Organizing for technology in practice: implementing Building Information Modeling in a design firm

The Bartlett School of Construction & Project Management,

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Bethan Morgan, February 2016

Declaration

I, Bethan Morgan, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed:

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Preface

My decision to embark on doctoral studies was guided by a number of factors. Foremost it provided an opportunity to explore a series of "perplexing questions" that I had experienced in business (Cuff, 1991). Having worked in the construction industry in the UK for some time, I frequently witnessed its resistance to change and the substantial gap between policy aspirations and the realities of daily work. The current struggle to implement Building Information Modeling (BIM) in the industry exemplifies this.

Undertaking doctoral studies offered an opportunity to develop focused expertise in one area. In my experience, such opportunities are lacking in business, where the ability to juggle multiple demands for time and attention takes priority. While this is undoubtedly an important skill, it provides limited opportunity for developing detailed understanding in any given domain.

I was also interested in developing expertise in research methods. During my early career I worked for firms that place great value on research - DEGW and Arup. I consequently benefitted from a number of opportunities to participate in business-led research. I consolidated these experiences recently, while working for Constructing Excellence, where I undertook a number of research projects with business, policy and academic bodies.

During these projects, I recognized (in myself and others) a lack of understanding about how rigorous research should be conducted. While the construction industry was waking up to the value of research - to the need to base decisions on robust evidence – all too often decisions were made based on evidence that was not dependable. In order to increase the quality of research undertaken in the industry, the methods used to conduct research – particularly in collaboration with academia - needed to be improved.

Some 10 years ago I undertook a Masters in Business Administration, during which time I gained a broad understanding of management and organizational literature.

However I observed that much of it originated from the industrial, manufacturing organization. Management literature often did not fit with my experiences working in the construction industry in professional service, project-based organizations. My master's dissertation provided some opportunity to begin exploring alternative perspectives of management in professional service firms. In undertaking this PhD I was able to develop this research interest further.

During the PhD, the greatest challenge for me has been incorporating theory well and appropriately into my studies. On starting this thesis, understanding the role of theory in academic study, while becoming familiar with the content, seemed a daunting task to me. Over the course of this study, my perceptions of theory have shifted. As data collection commenced and I became more familiar with theory, I moved to seeing it as an invaluable source of useful frameworks and concepts, to viewing theory as a body of knowledge to which I could make valuable contributions.

The process of data collection was instrumental in changing my perception of theory. I felt confident during this phase – although the activities I was undertaking were new, I was carrying them out in a familiar setting. The findings that emerged during data collection resonated with a number of theoretical constructs. This realization helped me to ground my research in theory. I ensured that the relationship between theory and data was close, iterating between the two to refocus data collection or pursue new research streams. The volume of data I was collecting and the quantity of existing and new studies in the broad research area of technology and organizations made this more challenging than I anticipated.

Constant dialogue played a vital part in this process. Conversations with experienced academics and practitioners, working in a diverse range of areas, along with skillful guidance from my supervisors, helped me understand my data. These conversations happened through formal and informal conversations, through presentations at academic conferences and attending relevant events and conferences.

In this study I am researching the implementation of BIM. This has the advantage of being a contemporary phenomenon thus offering the opportunity to observe in real time how BIM is being used "at the coalface". However it also presents a substantial challenge in keeping up-to-date with developments in BIM. The volume of new practitioner and academic studies, conferences and applications of BIM is tremendous. I had to balance the need to write this study with attempts to sift through, digest and reflect upon emerging information.

As with much research, in addressing this study's research questions a greater number of questions have been generated. These are theoretical and methodological. They relate to organizing for implementation and undertaking collaborative process research with business. In keeping with the original goal of this research, a number of practical recommendations emerge that should help improve the construction industry's ability to implement technologies.

Abstract

This research examines how technologies are implemented in firms. As the rate of technological change increases, the ability of firms to implement technologies effectively is increasingly important. By adopting a practice perspective of implementation, this study generates insights that contribute to our theoretical and practical understandings of the process of implementation.

Specifically, it is guided by two research questions, which are:
a) How do organizational routines and practices influence processes of technological implementation in firms? And
b) How can firms organize for technological implementation in complex operations?

This study draws on data collected about the implementation of one technology in the construction industry. Specifically it studies contemporary attempts to implement Building Information Modeling (BIM) in a large design firm working in the industry. An embedded, longitudinal case study is developed to describe the process of implementation at multiple levels, including individual actors, firm and institutional.

A process model of technological implementation is derived from the data. This conceptual circular model identifies four stages in an iterative implementation process, comprising preparing, forming, enacting and reflecting. The source of generative change in the process is organizational routines, which are created and adapted during implementation. The relationship between practices and routines is unpacked, and illustrated by applying the conceptual model to a project in the construction industry.

In taking a practice perspective of implementation, it is seen as an iterative and continuous process rather than a linear and finite one, as suggested in a number of past studies (Leonard-Barton, 1998; Tyre and Orlikowski, 1992; Edmondson et al,

2001). This indicates that in the present-day, firms are constantly undergoing processes of technological implementation, at varying rates and stages.

This research generates insights into organizing for implementation. It suggests that firms play a key role in enabling implementation, despite viewing it as a user driven process. In organizing for technological implementation in complex operations, activities occurring at firm and practice level should be aligned. The role of the firm is to create an "infrastructure of support", changing and being changed by the actions of internal actors and seeking to influence external institutions on their behalf.

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1. Overview

This thesis explores the implementation of Building Information Modeling (BIM) in firms working in the construction industry. Technological implementation is a crucial process for this industry. Unlike manufacturing industries, construction does not generally create or invent new technologies but usually imports generic ones (Whyte, 2013, 2003; Pavitt, 1984). These generic technologies have similar but not identical applications across different sectors and industries (Rosenberg, 1963). This is the case with BIM, which draws on parametric technologies that have been widely used in other industries since the 1980s (Eastman, Teicholz and Sacks, 2011).

Despite its significance, technological implementation is a problematic process for the industry and its firms. For example, studies of the adoption of CAD in the late 1990s showed uptake was unexpectedly slow (Bouchlaghem and Liyanage, 1996). Firms efforts to implement ICTs resulted in “islands of automation” rather than full integration (Salter and Gann, 2003). The most recent ICT to be introduced to the industry, BIM, follows this slow rate of adoption (Bew and Underwood, 2010). Early attempts to use BIM date from 2000 (Grilo and Jardim-Goncalves, 2010). Some 16 years later, the industry is struggling to achieve the government mandate for public sector projects to be carried out using BIM Level 2 by 2016.

Given technological implementation is a critical process for the construction industry, why is it so poor at it? An early attempt to use BIM, dating from 2002, provides some answers to this. Avanti, a collaborative action-research project, demonstrated the substantial potential that BIM held for improving the products and processes of UK construction industry. However, it also confirmed the scale of the disruption that BIM-enabled working would bring. It became apparent that while the software required substantial learning, integrating the technology with the complex, interdependent work of the construction industry posed a huge challenge.

The disruption created by technological change seemed particularly problematic for firms working in the industry. These firms struggle to implement technologies effectively, where the outcome of technological implementation is often far removed from the benefits envisaged (Salter and Gann, 2003). Research identifies a number of barriers to implementation at firm level - a lack of organizational learning, resistance amongst senior staff in using new technologies, and that the rapid rate of obsolescence of technologies deters investment and adoption (Gann, 2000). At managerial level in firm a mismatch between investment and broader corporate strategy impeded implementation (Currie 1989). A lack of end user involvement also impedes the implementation process (Whyte, 2002).

Valuable insights in our understanding of technological implementation in the construction industry have been generated by a number of recent practice studies Such research focuses on how technologies and wider digital infrastructures are used, thus revealing the reality of how technological work is performed in the construction industry (for example Whyte 2013; Harty and Whyte, 2010; Whyte and Lobo 2010; Harty 2005). Studies of digital infrastructure, including BIM, show that individuals juggle multiple and often conflicting demands at work (Dossick and Neff, 2010). Together these studies emphasize the substantial gap that exists between intended and actual uses of technologies (Harty and Whyte 2010; Whyte and Lobo 2010).

