in strategic management (Cohen and Levinthal, 1990; Teece *et al.*, 1997; Winter, 2003; Ambrosini and Bowman, 2009)'s that recruiting new professionals enhances the firm's ability to improve its absorptive capacity.

Whilst the study confirms the importance of recruiting multi-skilled professionals, a striking feature of BIM process standards is that their application involves the use of digital collaboration technologies. Due to their highly technical nature, professionals should possess the relevant skills to use not only the standard but also the digital technology. The study also shows the relevance of changes in the organisational structure to support the adaptation process. Centrally located coordinating teams are capable of making sense of the technology; learning about it, and exploiting technical interactions with IT suppliers.

6.3.2 Managing resistance to change

In product and process developing projects, Leonard-Barton (1992) argues that increased routinisation in the organisation's activities may increase resistance to change. According to Benner and Tushman (2003), such routinisation increases and in turn resistance to change when the organisation adopts process standards. Therefore, building the capacity to address resistance is an important capability required by the large construction firm. Data analyses show that even though Conco UK acknowledges the benefits of adapting new industry process standards in terms of production efficiency, there is significant resistance to the new process management standards. The firm addresses the problem of inertia by recruiting new professionals and changing the organisational structure. However, this does not sufficiently address the problem, suggesting instead that there may be deeper issues about the adaptation of process standards and resistance to change that need to be uncovered.

The firm initiates strategies such as participation in industry level initiatives, engaging in virtual simulations and co-operation with competitors in standards development initiatives. Even though the recruitment of multi-skilled professionals mitigates resistance, the study shows that this is not enough. Therefore, to understand how the large construction firm addresses this challenge over time, further longitudinal studies are necessary.

6.3.3 Managing perceptions about the industry-wide process standards

In addressing the problem of inertia discussed above, it is necessary to focus on a closely associated issue, which concerns the management of perceptions about the industry-wide BIM process standards. In Conco, data analyses show that developing the strategic capacity to manage internal perceptions about a new technology is necessary. For instance, some senior managers explained that industry BIM process standards were too expensive to apply, required extensive learning and were rapidly changing (Chapter 5, Section 5.4.2). In the projects, some users resisted because they felt that there standards did not resemble best practice (Chapter 5, Section 5.5). These issues collectively show how the different perceptions may affect the adaptation.

Nam and Tatum (1997) argue that the use of technology sponsors and champions facilitate new technology use in construction firms. In Conco UK, the BIM strategy manager could be the technology sponsor and the BIM core team may be viewed as the champions. The situation becomes complicated when one considers that resistance did not stop following the creation of these roles. This calls for further examination. The research shows that the strategy manager and BIM core team had little influence over the adaptation of process standards. For instance, the BIM core team views the influential role of project managers (see Chapter 5, Section 5.2.2) as an impediment to the execution of their tasks. In in the Central London rail station project, the project manager had not heard of Conco UK's BIM execution plan because they were involved in a joint venture contract (Chapter 5, Section 5.5.3.4). Addressing these complexities and different impressions about the industry-wide BIM process standards is an important strategic management capability required by the large construction firm in the application of industry process standards.

6.3.4 Participating in virtual projects

The COBie trial project is an example of how Conco is collaborating to improve its adaptation and exploitation of industry BIM process standards to improve project delivery activities. The COBie virtual project is useful to identify and address problems relating to the enactment of industry BIM process standards. The research findings show that members of the BIM core team used knowledge from the COBie trial project to solve problems in real-life ongoing projects. These findings show that Conco UK is adapting to technological changes to simulate real life situations to improve its project delivery activities.

In other sectors, Davies *et al.* (2005) argue that vanguard projects can be used to develop strategic capabilities to enter new markets. As argued before in Chapter 2, Section 2.4.5.2, vanguard projects are not economical for construction, hence that approach does not apply. This study shows that Conco UK and other firms participate in virtual projects to experiment, share knowledge of experiences and influence the development of the standard. For instance, Chapter 5, Section 5.4.2 discusses that such collaborations provide the momentum required to influence IT suppliers to provide better integrations between process standards and collaboration technologies. The study shows that engaging in virtual implementation projects involving industry players is an important strategic activity for Conco. These findings indicate the strategic importance of integrating process standards and other digital tools to facilitate the adaptation of BIM process standards.

This section discussed the way Conco is improving its strategic capabilities by adapting industry process standards. The focus is not immediately on the industry BIM process standards, but on Conco's behavior during standards adaptation. The next section discusses capability building at the operational (project) level.

6.4 Building project capabilities using industry process standards

Conco is adapting industry BIM process standards to improve its capacity to coordinate and control project execution activities. However, the process is not smooth as shall be explained below. There are significant challenges particularly because of the multiple interpretations of standards that persist, the rapid changes to the standards, systemic linkages between standards and the voluntary nature of BIM process standards. These issues collectively influence capability development using BIM process standards. This section discusses how Conco is developing an integrated project delivery capability. The section also explains why this is important to the debate on industry process standards and PBF organisational capability development.

6.4.1 The integrated project delivery capability

In Conco UK, the use of the industry BIM process standards provides a digital environment for coordinating, controlling and combining project execution activities. Through a) facilitating digital interactions by product and service suppliers in design activities, b) customising project communication processes, c) prescribing the use of a shared information environment and finally c) enhancing collaboration in problem solving activities between designers, site engineers, skilled operatives and service supply subcontractors in the CDE, Conco is able to build its project capability. Data analyses show that by integrating the activities of project activities, Conco is able to build integrated project delivery capabilities (IPD). Integration refers to the seamless interactions between project actors in the performance of project activities such as biding, design and project management. The concept of IPD capability addressed here explains the skills, knowledge and competences involved in combining, coordinating, and controlling the activities of actors involved in the execution of project activities.

In construction, IPD is discussed a form of project procurement similar to management contracting; design, build, finance and operate, and contract management (Thomsen *et al.*, 2009; Azhar, 2011; Azhar *et al.*, 2014). In such discussions, IPD refers to the "seamless project team, not partitioned by economic self-interest or contractual silos of responsibility, but a collection of companies with a mutual responsibility to help one another meet an owner's goals" (Thomsen *et al.*, 2009). Drawing insights from research on systems integration capabilities (Pavitt, 2002; Prencipe *et al.*, 2004; Hobday *et al.*, 2005) and project capabilities (Brady and Davies, 2004; Davies and Brady, 2015), this research argues that the concept of IPD is relevant to explain the integrative functions that are performed by Conco using industry process standards. Conco achieves functional efficiencies through applying industry process standards together with digital collaboration technologies such as Collabtec and Projecttec to coordinate digital interactions between designers, to facilitate co-production of 3D models and detect clashes in designs that, which is important to solve design problems.

Within the CDE, common process of naming project information, structured processes of managing information and the creation of new roles and responsibilities facilitate the integration of design activities. Even as scholars emphasize the integrated solutions capability at the business level (Davies, 2002; Brady *et al.*, 2005b; Windahl and Lakemond, 2006), this research shows that the integration of project delivery activities is enhanced by the use of BIM process standards. Analysis of the data shows that Conco UK is using industry BIM process standards as a tool for integrating bidding and designing activities. Industry standards help the firm to establish a common protocol that guides designers as they produce and share construction information. At the same time, Conco UK is able to disintegrate[108] and integrate services from designers as and when required. Economies of integration discussed in Davies and Brady (2005) are realised through reduced time in physical interaction such as in meetings; and in communicating, searching and retrieving project information.

Hobday *et al.* (2005) argued that PBFs achieve functional efficiency through moving up and down the supply chain, integrating and disintegrating services as necessary. PBF also achieve economies of scale by establishing effective relationships with suppliers, employing new tools for managing subcontractors and outsourcing of production activities (Gann, 2000b; Whitley, 2007). This research shows that at the operational level, Conco uses BIM process standards to support efficient collaboration of design activities by providing a common language used by designers to coordinate and control their digital interactions. Using a CDE, design managers and project managers are able to monitor, control and intervene where necessary to support the production of information by designers located at different geographical locations.