These practice studies offer a promising alternative perspective to view implementation in firms working in the construction industry. They draw attention to the context of action; therefore multiple levels of analysis are significant. By focusing on how technologies are used at work, they shift attention to the heterogeneous and complex practices that constitute the industry and away from recent homogeneous policies (Whyte and Sexton, 2011).

This study builds on such studies, and develops a longitudinal case study of the process of implementation in one firm. The case explores this process in multiple embedded levels of individual actors, firm and industry, using a sociomaterial perspective that views technology and organization as represented in an

assemblage of actions. This approach is used to address this study's research questions of:
a) How do organizational routines and practices influence processes of technological implementation in firms? And
b) How can firms organize for technological implementation in complex operations?

The case developed describes the process of BIM implementation at a design firm working in the construction industry, referred to in this study as Design Partnership. This firm is a large, established organization providing multidisciplinary design services in the construction industry in the UK and globally. As the case studies contemporary attempts to implement BIM, implementation can be viewed from a practice perspective, recording situated actions carried out at work at Design Partnership. Multiple levels are studied in this longitudinal process in order to study implementation embedded in a wider "ecology of practice" (Harty and Whyte, 2010).

The findings of this study are presented in three parts. First, a phased longitudinal study of BIM implementation at Design Partnership is described, using retrospective and contemporary data to build an embedded picture of implementation between 2000-2015. Second, recent practices enacted during technological implementation are discussed and their relationship with routines described. Third, different approaches to organizing for technological implementation are considered with reference to the longitudinal process model.

From these findings a number of contributions are derived. An alternative process view of the nature and form of technological implementation in firms is presented. I propose that this is an iterative and continuous process rather than a linear and finite one, that moves through four stages of implementation: preparing, forming, enacting and reflecting. Organizational routines are the source of this generative change. The relationship between practices and routines is unpacked by applying the conceptual model to a project in the construction industry.

I find that the firm plays a key role in enabling implementation, despite viewing it as a process led by users of BIM. My data suggests that in organizing for technological implementation in complex operations, the relationship between firm and users of BIM is interdependent. The role of the firm is to create an "infrastructure of support", changing and being changed by users' of BIM[1] evolving practices and routines and seeking to influence external institutions on their behalf.

Returning to the empirical origins of this study, I draw out a number of recommendations for managers and policy makers working in the construction industry. Overwhelmingly, they should attend to actors' use of BIM – their evolving practices and routines - in attempting to accelerate technological implementation. By doing so, variation in heterogeneous practices will become apparent. Normative advice for possible responses to this variation is grounded in the need and potential for the construction industry to develop much-improved capabilities in technological implementation.

1.2 The role of theory

Theories drawn from organization and management studies guide this study in different ways throughout. This reflects its use of inductive and deductive research approaches as befits process studies (Langley, 1999). During early stages, deductive theory-driven reasoning helped hone my initial research ideas into more focused questions. These questions evolved during data collection, guided by constant iteration between empirical findings and theoretical frameworks. When analyzing this data, established theories were used to code findings, informing second order codes and deriving models from the data. The contributions and limitations of this study are drawn from comparison with existing theory.

Initial reviews of the literature established that the role of and relationship between technology and organizations has attracted a great deal of researcher attention. A number of perspectives and theories have been applied to such

[1] Henceforth, in this study the term 'users' refers to users of BIM unless indicated otherwise.

studies. However, common to this body of work is the recognition that the relationship between technology and organizations is important and complex.

Early positivist accounts of how technologies were selected by organizations gave way to sociotechnical views that looked at the adoption or appropriation of technologies. Orlikowski's concept of the duality of technology places the user at the center of technological adoption (Orlikowski 1992). The interpretive flexibility of technologies recognizes that users always have the potential to choose to do otherwise when they use technology (Bjiker, 1994). More recent studies in this area adopt a sociomaterial stance, viewing agents and objects (in this instance technology and humans or organizations) as independent entities (Orlikowski and Scott, 2008). As illustrated in Figure 1, each of these views describes a different relationship between technological artifacts and users (both individual and collective).

Researchers adopting sociomaterial perspectives are interested in actions as opposed to outputs, in verbs rather than nouns (Weick, 1979). They view the social and the material as constitutively entangled - neither human nor technologies are privileged (Orlikowski, 2007). They posit that understanding actors' use of technology requires a focus on evolving practices (Feldman and Orlikowski 2011).

Sociomaterial studies of technology and organizations therefore attend to practices. The practice perspective of organizational routines draws attention to the situated actions of individuals in their performances of organizational routines (Pentland and Feldman, 2005; Feldman and Pentland, 2003; Feldman, 2000). It emphasizes users' ever-present ability to change these enactments when using technologies (Feldman and Orlikowski 2011). Routines are created or adapted during the process of technological implementation through changing practices (Edmondson, Bohmer and Pisano, 2001). By applying the concepts from the practice perspective of organizational routines to technological implementation, the process is reconceived as one of generative, continuous change.

Sociomaterial studies also emphasize the importance of the context of practice. Field and practice dynamics reciprocally enable and constrain change. Practices change and are changed by their wider context (see, for example, Smets, Morris and Greenwood, 2012). Recent studies view the ecology of practices to show how practices cannot be considered in isolation (Grabher and Thiel, 2015; Harty and Whyte 2010). What can such embedded studies tell us about the role of the organization in this? How can organizing for technological implementation in firms be achieved? If managerial influence varies with user perspectives (Leonard-Barton and Deschamps, 1988), how can managers influence the autonomous and highly-skilled users found in some firms in the construction industry?

Edmondson's concept of matching organizing with operational settings provides a framework for studying how organizing for implementation is achieved in different settings (2012). She says that firms work in routine, complex and innovative operational settings. Work in complex operations involves a mixture of "well-understood processes, novel situations and unexpected events" (Edmondson, 2012: 37). Actors working in complex operations draw on existing routines and create or adapt routines in order to enact old and new tasks.

1.3 Research setting

The case study for this thesis is a design firm working in the UK construction industry. This is an interesting and appropriate empirical situation to explore the research questions raised in this study for a number of reasons.

As discussed previously technological implementation is a critical but problematic process for the construction industry and its firms. Reflecting the wider construction industry, practices at Design Partnership are heterogeneous and situated in a complex ecology (Whyte and Sexton, 2011). It comprises multiple institutions, firms, disciplines, projects and individuals.

In exploring BIM implementation in Design Partnership, I focus on a particular set of users. They are drawn from a number of design professions (predominantly architecture and engineering); they expect to work autonomously and value creativity yet they operate within professional and organizational constraints. How do such users incorporate new technologies into existing practices and routines? In focusing on how implementation happens, this study views the actions or processes that are involved in implementing technologies, rather than researching the influence of organizational or technological characteristics in implementation (Whyte, Bouchlagehem and Thorpe, 2002).

The introduction of BIM technology to the industry follows a trajectory of technologically driven change. A number of ICTs have been adopted by the industry since the 1950s, including Computer Aided Design, databases and the Internet. BIM brings together these technologies to provide a shared knowledge resource for built assets, covering the entire lifecycle of these assets. While the technology itself is not new (similar technologies have been used in other industry sectors since the 1980s), its application to the construction industry necessitates substantial and far-reaching changes.

1.4 Method

This study follows process, rather than variance, methodologies (Van de Ven and Poole 1995, Langley 1999; Langley et al, 2013). It therefore combines inductive and deductive approaches as befit process studies (Langley, 1999). Its design comprises a single, embedded case study, which shows how the process of implementation evolves over time. This case presents a longitudinal view of the process of BIM implementation in one firm operating in the construction industry – a global design firm that, for the purposes of this study, will be known as Design Partnership. It focuses on one major service stream in Design Partnership where complex operations are the dominant form of work.

I use qualitative methods to collect and analyze data. In order to build this longitudinal study contemporary and retrospective data were collected – a combination of data gathering approaches that are effective in building longitudinal studies (Leonard-Barton, 1990). Contemporary data relating to the current phase of the implementation was collected in the field between 2013-2014. Retrospective data on the first two phases of implementation (2000-2005;

2005-2013 respectively) was collected from interviews with business leaders and archival sources.

The implementation process is viewed at multiple nested levels within Design Partnership, at individual, firm and industry level. Empirical data is clustered around three core and 23 referent projects. As practice studies demand observations of situated actions, these projects are current or recently completed rather than retrospective. The data relating to embedded firm and industry processes was gathered through interviews, attendance at events, and archival material from sources inside Design Partnership and in wider industry.

In order to collect this data I spent at least one day a week in Design Partnership's offices in London between July 2013 and September 2014. During this time I conducted 54 interviews with individual designers and business leaders at Design Partnership and external individuals who were heavily involved with BIM implementation in the UK construction industry. I also attended meetings and training events in Design Partnership and beyond, and drew extensively on other archival sources.

1.5 Findings

The findings of this thesis are derived from the phased longitudinal view of BIM implementation at Design Partnership, shown by my data. Using a temporal bracketing strategy three phases are identified. The initial stage spans 2000-2005. During this time, Design Partnership adopts a "hands-off" approach to implementation, based on its experience of adopting technologies in the past. At the end of this phase, the use of BIM remains restricted to certain BIM enthusiasts practicing in isolated "islands of automation".

The middle phase occurs between 2005-2013. During this time, Design Partnership learns how to implement BIM: the potential opportunities and the challenge of implementing BIM becomes apparent. In particular, the variability of practices and routines across disciplines, users and service streams is made clear.

During the final phase – lasting between 2013-2015 - a strategic shift takes place at Design Partnership. The firm dedicates exceptional resources to implementing BIM across the organization. It aims to provide an "infrastructure of support" for practitioners using BIM. This change reflects and is supported by wider industry changes, by numerous institutional standards and policies.

This study's initial research question of how organizational routines and practices influence technological implementation in firms is addressed using this model. A process model of technological implementation is presented, which is derived from data clustered around three projects at Design Partnership. The model builds on Edmondson et al's 2001 process model of technological implementation, developing it to fit the theoretical, methodological and empirical setting of this study.

This model describes a generative process of routine development in technological implementation using four process stages – forming, preparing, enacting, and reflecting. Collective learning and leadership enable this generative process. In applying this model in this study's empirical context, the process of implementing BIM in building projects is illustrated.

The second finding addresses this study's other research question, which asks how firms organize for technological implementation in complex operations. A conceptual model is presented that illustrates the process of organizing. It draws on the process model of technological implementation and embeds it in a wider ecology. This model illustrates that during implementation of a new technology, when firm and users are aligned, an infrastructure of support is created that enables processes of implementation. When firm and users are misaligned, the process of technological implementation is constrained. In this model, the firm responds to and influences exogenous and endogenous change.

The derivation of this model is shown by applying it to the longitudinal model of BIM implementation at Design Partnership. The three approaches to organizing for implementation used during this process illustrate a progression from misalignment to alignment between the firm and users in technological implementation. Relevant aspects of work are used to illustrate dimensions in which the firm and user levels serve to constrain and enable one another. In particular, three areas are drawn on to demonstrate its application: collaborative working, skills and training, and software development. Mechanisms for forming this relationship are identified. Data indicates that these mechanisms include formal policies, standards and guidance, and informal approaches, such as collective learning and leadership.

1.6 Discussion

A number of theoretical contributions are made in this study. The most significant is that the evolving practices and routines of users of BIM are central to processes of technological implementation in firms today. The proposed relationship between evolving practices and routines is described in a process model of technological implementation. In it, the process of implementing technologies is seen as iterative and continuous. This finding is uncovered by viewing the process of implementation using the practice perspective of organization routines, meaning routines are viewed as sources of generative change in processes of technological implementation in firms. This contrasts with views of organization routines as malleable during implementation, and fixed on completion.

In studying organizing for implementation in firms, this study draws attention to the relationship between firm and users of BIM. It draws on and develops earlier studies that indicate a process of mutual adaptation occurring during implementation (Leonard-Barton, 1988) and unpacks the nature of this relationship. It finds that in organizing for technological implementation in complex operations the relationship between firm and users of technology is mutually constitutive. Aligning investment and action around both is critical for effective technological implementation.

Existing theory suggests that organizing in complex operations should be done using an "organizing to learn" approach (Edmonson, 2012). This thesis extends this model by finding that during technological implementation, organizing is achieved through informal (collective learning and leadership) and formal mechanisms (policies, standards and guidance).

This study also makes methodological contributions. It observes that the lack of guidance around visual representations in research of process in organizations restricts communication of results and analyses. The need and potential for academic institutions and business to improve their capabilities in conducting collaborative research is elaborated.

Practical recommendations to managers and policy makers in the construction industry are suggested. This normative advice is grounded in the growing importance and potential for the construction industry and its firms to develop capabilities in technological implementation. Overall, technological change is constant in the construction industry, as with many other industries. Firms in the industry operate in a continually changing environment. Managers and policy makers need to develop strategies and policies that accommodate these "relentlessly shifting organizations" (Brown and Eisenhardt, 1997).

Managers of knowledge-intensive, professional service firms (PSFs) such as Design Partnership are advised to adopt organizing to learn approaches. Under this style, managers focus their resources and knowledge on enabling valuable firm assets residing in skillful individual practitioners.

Policy-makers working in the construction industry are encouraged to pay more attention to the realities of work, to what is happening at *the coalface*, rather than focusing on the senior echelons of organizations and industry. Formal and informal mechanisms such as policies, standards and guidance, collective learning and leadership are tools in organizing to learn.

The limitations of this study are discussed. The steps taken to address limitations of the case study design are detailed, with relation to the thick descriptions developed, the theoretical sampling strategy used, the strong theoretical grounding maintained throughout, and the rigor of data analysis.

Limitations of the theoretical generalizability offer opportunities for future research. For example, does the type of technology change the nature and form of the implementation process? Can studying change from a practice-perspective enhance our understanding of other organizational processes? How does the firm and industrial setting of implementation affect the process?

Turning to the organizational routines literature, the process model developed here offers an opportunity to see how routines are created and adapted over time. By viewing implementation using the practice-perspective of organizational routines, the relationship between practices and routines is made explicit. Exploring the role of elements in the routine, such as artifacts, across this process, could bring further focus. Such research could contribute to theories of boundary objects and inter organizational routines. Other observations made in this study merit further research. The lack of engagement of external technology developers in the implementation process offers numerous research opportunities.

Overall, the findings of this thesis contribute to the understanding of project based and professional service firms and have implications for how they are studied in the future.

2. Structure of thesis

This thesis proceeds as follows. Chapter 2 discusses theory drawn from management and organization studies. This literature is reviewed to show how the relationship between technology and organizations has been characterized. Attention is drawn to theories that help address this study's research questions, focusing on concepts that draw on practice theory.

In Chapter 3 the methods used in this study are presented. Process research methodologies are described, as is the study's design, how data was collected and how it was analyzed.

Chapter 4 presents the setting for this research. Change in the construction industry in the UK is described across multiple levels. In reviewing technological change in this industry, a historical context is provided for the technology being studied here. The properties of Building Information Modeling and its use in the industry to date are described.

The findings of this study are presented in Chapters 5-7. In Chapter 5 a longitudinal overview of the BIM implementation process at the case study firm, Design Partnership, is presented. In Chapter 6, the ways BIM was used in three project case studies and how practices and routines evolved from this are described and a process model of implementation is proposed. In Chapter 7 this model is embedded in the organizational and institutional context to build an explanatory process model of technological implementation in complex organizations.

In chapter 8, the theoretical and practical contributions made by this study are presented. Limitations of the study are discussed, with reference to opportunities for future research.

The final chapter of this thesis summarizes its approach, and the findings and contributions it makes.

Chapter 2: Organizing for technology: routines, practices and context

1. Introduction

The purpose of this chapter is to describe how theoretical perspectives are used to address this study's research questions of a) how do organizational routines and practices influence processes of technological implementation in firms and b) how can firms organize for technological implementation in complex operations? Table 1 shows the broad theoretical perspective and frameworks used to address these questions.