[108] Disintegration as a term has been described by Hobday et al. (2005) describe the firm's managerial ability to outsource some of its business functions to suppliers and subcontractors

Even as the BIM process standards help to achieve efficiencies in project execution activities, the studies shows that Conco faces significant challenges. These include a) the systemic nature of standards means that information communication and exchange becomes a challenge when other project team members do not use the same standards. For example in the central London station project, the client requested that a specific IT supplier provide all the project's IT requirements. The digital tools provided by the IT supplier were incompatible with the technologies used in Conco. b) BIM standards attract multiple interpretations. This became prevalent when Conco's subcontractors refused to engage in the standardisation process. c) The availability of many off-the-shelf proprietary digital tools embedded with process standards became an issue when engineers had to share information or collaborate. This affected the integration of design activities particularly when the outsourced designers were contributing to the same 3D model. Finally, the standards themselves were rapidly changing. This affected the firm's capacity to learn and use them to manage the integration of project delivery activities. It is worth mentioning here that since the research begun in 2012, the PAS 1192:2012 (1-3) has undergone three changes. These issues collectively highlight the complexities faced in the development of project capabilities.

By explaining that Conco is improving its project capabilities using industry BIM process standards this research expands on the extant understanding of systems integration and integrated solutions capabilities (Prencipe *et al.*, 2003; Davies *et al.*, 2009b). It argues that at the operational level, a combination of BIM process standards and digital tools enhances the integration of project delivery activities. Whereas integrated solutions capabilities address the expanding of the core business by offering solutions for clients (Davies *et al.*, 2006); this research argues that at the operations level, the CDE enhances the integration and performance of project management activities. These findings are important to claim that the adaptation of industry process standards in Conco plays a role in transforming the skills, competences and knowledge required to organise and deliver projects.

6.4.2 Project management activities

Project capabilities are the skills, competences and knowledge required to perform bidding, design and project management activities in the execution of projects (Gann and Salter, 2000, Davies and Brady, 2000). Project capabilities develop through integrating technical specialists into project processes (Davies *et al.*, 2006). Table 6.1 contrasts previous views on project capabilities with the research findings. The discussion that follows examines the differences.

The research findings illustrate that BIM standards are a useful way of enhancing collaboration in projects. By so doing, it builds on research on the management of engineering design activities (Salter and Torbett, 2003). The research shows that industry process standards also contribute to the eliminating fragmentation in the production process because they provide a collaborative environment for professionals.

	Project execution activities in (Davies, *et al.*,2005)	**Project execution activities in Conco**
Project execution activities	Learning from unsuccessful bids	No significant role-played in learning from unsuccessful bids.
	Abandoning traditional tender preparation procedures	3D visualisations and 4D simulations become an important part of the tendering procedure.
	Establishment of technical capabilities that integrate IT	The introduction of BIM process standards improves the ability to create and manage design, construction and maintenance activities.
	Co-location of production teams (creation of a war room)	Embedding process standards in collaboration technologies, e.g. Collabtec enhances the efficient exchange of information thus reducing the need for people to be located in the same office.
	Establishment of new teams responsible for specific functions	The BIM core team is created to support business and project processes. BIM modeller role emerges. IT supplier relationship change
	Flexible, organic and informal ways of management	BIM standards support early involvement of suppliers, tradesmen and other stakeholders into the project design and development process.
	Integration of the construction team	BIM standards facilitate interactions between the construction team. Moreover, they also regulate and structure information sharing relationships between service providers.

Table 6:1 Implications of industry BIM process standards process standards on project execution activities

6.5 On the nature of knowledge flows and interactive learning processes

This section draws insights from research on innovation in construction and the SI concept, to explain that IT suppliers and standards developers have an influence in knowledge flows in construction as BIM process standards become integral to project delivery. In Chapter 2, Section 2.2.2.1, Figure 2.1 outlines the components and actors involved in the execution of project activities. The argument advanced here is that the model in Figure 2.1 should be modified to include IT suppliers and standards developers because of the functions they play in the delivery of projects using BIM process standards. The rest of the section examines why and how IT suppliers and standards developers are playing an important role in providing knowledge required to adapt process standards and to facilitate the delivery of construction projects. Thus, these new actors are transforming interactions within the construction innovation system. This is relevant to understand the nature of knowledge flow in construction as industry BIM process standards become integral to the digital delivery of projects.

6.5.1 Components and actors in the construction innovation system

Conco UK has identified that IT suppliers and SDOs are influential in the adaptation of BIM process standards. To gain knowledge about the new technology, Conco transforms its arm's length market based relationship to one where Conco UK becomes a test bed for the for Collabtec. That the PAS 1192:2012 embedded in digital collaboration technologies used in day-to-day project activities means that IT suppliers featured prominently in discussions of BIM process standards adaptation in Conco.

Despite that, the research shows IT suppliers are becoming influential; research on innovation in construction does not sufficiently address the functions of IT suppliers. The system of innovation view argues that interactive learning activities between firms are important for knowledge sharing (Lundvall, 2007; Fagerberg and Srholec, 2008; Dodgson *et al.*, 2011). Lundvall (2010) argues that feedback loops between technology suppliers and users perpetuate the process of innovation. Gann and Salter (2000) presented a model to outline the components that share knowledge in construction activities such as PBFs, supply networks, technical infrastructure, projects and the regulatory frameworks. Building upon these ideas, the research findings show that IT suppliers and standards developers play an important role.

In Conco, data analyses show that IT suppliers and SDOs such as Collabtec and BuildingSmart respectively, are involved in the customisation of collaborative digital tools to suit the requirements of project teams as well as aligning the technology to the industry standard. IT suppliers are involved in designing project information management systems; including the customisation and calibration of Collabtec to ensure the project team's information production efficiencies. Standards developers serve an important function by facilitating the impartation of knowledge about the standards to Conco UK's BIM implementation teams. Gann and Salter (2000)'s framework offers a high-level account of the components and actors without delving into the interactions between the actors in the construction innovation system. Figure 6.1 outlines a revised model of knowledge flow between components involved in construction activities. Figure 6.1 below revises the model presented in Chapter 2; Figure 2.1 to advance the view that IT suppliers and standards developers are important components in the flow of knowledge in the projects Conco is engaged. The modified model identifies IT suppliers, SDOs, universities, clients, product supply network, and construction firm as important actors with the construction innovation system.