This chapter begins by introducing some key terms used in this study, namely technology, processes, practices and organizational routines. It proceeds by discussing how the relationship between technology and organizations has been conceived in past literature. Recent sociomaterial approaches to organizing with technology provide the broad theoretical perspective for this study. Researchers working in this tradition view technology and organizations as represented in material and human agency and apparent in constantly shifting assemblages of action. The theoretical frameworks used here draw on key principles of sociomaterialism - that both practices and their embedded context are significant in understanding processes of organizing.

The practice perspective of organizational routines, combined with Edmondson et al's process model of technological implementation, provides the theoretical frameworks used to address this study's first research question (2001). Routines enable researchers to observe processes of change occurring at micro levels (Pentland and Feldman, 2005; Feldman and Pentland 2003). During implementation, users of technology develop routines leading to mutual adaptation, as shown in Edmondson et al's process model (2001). By combining this model with the practice perspective of organizational routines, an alternative view of the implementation processes is generated.

The second research question asks how firms organize for technological implementation in complex operations. It builds on the premise of the first research question, that is that routine dynamics play an important role in technological implementation. It adds to this the context of technological implementation, thus embedding this process in a specific operational and organizational context. A theoretical model of knowledge processes provides a framework to analyze this (Edmondson, 2012). This framework implies that the process of organizing is contingent on the setting. A good fit between the users and the firm creates an enabling relationship, and vice versa (Edmondson, 2012). When applied to organizing for technological implementation, this framework shows how organizations and practices enacted with it are mutually constitutive.

Research questions	**How do organizational routines and practices influence processes of technological implementation in firms?**	**How do firms organize for technological implementation in complex operations?**
Broad theoretical perspective	Sociomaterial views of technology and organizations	
Theoretical framework	Practice perspective of organizational routines	Knowledge Process Framework
Application	Technological implementation is driven by generative routine dynamics enacted by users.	In processes of organizing for technological implementation the organizational and wider context of implementation is significant.
Implications of framework	Technology and routines are changed by and change processes, including technological implementation. Users develop routines that allow them to use new technologies. Under a practice perspective of routines, routine change is generative and ongoing.	Organizing for technology varies in different settings.
Empirical fit	A significant gap exists between work and policies in the construction industry. Adopting a practice perspective and observing change in routines, brings attention to how implementation happens in reality. It generates a more finely grained account of how technologies such as BIM are changing, and being changed during implementation.	Work in the construction industry is highly interdependent and nested in a complex institutional and organizational ecology. The concept of complex operations describes this setting well. The multiple levels used in the model illuminate the relationship between user and organization, to show processes of organizing.

Table 1: Theoretical frameworks used in this thesis

Accordingly, this chapter proceeds as follows. It starts technology and organizations, establishing the evolution of this research and illustrating different treatments of it. Theoretical perspectives are discussed that view technology and organizations as discrete and mutually dependent variables, and as apparent in assemblages of action.

A number of key theoretical concepts used to guide this study are then defined - namely processes, practices and organizational routines – and the relationship between them discussed. This forms the basis for more detailed discussion of these concepts. The ontological principles of practice research are discussed and their application illustrated drawing on extant research. A range of research is reviewed that explores the relationship between organizational routines and technology and shows that they are means of understanding micro processes of organizational change evident. In light of this, the practice perspective of organizational routines is presented as a suitable theoretical framework for viewing technological implementation.

This insight is then applied to the importance of embedding the process of implementation in an organizational and wider context. One aspect of the contingent nature of technological implementation is thus revealed and applied to settings described as complex operations. Within such settings, the relationship between user and organization is critical in processes of organizing. The scope and nature of recommended collective learning activities are discussed, as they are integral to recommended approaches to organizing for complex operations.

2. Definitions and background

Concepts of technology, process, practices and organizational routines are central to this study. Definitions for these terms, as used in this study, are offered here. This introductory information is developed further in this chapter and chapters 3and 4, and is used to guide the collection, analysis and discussion of data collected in this study.

2.1 Technology

Technology has become an integral component of modern life. It is unsurprising then that technology has attracted significant scholarly attention in a broad range of academic disciplines, including management and organization studies. The invention and diffusion of technology within and between organizations and industries has been widely studied by economists and innovation scholars (for example Schumpeter, 1939; von Hippel, 1976; Nelson and Winter, 1982; Dosi, 1982; Anderson and Tushman, 1990; Pavitt, 2002). Business strategy scholars see technological change as a key component in creating competitive advantage which can be gained by developing the dynamic capabilities to innovate and embed technologies (Zollo and Winter, 2002; Teece, Pisano, and Shuen, 1997). However this study draws on a third major stream of literature that studies the relationship between technology and organizations, and more recent research examining processes of organizing with technologies.

A single definition of technology is elusive: thus Weick argued that technology is an e*quivoque*, meaning that it is open to several plausible interpretations (Weick, 1990). Orlikowski and Scott concur, suggesting that technology is best understood as a historically and theoretically contingent term (2008). They identify two ontological perspectives taken in studies, either viewing technology and organizations as discrete entities, or as mutually dependent ensembles (Orlikowski and Scott, 2008). As Table 1 illustrates, different logics, research designs and concepts underpin these two approaches.

	Research Stream 1	**Research Stream II**
Ontological Priority	Discrete Entities	Mutually dependent Ensembles
Primary Mechanisms	Impact; Moderation	Interaction; Affordance
Logical Structure	Variance	Process
Key Concepts	Technological Imperative Contingency	Social Constructivism Structuration
View of Social and Technical Worlds	Humans/organizations and technology are assumed to be discrete, independent entities with inherent characteristics	Humans/organizations and technology are assumed to be interdependent systems that shape each other through ongoing interaction

Examples	Blau et al. (1976) Huber (1990) Aiman-Smith & Green (2002)	Barley (1986) Prasad (1993) Boudreau & Robey (2205)

Table 2: Two streams of research on technology and organizations, reproduced from Orlikowski and Scott 2008.

Definitions of technology differ across these perspectives. For example, studies employing a discrete entity perspective often view the technology as an artifact, definining technology as computing or IT. Studies adopting a mutually dependent ensemble perspective take a broader view of technology, as illustrated in Collins, Hage and Hull's (1986) definition of technology as comprising three systems: mechanical (hardware), human (skills and human energy) and knowledge (abstract meanings and concepts).

A more recent body of research adopts a sociomaterial position wherein technologies and organizations are viewed as constantly changing assemblages of human and material agency. Within this perspective, boundaries between, and therefore definitions of, humans or organizations and technologies are not predetermined but are enacted through practice and constantly change. The emergent nature of this research, and the variable and shifting boundaries of agency in it, mean definitions of technology are rarely offered.

2.2 Processes, practice and organizational routines

Processes are defined in this thesis as "a sequence of events that describe how things change over time" (Van De Ven, 1992: 2). This follows a growing number of process studies exploring how "things emerge, develop, grow or terminate over time" in organizations (Langley, Smallman, Tsoukas, Van de Ven, 2013: 1). As with other process studies, in this thesis attention is paid to verbs as opposed to nouns: to organizing rather than organizations (Weick, 1979). Importance is attached to processes of organizing rather than the structure of organizations. Organizing is viewed as a socially constructed process, driven by individuals making sense of their environment and choosing actions which relate to wider organizational and institutional structures (Weick, 1990).

The process of organizing studied in this thesis is technological implementation. Like the equivocal nature of technology itself, explanations of implementation processes are historically and theoretically contingent (as discussed in detail later in this chapter). Overall, this thesis follows Leonard-Barton's explanation that implementation of technologies involves "getting them up and running in daily operations." (Leonard-Barton, 1988: 251). Successful implementation is taken as the routine (or regular) use of a technology on an ongoing basis in an organization (Edmondson et al, 2001).

Practices are defined in this study as "largely unconcious yet shared and recognizable ways of doing things" (Jarzabkowski, Kaplan, Seidl and Whittington, 2016: 271). This view follows the work of influential social scientists (for example Bourdieu, 1990, 1977; Latour, 1987; Giddens, 1984). Practices are therefore observed through empirical enactments, which vary according to circumstances and actors reflecting "the notion that social life is an ongoing production and thus emerges through people's recurrent actions" (Feldman and Orlikowski, 2011: 1240). Such an approach is appropriate in this thesis, as researchers are encouraged to take a practice perspective when studying technology and organizations (Feldman and Orlikowski, 2011).

The significant role of routines in organizational life has attracted considerable and sustained scholarly attention since the 1940s (see for example Simon, 1947; March and Simon 1958; Cyert and March 1963; Nelson and Winter, 1982; Levitt and March 1988). This substantial body of work firmly establishes organizational routines as a core capability in firm, describing them as the "regular and predictable behavior patterns of firms" (Nelson and Winter, 1982: 14). Building upon this work, Feldman and Pentland's conceptualization of organization routines as sources of generative organizational change offers an expanded definition of organizational routines, which is used in this study as "a repetitive, recognizable pattern of interdependent actions, involving multiple actors (Feldman and Pentland, 2003: 96). In Feldman and Pentland's practice perspective, organizational routines are shown to be sources of generative change.

Such a model is fitting for this study as it brings attention to the potential for endogenous change in routines as they are enacted in practice, and to the process for such change.

3. Perspectives of technology and organizations

The relationship between technology and organizations has interested researchers since the advent of the industrial organization (Leonardi and Barley 2010; Orlikowski, 2000; Orlikowski and Scott, 2008). Three main research traditions have evolved which take different perspectives of this relationship.

As illustrated in Figure 1, these three research streams adopt strategic choice theories, sociotechnical and sociomaterial perspectives. The first two of these research streams – strategic choice and sociotechnical perspectives - view technology and organizations as variables, but differ markedly in their treatment of them. Scholars working in the most recent and emergent research stream, use sociomaterial perspectives of technology and organizations, viewing assemblages of material and human agency, apparent in actions.

The earliest research stream draws on the technological turn, apparent in many organizations in the early part of the twentieth century. An influential group of Scholars used contingency theory to study this phenomenon. A pioneer of this approach, Woodward, correlated three different types of technology, small batch technology, large batch and mass production technology and continuous process production, with different management structures (1958). Her categories of technology increased in levels of complexity from small batch technology through to mass production technology (Woodward, 1958). In a later study, Perrow uses dimensions of task variability and analyzability to identify four types of technologies: routine, non-routine, craft and engineering technology (Perrow, 1967).

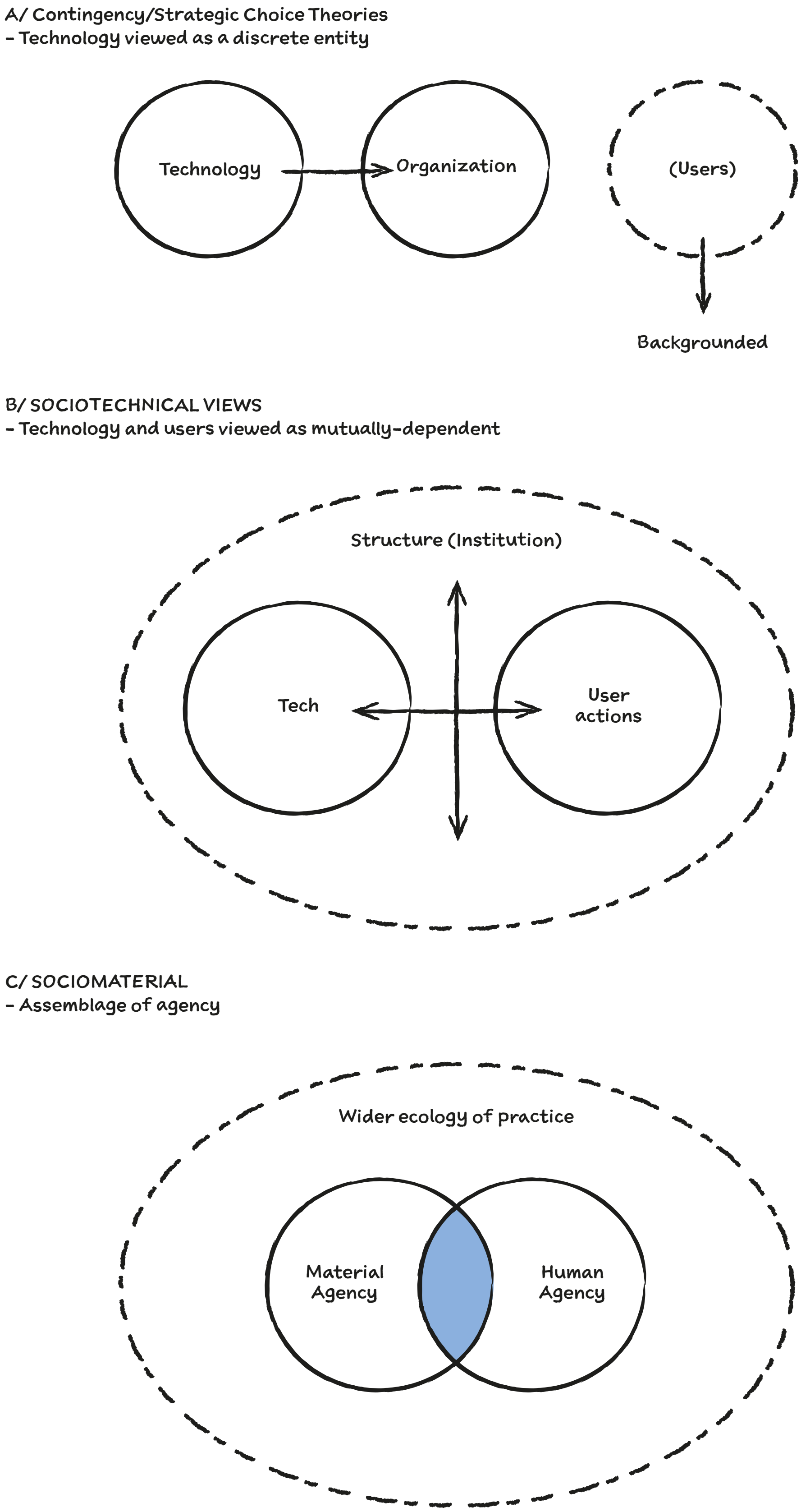

Figure 1: Theoretical views of the relationship between technology and organizations

Contingency theory researchers viewed technologies as discrete entities, treating them as independent or moderating variables. They were interested primarily in why organizations chose to invest in a particular technology. This choice was portrayed as limited to strategic choices made by key decision makers – management and business leaders. Individual users of technology appeared to have no volition in the process of technological adoption, simply complying with organizational directives to use technologies in a prescribed manner (Orlikowski and Barley, 2001).

Over time, these early studies attracted criticism for technological determinism, for ignoring the role of humans in their research. This absence was addressed in a second major body of research studying technology and organizations that employed sociotechnical perspectives, viewing technology and organizations as mutually dependent ensembles. Under sociotechnical views, researcher attention shifts to understanding how technologies are used, particularly during processes such as technological implementation, adoption and appropriation (Orlikowski and Scott, 2008). The user is in the foreground in sociotechnical research; users can always choose to do otherwise when employing technologies (Orlikowski, 1996). The ways individuals use technologies is variable and unpredictable, often straying from designers' original intentions (DeSanctis and Poole, 1994).

Scholars working at London's Tavistock Institute pioneered this alternative stance, conceiving of organizations as both technical and social systems (for example Trist and Bamforth, 1951; Emery, 1959). Trist and Bamforth's study of a technological innovation in British mines, the Longwall method, was highly influential in establishing this alternative perspective (1951). In this study, Trist and Bamforth focused on the social and psychological implications encountered when using technology in an organization.