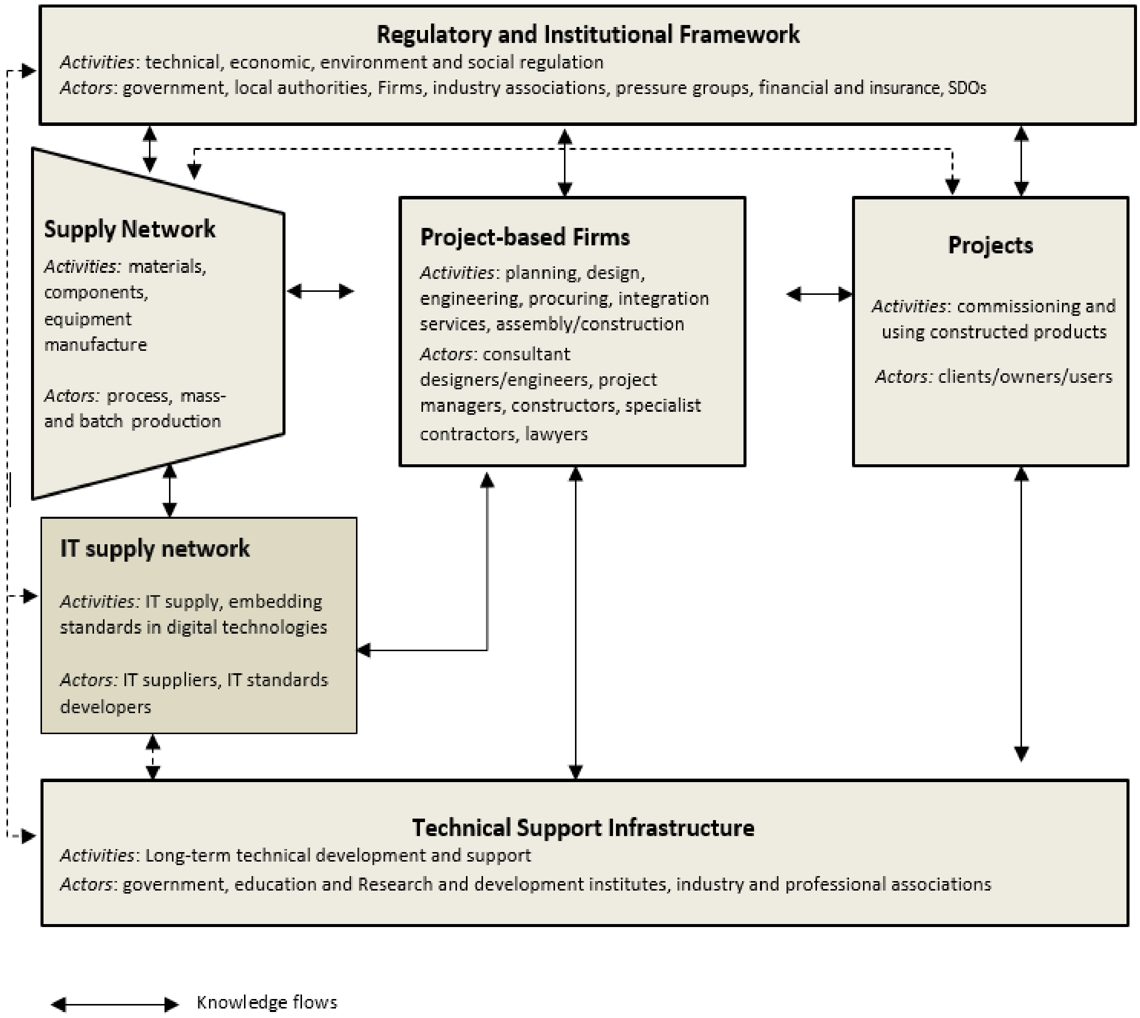

Figure 6:1: Framework showing interactive relations using industry BIM standards[109]

[109] This framework has been developed by the research from the framework presented in Gann and Salter (2000 p.960)

The involvement of IT suppliers and organisations such as BuildingSmart presents opportunities in the form of interactive learning and knowledge, financial sponsorship and leadership in standards development. However, negative consequences are that IT suppliers do not have sufficient capabilities to suitably address the needs of construction teams leading to some important sections of standards being left out as explained in Chapter 5, Section 5.3.2. This may explain the reason why Conco participates in the COBie trial project to contribute in the building of momentum required to influence the IT suppliers.

6.5.2 Knowledge flow and interactive learning processes

In Chapter 2, Section 2.2.2.2 it was explained that the PBF's resources are distributed between the project and business environment. In these multiple environments, Figure 2.2 outlined the nature of activities that the PBFs is engaged in. Gann and Salter (2000) argued that the ability to integrate project and business activities is important for the firm to achieve and sustain competitive advantage. Drawing insight from these ideas, it was suggested in Chapter2, section 2.2.2 that research has yet to address the fact that the firm and the project actors adopt industry process standards voluntarily. Therefore, adaptation does not only occur in that confines of the firm's sphere of influence but also in the project where the project actors may decide to adopt a different approach to the standard. In that situation, it is argued here that the nature of knowledge flows may change leading to transformations in knowledge sharing relations and interactive learning processes. Figure 6.2 illustrates the nature of resource flows between the firm and the project environment.

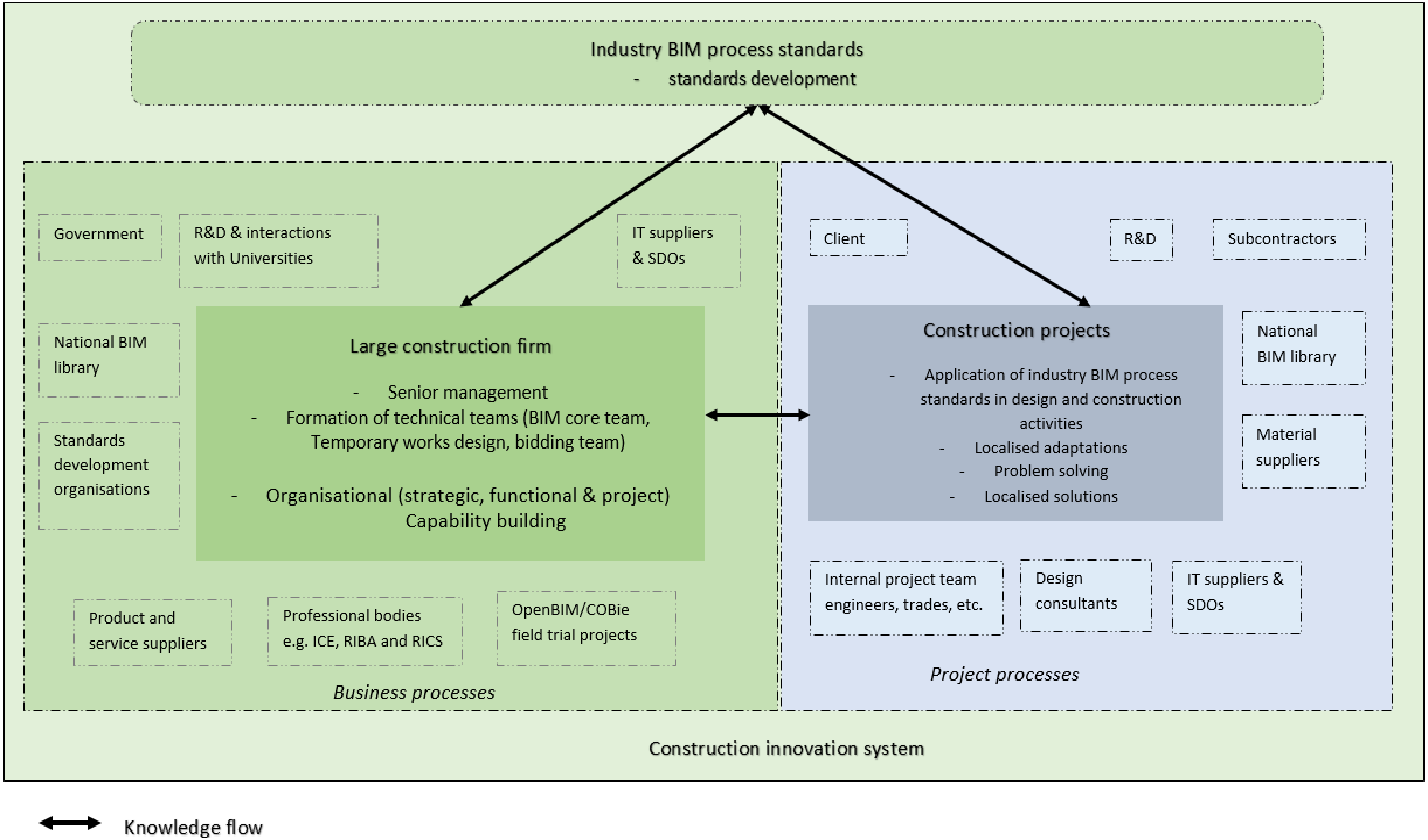

Figure 6:2 Knowledge flow and capability building in the adaptation of BIM process standards

As illustrated above, the nature of knowledge flow as BIM process standards are adapted has transformed with the inclusion of the IT suppliers and standards development organisations such as BuildingSmart. In Conco, data analyses shows that the BIM core has been central to the application of the technology. In addition to the technical teams such as the temporary works design team, the adaptation of the new BIM process standards has seen the BIM core team playing an important role in integrating knowledge from the projects into the firm's activities and into the developing standard. Hence, the BIM core team with its engineering and IT technical skills (Chapter 5, Section 5.4.2), the technical teams and the project teams through the design manager (Chapter 5, Section 5.5.3), have supported the development of integrated project delivery capabilities. In contrast to Figure 2.2 presented earlier in chapter 2, figure 6.2 shows that significant transformation have occurred with the firm being involved in interactions with IT suppliers, SDOs and being engaged in the COBie project. The study shows that these interactions are enhancing the ability to deliver construction projects. They also enhance the firm's ability to develop IPD capabilities at the operational level, even though there are impediments such as the resistance of some subcontractors to support the adaptation process.