With the publication of Gidden's influential structuration theory in 1984, and its core tenet of the dichotomy between agency and structure, an increasing number of scholars produced sociotechnical studies (for example Barley 1986; Yates and Orlikowski, 1992; Tyre and Orlikowski, 1994; Orlikowski and Yates, 1994;

Orlikowski and Gash, 1994; DeSanctis and Poole, 1994; Garud and Rappa, 1994; Orlikowski 1996, 1993; 1992) [2]. The nature of processes involving technology and organizations were a preoccupation of sociotechnical scholars. Their work adopts perception, interpretation, appropriation, enactment and alignment approaches in studying different aspects and stages of technological implementation and use (Leonardi and Barley, 2010).

The first two of these approaches – perception and interpretation – are closely linked (Leonardi and Barley, 2010). Perception researchers focus on adoption, taken as the earliest stage of implementation, exploring why users share perceptions of technology and what effect these perceptions have on individuals' use of technology. Interpretation research focuses on use rather than adoption of technology.

For example, Barley's 1986 study draws on structuration theory to explore how the introduction of technology changes established organizational and occupational structures at work. A longitudinal ethnographic study of a radiologist and technician using new CT scanning technology, finds that the changes which technology effects in roles and work routines differ depending on organizational and institutional contexts; technologies influence organizational structures but their influence depends on the specific historical context in which they are embedded (Barley, 1986).

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[2] The process of structuration involves reciprocal action between human actors who exercise agency and structural features, whereby human actions are enabled and constrained by structural features and *vice versa.* Structuration implies that agents and technology are interdependent systems that shape each other through ongoing interaction (Orlikowski and Scott, 2008). Structuration theory has profoundly influenced many fields of organizational research, for example in institutional theory and change (Cooper et al., 1996; Greenwood et al., 1996); practice studies (Jarzabkowski, 2004; Whittington, 2007, 1996); communities of practice (Wenger 1999), to name but a few.

Appropriation research also addresses how technologies are used after the initial adoption stages (Leonardi and Barley 2010). It is primarily concerned with whether individuals use technology as developers intend. DeSanctis and Poole propose Adaptive Structuration Theory as a way to explain the enabling and constraining effects of technology on structures (DeSanctis and Poole, 1994). Users are found to appropriate technologies both faithfully and unfaithfully (DeSanctis and Poole, 1994).

Orlikowski's study of the appropriation of technology draws on Giddens' structuration theory to show how the intentions of the creators of technologies differ from the actions of individuals who use them (1992). In an ethnographic study of the use of engineering tools in a consulting company, Orlikowski finds that technology can both enable and constrain human action and *vice versa* (Orlikowski, 1992).

A series of papers by Yates, Orlikowski and colleagues in the 1990s, contributes significantly to the enactment perspective (Leonardi and Barley, 2010). In a developing body of work on genres of electronic communication, enactment describes how genres were produced through action (Yates, Orlikowski, and Okamura, 1999; Orlikowski and Yates, 1994; Yates and Orlikowski, 1992). Orlikowski's 2000 paper, which presents the value of adopting a practice perspective in studying technology, shows that technologies in use should be viewed as enactments, rather than appropriation:

> "Thus, rather than starting with the technology and examining how actors appropriate its embodied structures, this view starts with human action and examines how it enacts emergent structures through recurrent interaction with the technology at hand." (Orlikowski, 2000: 407)

The final research stream in sociotechnical literature takes an alignment perspective. It is principally concerned with processes of adaptation, with the mutually constitutive relationship between technologies and structures – organizational, occupational and institutional - that develops during technological implementation. Structuration theory lies at the core of research taking an alignment perspective, with role change and hierarchies as central themes.

Studies using alignment perspectives include Edmondson, Bohmer and Pisano study of technological implementation in 16 US hospitals introducing Minimally Invasive Cardiac Surgery (MICS) technology (2001). Through comparative analysis, they show that successful implementation occurs where role relations become less hierarchical and more collaborative. New routines are developed that allow the use of MICS (Edmondson et al, 2001).

Despite the valuable contributions made by sociotechnical research, such studies were criticized in time for downplaying the role of technology in the social construction process (Leonardi and Barley, 2010). Following a notable absence of technology in the organizational studies literature, a number of scholars working in the field have followed the admonitions of several influential academics and are taking a sociomaterial perspective in their studies of technology and organizations (Leonardi and Barley, 2010; Orlikowski and Scott, 2008; Orlikowski, 2007). Heralded as a "promising stream of research" (Orlikowski and Scott, 2008: 455), sociomateriality moves away from viewing agents and objects (in this instance technology and humans or organization) as independent entities and instead focuses on the materiality of everyday work (Orlikowski and Scott, 2008). In this view, the social and the material are constitutively entangled: neither human nor technologies are privileged (Orlikowski, 2007).

Sociomaterialism has influenced and been developed by a number of scholars working in other research fields. One of the most noteworthy of these is actor network theory, in which pre-eminent scholars such as Latour (1987) and Callon (1986) describe the equivalency of human and material agencies (Orlikowski and Scott, 2008). Material agency is defined as "the capacity for nonhuman entities to act on their own, apart from human intervention" (Leonardi, 2011: 148). Sociomaterialism is a relational ontology that brings actors' situated performances to the foreground (Orlikowski, 2000). A number of scholars of sociomateriality are therefore primarily concerned with performances, viewing these as enacted in the "mangle of practice" (Pickering, 1995). Researchers are encouraged to use a practice perspective when employing sociomaterial approaches (Feldman and Orlikowski, 2010). In turn, this draws attention to how relations and boundaries between humans and technologies are not pre-given or fixed, but are enacted (Orlikowski and Scott, 2008).

Sociomaterialism moves away from seeing actors and objects as autonomous entities that influence each other, thus addressing perceived weaknesses of sociotechnical research (Orlikowski and Scott, 2008). However, applying this theoretical perspective in empirical studies is challenging and contested (Leonardi and Barley, 2010). On the one hand, the constitutive entanglement of the social and material implies that researchers should weave the socio and material together (Orlikowski, 2007; Orlikowski and Scott, 2008). On the other hand, scholars are advised to view events such as technological implementation as opportunities to disentangle the social and material in order to view how:

> "The material constrains and affords the social, as well as how and when the social shapes the material and its effects."
> (Leonardi and Barley, 2010: 35)

Despite these debates and the emergent nature of this perspective, recent empirical studies employing a sociomaterial perspective demonstrate the value it can bring. Researchers use sociomaterialism to generate insights in a diverse range of topics such as how mobile email devices are being used by knowledge workers (Mazmanian, Orlikowski, and Yates, 2013); how robotics are influencing the work of multioccupational groups (Barrett et al, 2012); and how social media is used in online valuations (Orlikowski and Scott, 2013).

Mazmanian, Orlikowski and Yates study how a specific group of workers – knowledge professionals – use mobile email devices in their everyday work and how this effects their autonomy, a defining and valued aspect of professional work (2013). They explore how workers navigate between their interests in personal autonomy and professional commitments. By looking at the material properties of mobile devices, Mazmanian and colleagues identify an autonomy paradox: professionals try to balance their desire for personal autonomy on one hand with their commitments to colleagues on the other. They find that this paradox shifts the norms of how work is, and should be, performed in organizations (Mazmanian et al, 2013). Barrett, Oborn, Orlikowski and Yates' recent study of the influence of robotic innovations on pharmacy work focuses on the boundary dynamics of three occupational groups (2012). It explores how multi occupational groups influence each other as work and relations are restructured around a technological innovation. Of the three occupational groups – pharmacists, technicians and assistants – using the robotic technology across two similar sites, the study shows that when digital innovations are advantageous to a group's interests, relations of boundary cooperation are found. Boundary neglect is found where one occupational group's input was not sought; boundary strain was found where occupations seems to encroach on another occupation's role (Barrett et al, 2012).

Similarly, Orlikowski and Scott use a sociomaterial perspective in their 2013 study of social media and online valuations. They explore the changing nature of valuations and their outcomes by comparing the online valuation schemes of two hotel chains, adopting a practice lens to explore the materiality of these valuations. They find significant differences in the intended and actual outcomes of valuations in two hotels (Orlikowski and Scott, 2013).