6.5.3 Feedback in the development standards and project capabilities

Conco is not only improving its capacity to deliver projects; feedback from use is contributing to the development of BIM process standards. Scholars have argued that innovation in construction requires the management of the institutional environment, firm capability development activities and interactions with the systemic innovation environment (Miozzo and Bewick, 2002, Manley 2008). In the introduction chapter, it was suggested that a broader view to innovation is necessary in order to appreciate that innovation can occur in the adaptation of a new technology, which may contribute to innovations activities with the adopting firm. Figure 6.2 shows the recursive process of developing the standard and innovation in the development of project delivery capabilities within Conco.

6.6 Summary

This Chapter discussed the research findings in relation to the theoretical framework presented in Chapter 2, Section 2.5. The discussion highlights Conco's ability to improve the delivery of project activities even though there are pertinent challenges. There is need to acknowledge the influential role of IT supplier and standards developer in discussions of knowledge flow in construction; hence, Figure 6.2 outlines a new model to include these actors. The next Chapter concludes the thesis and examines the directions for future work.

Chapter 7: Conclusion

7.1 Introduction

This chapter concludes the study of industry BIM process standards adaptation in a large UK construction firm. It is structured as follows; section 7.2 revisits to the research aim and objectives to explain how they are addressed and section 7.3 explains the key contributions of the research. Section 7.4 explains the research's limitations, whilst section 7.5 identifies directions for future research. Section 7.6 concludes with the final remarks.

7.2 Research aim and objectives revisited

As mentioned in Chapter 1, research on innovation in the production of built environments addresses industry product and technical standards, and standards developed within firms, however industry process standards receive little empirical attention. Chapter 2 explained that the adaptation of industry process standards associated with the BIM process is gaining momentum with the UK government having to redefine its policy on construction. To address this problem the research investigates the adaptation of industry process standards in a large UK construction firm. The objectives of this research were: a) to establish the barriers and enablers of industry BIM process standards use within a large UK construction firm. b) to understand how new industry BIM process standards are adapted by a large UK construction firm in its projects, and finally c) to examine how the large construction firm's interactions with systemic innovation actors such as suppliers, universities and clients are transformed by the uptake of BIM process standards. The conceptual framework presented in Chapter 2, Section 2.5 was useful to make sense of the research findings. Table 7:1 below explains how the research objectives are addressed.

Research objective	How the objective is addressed in the research	Research finding	Interpretation of research finding
What are the barriers and enablers of new industry BIM process standards use within a large UK construction firm? (Objective 1)	The research investigates the adaptation of industry BIM process standards by a large construction firm.	Enablers • Industry BIM process standards application led to the creation of the BIM core team and the BIM strategy team (Chapter 5, Section5.4.2). • Engagement in industry level discussions supports adaptation (Chapter 5, Section 5.3.3). • Recruitment of multi-skilled professional that improved the adaptation process. (Chapter 5, Section 5.4.2). • A collaborative approach improves experience with BIM process standards, produces new knowledge about standards, which is important for project delivery (Chapter 5, Section 5.3.3) Barriers • Systemic nature of standards • Rapid changes to standards • Perception of standards	• Improving the firm's absorptive capacity is useful in the adaptation of an industry wide process standard (Chapter 6, Section 6.3). • Participation in standards development collectives is not only necessary in the development of standards; they are also important in the adaptation phase (Chapter 6, Section 6.3 and 6.5). • The adaptation of industry wide technologies is complex in construction because of the nature of contracts and the many players involved in the construction process (Chapter 6, Section 6.2 & 6.5).

		• Financial investment is required • Project based nature of construction means that enforcement of a particular technology is hard (Chapter 5, Section 5.4 & 5.5).	
How are new industry BIM process standards adapted in the projects of a large UK construction firm? (Objective 2)	The case study focuses on use of industry BIM process standards in operations (projects)	• The standards provide a digital collaborative common data environment (Chapter 5, Section 5.5). • Using BIM standards improves the capacity coordinate tendering activities (Chapter 5, Section 5.2 & 5.4.3). • Technical skills enhance the appeal to clients during the bidding process (Chapter 5, Section 5.4.3). • Technical skills in the use of industry BIM process standards accompanied by simulations of project activities helps to address design problems between designers, tradesmen and site engineers (Chapter 5, Section 5.5). • The standards improve the ability to integrate project delivery activities, which enhances the efficient use of resources (Chapter 5, Section 5.5.3).	• The use of industry process standards facilitates the development of integrated project delivery capability (Chapter 6, Section 6.4). • Whilst integrated solutions are a strategic capability for PBFs, industry BIM process standards help to support the development of integrated project delivery capabilities at the operations level (Chapter 6, Section 6.4).

How does the adaptation of new BIM process standards transform the construction firm's interactive relations with systemic innovation actors such as suppliers, universities and clients? (Objective 3)	The case study focuses on use of the implications of industry standards to the firm's interactions within the systemic innovation environment	• Strategic management intervention is directed at the creation of new teams and recruitment of multi-skilled professionals (Chapter 5, Section 5.4.2). • New interactive relations with IT suppliers and standards developers are forged (Chapter 5, Section 5.3.3.2). • Problem solving becomes more collaborative as the firm participates in industry level initiatives knowledge from the use of industry BIM process standards is important to continuously improve the standard (Chapter 5, Section 5.3.3 & 5.5).	• The adaptation of industry process standards necessitates transformation in interactive relations with some players in the systemic innovation environment (Chapter 6, Section 6.5). • The use of industry BIM process standards transforms the way the construction firm relates to its business environment. They lead to new ways of interaction that involve participating in industry initiatives (Chapter 6, Section 6.4). • Problem solving with support from the system becomes more collaborative (Chapter 6, Section 6.5).

Table 7:1 Summary of objectives and findings

7.2.1 Addressing objective 1:

What are the barriers and enablers of new industry BIM process standards use within a large UK construction firm?

This objective focused the barriers and enablers of industry BIM process standards in the large construction firm. To address the objective the discussions centred on the complexities, challenges, opportunities and hindrances encountered within the firm and in the projects. The research findings show Conco (the large construction firm) encounters many challenges such as a) the systemic nature of standards, b) rapid changes to standards, c) perception of standards, d) significant investment is required, and finally d) project based nature of construction means projects are often unique and involve different actors (Chapter 5, Section 5.4 & 5.5). The UK government as a key employer for Conco has mandated the use of BIM process standards, therefore to retain the key client, the firm has little choice than to adapt.

To address the above complexities Conco reconfigured its organisational structure, which saw the creation of the BIM core team and the BIM strategy team (Chapter 5, Section 5.4.2). Conco also engaged in industry level discussions (Chapter 5, Section 5.3.3), recruited multi-skilled professionals (Chapter 5, Section 5.4.2) and adopted a collaborative approach with some of its competitors, for example in the COBie standards project. Participating in the standards development initiatives confirms earlier work by Jakob (2006) that involvement in standards development is important. In the case of Conco, participation reduces resistance to change even though this does not completely solve the problem (Chapter 5, Section 5.3.3). This objective was important to articulate the complexities of adopting industry BIM process standards in the large UK construction firm.

7.2.2 Addressing objective 2:

How are new industry BIM process standards adapted in the projects of a large UK construction firm?

This objective sought to understand how industry BIM process standards are adapted in the projects of a large construction firm. To meet the objective the research focuses on the particular experiences of professionals involved in day-to-day activities within the firm's projects. The research findings show that BIM process standards facilitate the use of a digital collaborative common data environment (Chapter 5, Section 5.5). The common data environment streamline interactions between project team members, information exchange and communication activities. This improves the ability to realise production economies as double handling of information, time wastage and duplication of tasks is minimised especially between designers. Moreover, the use of BIM process standards enhances the ability to coordinate the activities of outsourced designers. Further still, the standards are used to coordinate the activities of project teams and central teams such as the bidding, and temporary works design teams (Chapter 5, Section 5.2 & 5.4.3). For example, design collaboration improved with the use of a web-based collaboration technology – Collabtec, which is embedded with industry BIM process standards. Coordination in addressing design problems between designers, tradesmen and site engineers improved (Chapter 5, Section

5.5). These findings show that industry BIM standards improve the ability to integrate and coordinate project delivery activities. Hence, their adaptation contributes to the development of project delivery capabilities.

7.2.3 Addressing objective 3:

How does the adaptation of new BIM process standards transform the construction firm's interactive relations with systemic innovation actors such as suppliers, universities and clients?

To address this objective, the research focused on the interactions between Conco, its product suppliers, clients, universities and subcontractors. This objective is important to explain the implications of adapting BIM process standards on the large construction firm's knowledge sharing interactive relations with actors in the construction innovation system. Drawing upon previous research on the systemic nature of innovation in construction (Miozzo and Dewick, 2004; Manley and McFallan, 2006), the study shows transformations in interactive relations with IT suppliers and SDOs. These actors gain prominence, and become important in the delivery of projects, because they are not only involved in the production of the standards and digital design tools, but they are engaged in making localised adaptations of the standards to facilitate their usage in projects. The knowledge possessed by the IT suppliers and SDOs consultants for instance improves the adaptation process and is used to address project specific challenges.

Consequently, Conco transforms its relationship with IT suppliers and SDOs so that feedback from BIM standards use is incorporated into the digital design and collaboration tools such as Collabtec. With the inclusion of these actors, information management activities in projects improve. This enhances Conco's to integrate the activities of designers and construction teams to solve design issues and to improve information sharing between them (Chapter 5, Section 5.5.3.2). The research does not confirm increased interaction with universities; however, there is a strong link between the firm and industry practitioners with extensive knowledge of BIM process standards such as standards development consultants (Chapter 5, Section 5.3.3.3). The research shows that clients influence the adaptation process by mandating the use of process standards. However, clients do not yet possess the technical expertise required to apply and exploit BIM process standards (Chapter 5, Section 5.3.3.1). These findings contribute to our understanding of the interactive relations and knowledge flow activities in the adaptation of BIM process standards in the production of the built environment.

7.3 Summary of key contributions

The research identified a limitation in the knowledge on the adaptation of industry process standards in construction. To address the limitation the study focused on the adaptation of industry BIM process standards in a large UK construction firm. The limitations of the contemporary literature on industry standards, PBF organisational capabilities and innovation in construction were discussed in Chapter 2. The research contributes to theory and practice as outlined below.

7.3.1 Contribution to theory

The research contributes to the literature on industry BIM standards, standards, PBF organisational capabilities and innovation in construction in the following four ways.

i) The research shows that by adapting industry process standards the large construction firm can enhance its ability to coordinate and control information production activities, integrate the activities of outsourced designers and support collaboration between centrally located and project teams. This improved the construction firm’s ability to realise production efficiencies and enhance project delivery capabilities. This aspect is seldom addressed in contemporary studies of industry process standards and PBF capabilities.

ii) The research contributes to the literature on innovation in construction by showing how interactive relations between construction systemic innovation actors are transformed by the adaptation of industry BIM process standards. The research shows the transformation occurring in the construction innovation system that saw IT suppliers and standards developers gaining more influence within the system, which makes it important for their inclusion in, and modification of the model presented by Gann and Salter (2000).

iii) The research contributes to the research on industry process standards and standardisation. It argues that industry product standards focus on modularity of products, and used to achieve production economies and manage quality. Technical standards focus on interoperability between technical systems. By examining process standards associated with BIM, the research has shown how this type of standards differs from other standards, and how their application control variations in human behaviour even though the standards may be embedded in digital technologies.

iv) Research on industry standards addresses the process of developing standards. The limited research that addresses standardisation from the user perspective does not address the link between industry process standards and the PBF organisational capabilities. By focusing on user-innovation from BIM process standardisation, the research shows how new industry standards alter the organizational structure, interactive relations in the construction innovation system and forms of organizing and delivering project activities.

7.3.2 Contribution to policy and practice

There is growing interest in BIM across the UK construction industry. The government and various other players at the national level has advocated for the use of BIM (Cabinet office, 2012, BIM Task Group, 2013, BIS, 2015). From a policy and practice perspective, this research is timely for the following four reasons:

i) As BIM increasingly becomes integral to delivery of projects, this study sheds light on the complexities surrounding the introduction of BIM process standards such as:

a) the need to understand the systemic nature of standards,

b) the need to understand the rapid changes to process standards,

c) the realisation that perceptions on BIM process standards vary,

d) the need to realise that there are significant investments required, and

d) the need to understand that the project based nature of construction means projects are often unique and involve different actors.

ii) Using industry BIM standards requires knowledge of digital design tools and engineering knowledge. This research contributes to practice by showing that in the large UK construction firm studied, effective use of new BIM process standards requires professionals with technical skills to assimilate valuable knowledge from interactions with IT suppliers, standards developers and other actors involved in construction projects (Chapter 5, Section 5.4.2.)

iii) For the large UK construction firm's managers, this research is particularly important because it provides a wide-ranging analysis of interactions of actors using BIM standards in different projects. It explains how industry BIM standards are an effective tool for managing digital interactions between professionals engaged in design, execution and delivery activities (Chapter 5, Section 5.5.3.2).

iv) The research contributes to practice by articulating how BIM process standards transform collaboration and the coordination of design and construction activities, integration of information production activities and cooperation in problem solving activities in the projects the firm is engaged (Chapter 5, Section 5.5.3).

7.4 Research's limitations

The research used an interpretive and case study strategy to investigate the use of new industry BIM process standards in a large UK construction firm. As explained in Chapter 4, Section 4.4, the qualitative approach is useful in identifying new relationships between constructs. A naturalistic approach is appropriate for research of this nature so that a detailed understanding of the implications of industry BIM process standards is developed. However, naturalistic inquiries focus on a limited group of participants in a particular setting. Therefore, there are limitations in terms of the generalizability of research findings. The generalization of the findings to a wider population is thus problematic. To address the generalizability of findings, this research used a case study design, appropriate sampling techniques, employed multiple data collection methods, and thematic data analysis technique. This approach to data collection makes theoretical generalization possible as argued in Chapter 4, Section 4.9.

Apart from the research methods limitations, industry BIM process standards are undergoing rapid changes as more users begin to embrace them. Since 2008, BIM process standards have received extensive revisions; consequently designing a study to examine them has been complex and challenging. For instance, at the end of 2014 the PAS 1192 standard had been revised three times since January 2012. This means that the research can only provide of a snapshot at a particular point in time, about a specific large UK construction firm – Conco. However, as suggested by scholars of industry standards such as Lampland and Star (Lampland and Star, 2009), Tassey (2000), Blind (2006) and Swan (2010) to mention but a few, this is to be anticipated because standards are always undergoing changes due to the multiple stakeholders.

7.5 Directions for future research

This research is limited to the activities of one large construction firm, in the UK at the particular time when the study was undertaken, hence it is difficult to generalize across the many construction firm sizes at different ages and stages of growth that are engaged in the adaptation of industry BIM process standards. This could be addressed in future studies by expanding the research and testing its findings in different sizes of firms of varying stages of growth and age. For example, small and medium size firms are not addressed in this research. Such firms may have a different approach to BIM standardisation.

This study has raised important issues about the systemic nature of industry BIM standards. For instance, there is a strong relationship between the COBie standard, the IFC standard and the Uniclass standard, which were not addressed. This could be a potential focus area for future studies to understand how the links between these standards may influence the adaptation of standards.