In summary, this account of the development of studies on technology and organizations describes three main research streams that have been used to study this growing phenomenon. Each of these perspectives views the relationship between the two differently. Early contingency and strategic choice literature presents a deterministic view of technology's impact on organizations. In contrast, sociotechnical studies place the user of technology in center stage. Sociomaterial approaches build on these research streams to explore patterns of action as evidence of materiality and agency.

Having described the development of sociomaterial perspectives in the evolution of research addressing technology and organizations, I build on this to discuss theory relevant to this study's first of how practices and organizational routines influence processes of technological implementation.

4. Organizational routines and technologies

This section lays out the theoretical framework used to address the question of how practices influence processes of technological implementation in firms. Studies considering processes of change and adaptation show a close correlation between organizational routines and technology. They offer opportunities for researchers to observe patterns of action at micro level.

The process and relationship between organizational routines and technology varies according to the research perspective employed, as summarized in Table 3. In alignment studies, research indicates that organizational routines and technology play key roles in enabling technological implementation. Routines are changed through implementation enabling adaptation of organization and technology, becoming rigid and fixed after implementation (Leonard-Barton, 1998; Tyre and Orlikowski 1994; Edmondson et al, 2001).

In studies of technological artifacts an alternative view of the relationship between technology and routines is presented, where technology is seen as a conduit and catalyst of routine creation and change (D'Adderio, 2011, 2008, 2003; Cacciatori, 2012, 2008; Hales and Tidd 2009). In sociomaterial research, technology and organizational routines are seen as entangled elements in an assemblage, where agency is constrained and enabled by structure, and whose relationship changes according to the context of enactment (Labatut, Aggeri and Girard, 2012; Leonardi, 2011; Volkoff, Strong and Elmes, 2007).

Although the studies discussed here originate from different research streams they have two features in common. Firstly, they use the relationship between routines and technology to study processes, whether these processes are organizing for technological implementation through mutual adaptation, or studying the dynamics of routines through processes of creation and adaptation. Secondly, they pay attention to the actions of individual actors, either implicitly in the alignment and technological artifacts studies, or explicitly in many sociomaterial studies.

Table 3: Studies of the relationship bewteen routines and technology.

	Alignment	Technological artifacts	Sociomateriality
Ontological perspective	- Technology and organizations - Sociotechnical perspective	- Organizational routines - Practice perspective	- Technology and organizations - Sociomaterial perspective
Nature of processes studied	- Technological implementation - Episodic: focuses on events of special interest, for example initial adoption of technology - Finite and linear	- Embedding routines in technological artifacts - Routine creation, dynamics, transfer and performances.	- Technological implementation and use - Long term view of technological implementation and use continuous process
Mechanisms and moderators	- Mutual adaptation at organizational and team level - Alignment between the technology and user environment - Learning and leadership are factors that drive alignment.	- Routines embedded in technological artifacts can be changed.	- Situated action: patterns of action studied - These actions are embedded in wider ecologies of practice, for example in institutional, historical and organizational contexts
View of routines	- Routine creation and adaptation is needed for technological implementation. - Routines are dynamic during implementation but fixed after implementation	- Routines embedded in technological artifacts can act as repositories for organizational memory, knowledge and learning. - Conversely, routines embedded in technological artifacts can become habitual or have limited influence.	- Routines and technology are seen as inseparable, as imbricated. - Nature of technology (complexity, degree of embeddedness, flexibility, perceptions of constraint) and routines (flexibility, perceptions of affordance) influences how routines and technologies are changed. - Occupational, individual, group and institutional boundaries are constantly shifting
View of technologies	- Need for adaptations to the technology in aligning it with the user environment - Technology is treated as the independent variable (Edmondson et al 2001)	- Technological artifacts (often software packages) can act as boundary objects and they can create truce / conflict between groups; - They can facilitate the transfer of routines.	
Exemplar studies	Leonard-Barton (1988) Tyre and Orlikowski (1994) Edmondson, Bohmer and Pisano (2001)	D'Adderio (2003, 2008, 2011) Cacciatori (2008, 2012) Hales and Tidd, (2009)	Pentland and Feldman (2007) Volkoff, Strong and Elmes (2007) Leonardi (2011) Pentland, Feldman, Becker and Lui (2012) Labatut, Aggeri and Girard (2012)

4.1 Alignment studies

The earliest set of literature studying the relationship between organizational routines and technology describes routines as enabling the adaptation needed for technological implementation. As illustrated in Figure 2, the three papers drawn on here all study the process of technological implementation from a similar perspective but make distinct contributions through research.

The first study considered is Leonard-Barton's research into technological implementation in 12 large American manufacturing firms (1988). In it, Leonard-Barton identifies technological implementation as being key to firms' competitiveness, and as great a managerial challenge as creating technologies. Technological implementation is portrayed as a dynamic process rather than a predictable realizable plan (Leonard-Barton, 1988).

Leonard-Barton finds that technological implementation is a process of mutual adaptation involving alignment between the user environment and technologies. In a break from extant research, which characterizes technological implementation as involving change to one variable - the technology or (more commonly) the organization - she characterizes implementation as a process of mutual adaptation between the two. Leonard-Barton explains that mutual adaptation is needed because the technology never fits perfectly into its user environment. Three main elements contribute to this misalignment: technical requirements, the system through which the technology is delivered to users, and organization performance. Organizational routines drive this alignment process, developed through learning. After alignment is complete, these routines become fixed and potential core rigidities for the organization (Leonard-Barton, 1992, 1988).

Tyre and Orlikowski's later study draws on data collected in three research sites across Europe and American including manufacturing operations introducing new