This research has also raised important points about the interactive relations in the construction innovation system. The research has shown that there are opportunities in the development of project capabilities through BIM process standards adaptation. For the innovation in construction scholar, there is an opportunity to understand how these capabilities are shaped by rapid development of standards, and how construction firms addresses such dynamics. The research raised important issues that require management such as inertia at the project and business levels. Further research could examine how other firms engaged in construction address this problem. Such research could be important to advance new understandings of the way industry standards may be exploited in temporary construction settings.

7.6 Concluding remarks

The introduction and subsequent employment of BIM process standards is widely considered useful in progressing innovation and competitiveness in the UK construction industry. This research explored how a large UK construction firm experiences the adaptation of industry BIM standards. Drawing upon theoretical ideas and notions about industry standards, innovation in construction, and PBF organisational capability development, the research highlights the complexities of adapting industry wide process standards and how the large construction firm responds. For the large construction firm, using new industry BIM standards, the study articulates the potential complexities and benefits. The study shows that localised adaptations are often necessary to exploit the industry BIM process standards, however, the firm must also deal with internal challenges, and resistance in the projects where the firm has limited influence over project stakeholders.

This may become an issue where the project stakeholders have little interest in the industry process standard. A failure to establish and support a coherent interpretation of the standard within the business may have implications on the way projects adapt the industry standards. This can have implications on the large construction firm's ability to adapt and develop specific skills, competences and capabilities.

As BIM process standards continue to draw more attention from practitioners, policy makers and academics, there is need to build a better, evidence based understanding of how industry process standards influence the economic activities of firms that produce the built environment. This research has shown how industry process standards associated with BIM influence the firm's business and project processes. The challenges faced by the construction firm became illuminated, as the BIM process standards are applied. Despite the drawbacks noted, this research shows that there is an intricate relationship between industry process standards and capability development in the large construction firm. This is becoming an important area for academic and practitioner attention, as industry BIM process standards become integral to the delivery of the built environment, and as governments make BIM compliance a mandatory requirement in public contracts.

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Appendices

University of Reading

Appendix A: Research information

Design Innovation Research Centre
School of Construction Management and Engineering

PhD research: BIM process standards in large UK construction firms

Research Team	Energy Maradza; Prof Jennifer Whyte and Dr Graeme Larsen.
Data collection programme	Project: 16 October 2013 – 15 October 2014 (12 months)

Aim

To investigate how the use of industry BIM process standards influences the capabilities of large UK construction firms

Background

Building Information Modelling (BIM) is a process for managing the design, construction and maintenance of built assets. BIM is an amalgam of many sets of process standards that facilitate its use by practitioners. This research investigates the role of such BIM process standards in shaping the capabilities of construction firms that use these standards to deliver complex construction projects. At a time when the UK government is mandating the use of BIM by 2016, this study provides empirically based framework for understanding how BIM standards shape innovation and competivity in UK construction. This study advances practice and theory on the management of innovation in construction firms by focusing on the implications on the creation and exploitation of resources and capabilities.

Research objectives

1. To understand the implications of using industry BIM process standards on the construction firm's interactions with the systemic innovation external environment
2. To investigate how the use of industry BIM process standards influences the construction firm's strategic capabilities.
3. To understand the implications of using industry BIM process standards on the construction firm's functional and project capabilities

Data collection, Sample and analysis time scales

- (Sept – May 2014): Data collection (Interviews, Observations and publications from firms, data analysis, reports and dissemination of findings to participating firms)

- ***Strategy:*** A single construction firm has been selected for a detailed study. The firm is expected to have implemented BIM and participating in some of the government sponsored BIM trial projects. *Interviews* and *participant observations* will be used. *Secondary documentary evidence* will be used to gather data about the firm. Interviews will last no more than 1hour and a semi structured interview protocol is attached.

Expected results

- Academic and industry conference presentations
- Academic and industry journal and conference publications
- PhD thesis

Resources requested

1. Access to interview and shadow participants in project meetings and interview designers, engineers, managers and directors.
2. Access to publications about the firm as press releases and internal declassified publications.

Research ethics

Interviews will be taped and transcribed with participant's permission. Participants can choose not to answer any questions and /or not to participate in any phase of the research. They can withdraw from the study at any time. Their personal identity and information will remain confidential to the research team. The data will be kept securely on a university server and destroyed in accordance with higher education best practice and will be used for academic purposes only. This project has been subject to ethical review, according to the procedures specified by the University Research Ethics Committee, and has been given a favourable ethical opinion for conduct. Copies of the completed publications will be made available on request.

Contact information

For more details please contact Energy Maradza, [redacted] ([redacted]) and Professor Jennifer Whyte, Director, [redacted] ([redacted]). [redacted].

Appendix B: Ethics approval and consent form

BIM process standards use in a large UK construction firm

1. I have read and had explained to me by **Energy Maradza** the Information Sheet relating to this project and any questions have been answered to my satisfaction.

2. I understand that my participation is entirely voluntary and that I have the right to withdraw from the project any time, and that this will be without detriment.

3. I understand that my personal information will remain confidential to the researcher and their supervisors at the University of Reading, unless my explicit consent is given.

4. I understand that my organisation will not be identified either directly or indirectly without my consent.

5. I agree to the arrangements described in the Information Sheet in so far as they relate to my participation.

Signed

Print Name

Date

Appendix C: Record of interview participants

Phase 1 Key informants

Interview participant code	Participant job	Interview location	Date & time of interview	Interview duration
X01.12	Design Manager, UK	Basingstoke	09/08/2012 @ 11am	67 mins
X02.12	CAD Standards Developer, UK	Telephone	16/08/2012 @ 9.30am	65.30min
X03.12	Software developer, UK	Skype	28/08/2012 @ 3pm	45 mins
X04.12	Standards Developer, UK	ICE HQ, London	23/03/2012 @ 12.45pm	50 mins
X05.12	BIM standards research and development consultant	Skype	31/08/2012 @ 8pm	39 mins
X06.12	Standards Developer, UK	Telephone	19/04/2012 @ 3pm	42 mins
X07.12	Standards Developer, UK	Telephone	01/03/2013 @ 3.30pm	50.06 mins
X08.12	BIM Manager, UK	BIM Academy, Northumbria University	06/09/2012 @ 1pm	38 mins
X09.12	BIM Standards developer USA based	Skype	11/09/2012 @ 1pm	34.40min

Phase 2 Case study interviewees

Interview participant Code	Participant job	Interview location	Date & time of interview	Interview duration
X10.13	BIM manager	Head office – Core BIM team	21/10/2013 @ 10.30am	76 mins
X11.13	BIM modeller	Head office – Core BIM team	25/11/2013 @ 11.00am	104 mins
X12.13	BIM modeller	Head office – Core BIM team	02/12/2013 @ 10.15am	104 mins
X13.13	BIM modeller	Head office – Core BIM team	06/12/2013 @ 9.45am	124 mins
X14.14	Site based BIM modeller	Project based – East London rail station upgrade	04/02/2014 @ 10.40am	125 mins
X15.14	Section Engineer	Project based – East London rail station upgrade	14/02/2014 @ 12.08pm	38mins
X16.14	Senior Engineer	Project based – East London rail station upgrade	14/02/2014 @ 13.10pm	45 mins
X17.14	Senior Engineer	Project based – East London rail station upgrade	14/02/2014 @ 14.15pm	48mins
Group discussion	Site engineers (2), Engineering assistant (2), Site Foreman (1), Document manager (1), BIM modeller (1)	Project based – East London rail station upgrade – Canteen over Friday breakfast	14/02/2014 @ 11.18am	35mins
X18.14	Design meeting	Manchester Project	06/03/2014 @ 11.00 – 15.43 am-pm	120 mins
X19.14	Design Manager	Manchester Project	06/03/2014 @ 13.30pm	25 mins

X20.14	Structural engineer	Manchester Project	06/03/2014 @ 13.58pm	12 mins
X21.14	Structural engineer	Manchester Project	06/03/2014 @ 14.20pm	18 mins
X22.14	Lead architect	Manchester Project	06/03/2014 @ 14.50pm	15 mins
X23.14	Landscaping architect	Manchester Project	06/03/2014 @ 13.15pm	5 mins
Group discussion	Design Manager (1), Architect (2), Structural & Electrical engineers (3), BIM modeller (1)	Manchester Project	06/03/2014 @ 15.30 – 15.43pm	13 mins
X24.14	Design manager	Project based – Central London rail station upgrade	06/03/2014 @ 15.30pm	70 mins
X25.14	Engineering Director	Management	18/08/2014 @ 9.30am	64 mins
X26.14	Permanent works Manager	Management	18/08/2014 @ 11.00am	48 mins
X27.14	Section engineer	Project based – Central London rail station upgrade	21/08/2014 @ 13.30pm	50 mins
Group discussion	Site engineers (3), BIM modeller (1), Section engineer (1), Surveyor (1), Junior site engineer (1)	Project based – East London rail station upgrade	21/08/2014 @ 15.30pm	25mins
X28.14	Project Manager	Project based – Central London rail station upgrade	28/08/2014 @ 13.30pm	52 mins

Appendix D: Profiles of key informants

Key informant code	Brief profile	Professional background/	Type of employer	Experience (Years)
X01.13	He has been involved in implementing BIM process standards in one of the largest UK construction firms (by turnover). He has qualification in information systems management and civil engineering. In 1995, he moved into design and construction management. He has developed customized solutions to support BIM process standards implementation in design and construction activities. He has been involved in various UK wide BIM process standards implementation initiatives.	Civil engineer, Project manager and information systems engineer, BIM development manager	One of largest construction firm in UK by turnover	18 years
X02.13	Recently retired. Began career in 1969 with a renowned construction firm. Initially involved in the development of 3D models and standards. Participated in the development of the STEP standard and various CAD standards in the early 1980s. Contributed to government BIM policy formulation.	Retired structural engineer, CAD Standards developer	Construction design consulting firm	45 years

X03.13	He has been involved in the development and implementation of CAD standards since the early 1980s. He has also development some of the early 3D modelling software. He has contributed to the formulation of the government policy on the use of BIM process standards in UK construction.	Civil Engineer, later trained as a software engineer, Managing director, CAD and BIM software consultant, BIM process standards developer	One of the largest property development firm in the UK by Turnover	40 years
X04.13	Began his career in 1972. Worked for a large UK construction firm for 32 years, before becoming an independent consultant. He was involved in one of the largest airport construction projects the UK has ever seen. Was involved in the Avanti programme a precursor to the PAS 1192 standard. Committee member of Construction Project Information Committee (CPIC), the industry group, and has authored or co-authored two CPIC guides, one on Production Information and one on Building Information Management. Heavily involved in government BIM strategy formulation. Remains involved in a number of initiatives aimed at BIM standards development and implementation in the UK	Information systems manager, BIM process standards developer, visiting professor at researcher's University	Standards development consultant firm	42 years

X05.13	She qualified as an Architect in 1990. She provides consulting and training services in the area of computer-aided building design. In the year 2000, she acquired a PhD in Architecture. She works as an independent construction management consultant. She is also a researcher in both the UK and the USA, and edits an online publication that has been researching, analysing, and reviewing technology products and services for the building industry since its establishment in 2003.	Architect, BIM standards researcher, construction management consultant	Architectural consulting firm	24 years
X06.13	She is programme manager at a leading British standards organisation. She is involved in the coordination of experts involved in the process of creating standards. She represents the UK's interests in international standards development organisations. Recently she has been involved in organizing national and international BIM process standards development initiatives.	Standards development consultant	Standards Development Organisation	18 years
X07.13	He qualified as an architect and currently leads a software development firm. He has been involved in the development of IFC applications based on model server databases, XML/XSL developments, the XML Schema Development (XSD) standard and CAD implementations. He contributed to the BS1192:2007 standard, the	Architect, BIM process standards consultant	Construction firm and independent consulting services	32 Years

	precursor to PAS 1192 (1-4) standards for managing BIM information. Contributed to UK government BIM policy formulation.			
X08.13	He studied building and construction management and is a holder of a PhD in knowledge management in construction firms. He has been heavily involved in adopting and implementing BIM in his organisation. He works for one of the largest construction firms in the UK. He has also participated in the development of BIM process standards and regularly presents case studies of use in his firm at industry conferences.	Structural engineer, Building and construction management, BIM manager	One of the largest construction firms in the UK by turnover	27 years
X09.13	For 32 years he worked as an architect with a government agency, before beginning starting a career as standards consultant. He has been involved in various capacities in the development and implementation of BIM process standards particularly in the USA. At present, he is an executive director in one of the internationally leading CAD standards development organisation.	Architect, BIM process standards consultant	Consultant for several large design and construction firms, government agencies and local authorities in the UK and USA	40 years

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Appendix E: Sample Aide Memoire – Preliminary industry study

Industry BIM process standards in the UK construction industry

First of all, Could I please record this discussion?

Experience, role and responsibilities

Tell me about your work and role in the firm?
What do you do as a business?
Which organisations do you work with on the projects you are involved? Please provide example(s)

BIM experience
What is your opinion on BIM?

BIM standards experience
Can you explain the BIM standards you are familiar with?
Have you been involved in the development of these standards?
What physical and digital resources do you require to utilise the standards?
In what ways have the COBie and PAS 1192 standards specifically affected your work? With reference to:

BIM implementation
Project work coordination?
Information exchange in the project?
Communicating with work colleagues?
Training?
Please cite example(s)

The firm
Do you think your firm is influencing you in the way you use these two standards? Examples

What has been the involvement of the following organisations in your use of these standards as a business? Give examples of their involvement?

University of Reading

Universities?
Research consultants?
Government?
Suppliers?
Owners?
End users?

Project specific uses
Please describe for me how you are accessing, storing and retrieving digital design information in your current project?
Do you think these standards are affecting your ability to improve your technical skills?
Do you think the people in your organisation fully understand BIM standards?

Thank you for your time, please call me if you have any future questions or concerns. I will email you a transcript of our discussions for your comments if you wish.

Appendix F: Case study interview protocol

Design Innovation Research Centre

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Interview Protocol

The use of industry BIM standards in a large UK construction firm

First, can I record this discussion?

1. Tell me about your firm, your role and responsibilities?
2. Can you identify the types of projects on which you are using BIM standards as a firm?
3. Can you describe how you have enacted the requirements of the BS 1192: 2007/ PAS 1192: 2012 standard in the projects you are involved?
4. Can you explain to me how the use of the COBie and PAS 1192:2012 standards to manage and share information is affecting your relationship with the following in the projects you are involved in?
    a. Clients
    b. Subcontractors
    c. Suppliers
    d. IT suppliers
    e. Standards developers
    f. Universities
    g. Professional bodies
5. How does the use of the PAS 1192: 2012 affect your interactions with new and existing clients?

6. Can you describe how you ensure that all your project information is synchronised and kept up-to-date?

7. Can you describe for me how the use of BIM standards has affected your technical skills in accessing, storing and retrieving project information?

8. Do you think your firm is realigning its project management protocols with the industry wide BIM standard processes? Please cite examples

9. How does working in a BIM environment affect your ability to delivery projects on time and to budget? Please cite examples

10. In the past three months, have you attended any BIM related internal or external events? (Where and what was the context of the discussions in the event?)

11. Do you think the 2016 government BIM deadline has any effects on the approach taken by your firm in relation to BIM standards use? (Any specific examples?)

Note: Participant is shown or a description of the Gann and Salter's (2000) model of knowledge flows in construction is provided. A discussion ensues about the interactive relations and information sharing activities with the actors identified in the model.

Thank you for your time, please call me if you have any future questions or concerns. I will email you a transcript of our discussions for your comments if you wish.

Appendix G: Publication: Journal of the National Institute of Building Sciences

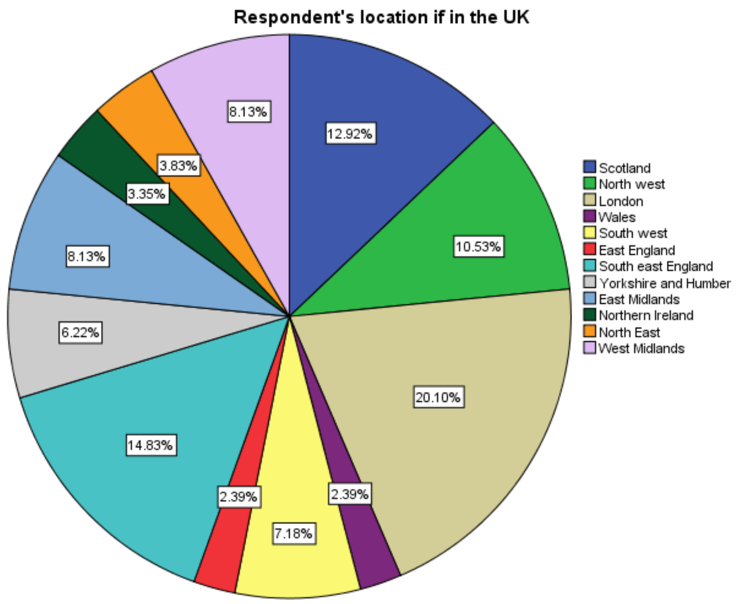
BIM awareness and implementation patterns in the UK construction

1. Introduction

Although the awareness and use of BIM in the Government of the United Kingdom (UK) construction sector is growing (BIM Task Group, 2012), there has been limited work in mapping BIM understanding, benefits appreciation and use patterns across the UK's geographical regions, contract sizes, job roles and the many different sectors. Engaging with professionals and providing them with tailored support during BIM implementation is not only important for professional bodies in the UK, but also for firms and organisations adopting BIM. Recognising this, a leading engineering professional body based in the UK through its BIM implementation group and in discussion with the BIM Task Group conducted a BIM survey across its world regions. The results below provide an interesting account of the variations in BIM understanding and use across the construction sector.

The purpose of the BIM survey was to investigate levels of BIM awareness, benefits appreciation, implementation patterns and support requirements across the professional body's global membership. Of the 279 participants that randomly took part in the survey, 209 were from the UK. Results presented in this paper focus on the UK participants only. The data analysis focuses on variations in participant's responses by contract size, geographical location, sector type and job role. A descriptive analysis of the participants by geographic location is presented in Fig 1 below.

Figure 1 - Geographic distribution of participants



2. BIM understanding, use, benefits appreciation and support requirements

There is a growing understanding and implementation of BIM in the construction sector. 56% of the participants indicate that their organisations have begun to implement BIM (See Fig 2). Below is a list of some of the key findings on the levels of BIM standards awareness, understanding and benefits appreciation.

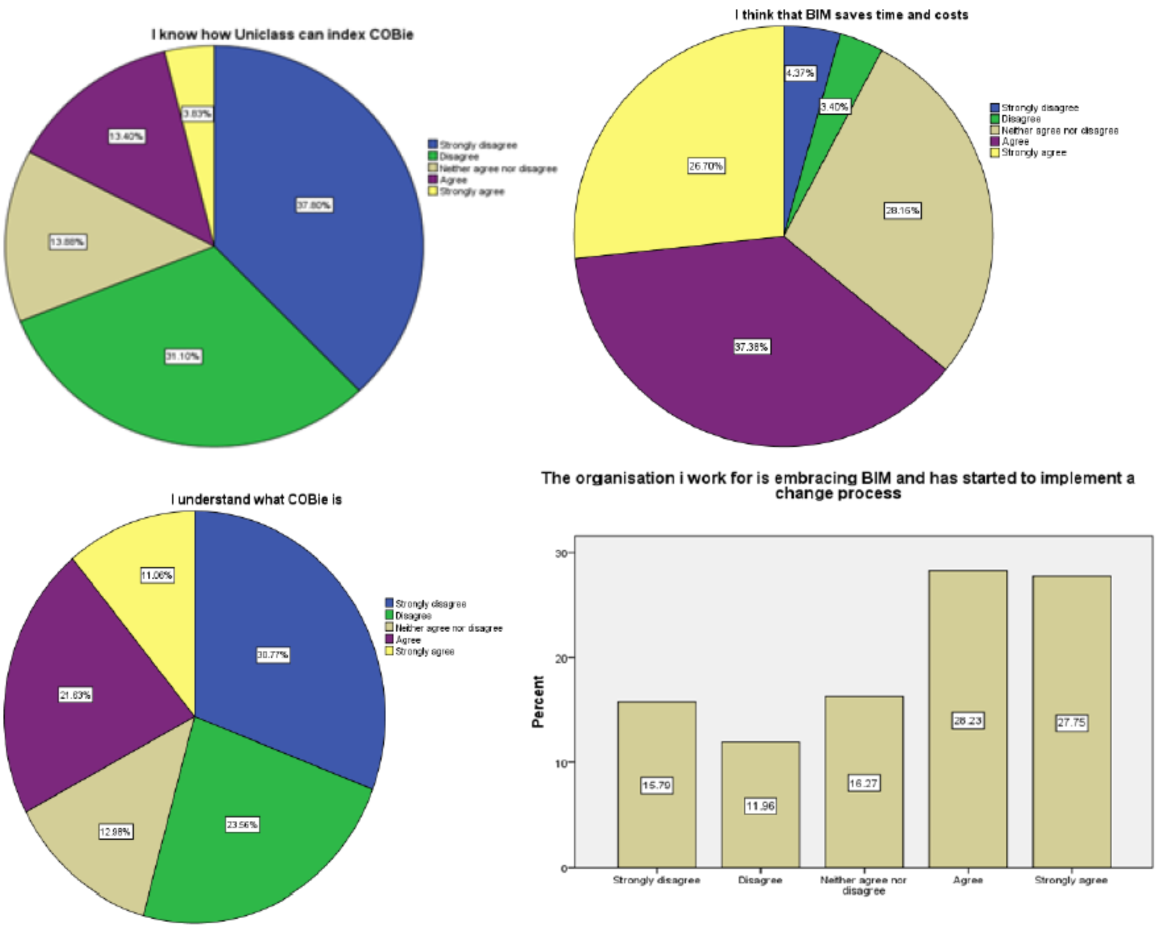
i. Managers and directors responsible for one or more projects have a better general understanding and awareness of BIM and its benefits than junior engineers.

ii. High levels of awareness and benefits appreciation among professionals throughout the UK (64% of participants either agree or strongly agree that BIM saves time and costs).

iii. The integration of BIM into internal management processes remains significantly low (Only 14.8% of the participants agree or strongly agree that BIM is helpful in checking compliance).

iv. There is less use of the COBie standard (69% either strongly disagree or disagree with the question: *I know how Uniclass indexes COBie*).

Figure 2 – Analysis of responses from survey



3. Conclusion

The survey shows a general level of engagement and appreciation of BIM across the UK construction sector. There are variations in BIM use across the different geographical regions and professional job roles. Moreover, there are less significant differences between firms involved in single and multiple sectors. Levels of BIM awareness and use vary significantly between engineers based on and offsite, senior managers and directors. In addition, findings suggest that project size and involvement of a firm in single or multiple sectors does not significantly affect BIM awareness and use.

The UK government has a target to implement BIM on public contracts by the year 2016 (Office, 2011). If this target is to be realised, firms will be rapidly embracing this standard process of managing information during the delivery of built assets. The results from the heat map survey have shown that BIM is in use across different contract sizes. Only 8% of the participants are involved in small contracts (contracts less than £5m). As design and construction activities increasingly get interdependent and executed by dispersed project teams, public and private organisations investing in BIM may seek to make use of such heatmap surveys to inform their strategic adoption and use of BIM.

4. Acknowledgements

The author would like to acknowledge the support provided by members of the ICE's BIM Action Group and the BIM Task Group, and for the constructive feedback during the preparation of the manuscript.