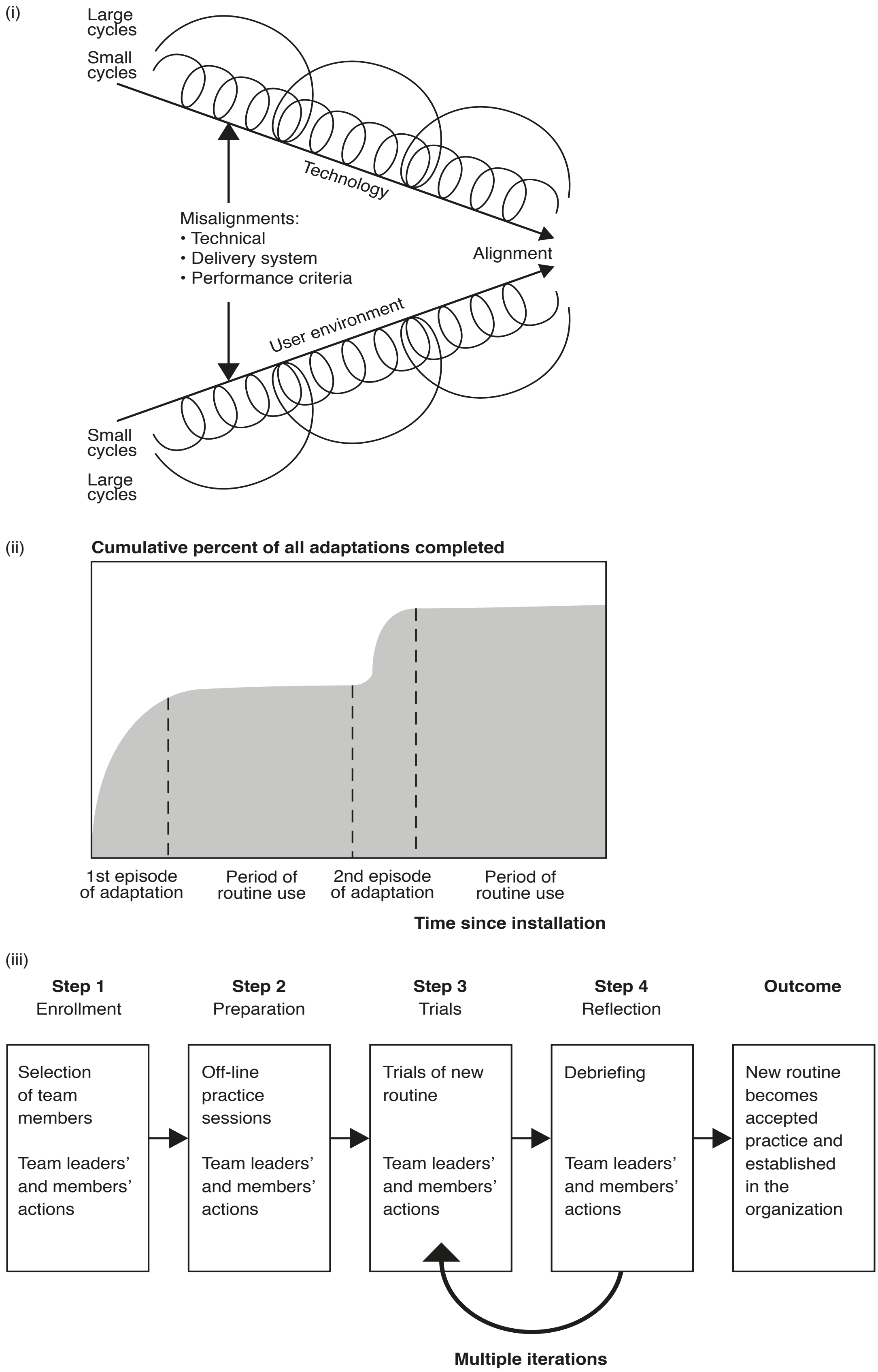

Figure 2: Processes of technological implementation in alignment studies, reproduced from i) Leonard-Barton, 1988 ii) Tyre & Orlikowski, 1994 iii) Edmondson et al 2001.

production equipment (1994). They show that technological implementation is not a smooth process but is discontinuous, contrasting with the gradual process.

Tyre and Orlikowski draw on Weick's suggestion that the initial introduction of technology is of special importance although later change is also possible (Weick, 1990). They find that implementation happens in an episodic manner, triggered either by discrepant events or by new user discoveries (Tyre and Orlikowski, 1994). They find that while the initial introduction of a new technology represents the first episode of adaptation, a second episode of adaptation is also possible, triggered by an unusual event or discovery. In their model, routines are learnt and developed during episodes of adaptation, but become fixed once routines are established and thus limit any further opportunities for adaptation (Tyre and Orlikowski, 1994).

The most recent of the three studies by Edmonson, Bohmer and Pisano focuses on an episode of adaptation from the perspective of users. The study shows that new organizational routines have to be learnt in the face of new technologies, especially highly interdependent ones (2001). Edmondson et al compare the implementation of Minimally Invasive Cardiac Surgery technology in surgical teams working in 16 teaching hospitals in the US. Comparative analysis between the hospital sites shows that implementation is successful in those sites where leaders enable collaboration and hierarchies are broken down. In contrast to extant literature, Edmonson et al find that organizational factors are not significant in the success of implementation. Collective learning, driven by leadership, is a critical factor in the success of technological implementation (Edmondson et al, 2001).

Edmondson and colleagues unpack the implementation process from the perspective of users. They show this process in a model comprising four discrete stages: enrollment, preparation, trials, and reflection. Enrollment involves selecting and motivating participants for the implementation effort. Preparation describes activities such as rehearsal sessions that simulate use of the technology off-line. Trials involve initial uses of the technology for actual work, and reflection involves discussion of trials among all or a subset of team members, planning changes for subsequent trials, and reviewing relevant data to learn from it for the purpose of informing ongoing work. The outcome of this four stage, linear process is the creation of routines that enable individuals and teams to use new technologies (Edmondson et al, 2001).

Together these exemplar papers show that routines are created and changed in the face of new technologies. They show that routine dynamics enable technological implementation through mutual adaptation and that collective learning is a vital part of this process. However these studies portray technological implementation as an episodic, linear process with a distinct beginning and an end. During periods of adaptation, routines are created and adapted; once completed routines are fixed and become sources of rigidity.

4.2 Technological artifacts

A second stream of research papers looks at the role of technological artifacts in the creation and change of organizational routines (D'Adderio, 2011, 2008, 2003; Cacciatori, 2012, 2008; Hales and Tidd, 2009).

In contrast to research dealing directly with technology and organizations, these studies draw on and contribute to the organizational routines literature. Therefore they bring a different ontological perspective to the relationship between organizational routines and technology. Despite this different theoretical objective, studies of technological artifacts create substantial insights into this relationship. Routines can be embedded in artifacts, particularly technological artifacts. Thus they play an essential role in routine creation (Cacciatori, 2012) and dynamics (D'Adderio, 2003, 2008, 2011, 2014).

Artifacts have been widely studied empirically and theoretically in relation to organizational routines (for example Cohen, Burkhart, Dosi, Egidi, Marengo, Warglien and Winter, 1996; Feldman and Pentland, 2003; Pentland and Feldman, 2005; Becker, Lazaric, Nelson and Winter, 2005; D'Adderio, 2003, 2011; Cacciatori, 2008, 2012). Artifacts enable or constrain organizational routines, either as proxies for the ostensive aspect of the routine or as material entities such as computers and physical space that influence routine performance (Parmigiani and Howard-Grenville, 2011). (The role of artifacts is discussed in detail in section 3.2 of this chapter.)

An early study by D'Adderio accepts that technological artifacts can be repositories for organizational memory and routines, but asks what the process and implications are for embedding knowledge and routines in technology (2003). The study finds that routines embedded in software can facilitate control and coordination and collaboration but can become unquestioned (D'Adderio, 2003).

Two studies published five years afterwards provide additional insights into the relationship between technological artifacts and organizational routines. The first of these by Cacciatori takes the theoretical metaphor of routines as organizational memory (2008). She asks what role artifacts have in the representation and transfer of learning across boundaries and studies this empirically by tracing how an Excel spreadsheet is used to develop a bid preparation routine in an engineering consultancy. She finds that technological artifacts facilitate the transfer of routines across project and occupational boundaries (Cacciatori, 2008).

The second study explores how technological artifacts influence routine dynamics (D'Adderio, 2008). In an ethnographic study, D'Adderio looks at how product data management software influences the dynamics of a bill of material routine. She finds that mutual adaptation occurs between the formal rules and routines embedded in software and the actual performances of routines. This mutually adaptive process is cyclical, going through stages of framing, overflowing and reframing (D'Adderio, 2008).

Hales and Tidd focus on representations of routines and rules in artifacts and ask what role representations play in the performance of routines (2009). Through a longitudinal case study of the creation of a new routine, a formalized product development process, using one technological artifact, a software wizard, they find that formal representations of routines have limited influence on performances, whereas non-formal representations have greater influence. Hales and Tidd conclude that the import of artifacts is more limited than previous studies implied. The influence of artifacts on performance is related to the extent to which they enable routine representation (Hales and Tidd, 2009).

D'Adderio challenges this view, positing that artifacts do more than represent routines and that they are central in our understanding of routine dynamics (2011). She contends that not only are artifacts key in how we understand routine creation and adaptation, they are also central in our understanding of materiality (D'Adderio, 2011).

Cacciatori builds on D'Adderio's view that artifacts are crucial in the creation and adaptation of routines (2012). In a longitudinal process study, she views the evolution of a technological artifact – an Excel spreadsheet - developed to afford the creation of a new routine - a bidding process in an engineering consultancy. Cacciatori uses the metaphor of routines as truce (Nelson and Winter, 1982) to explore the politics and conflicts inherent in problem solving and the creation of a new routine. She finds that the company was only marginally successful in restructuring its bidding process because of struggles for occupational dominance. Cacciatori proposes that researchers seeking to understand the development of new routines should focus on a system of artifacts rather than individual artifacts (Cacciatori, 2012).

4.3 Sociomaterialism

As has been discussed, a growing body of work takes sociomaterial perspectives in studying technology and organizational routines.

The selective studies discussed here theorize about the relationship between routines and technology. The earliest of these, published by influential organizational routines scholars, Pentland and Feldman, argues that routines and technology are inseparable (2007). Narrative networks are proposed as a way of representing patterns of technology in use (Pentland and Feldman, 2007). In their later paper (produced with colleagues Becker and Lui), Pentland and Feldman draw on notions of materiality to argue that researchers should study patterns of action, brought about through human and non-human agency, in order to understand routine dynamics (Pentland, Feldman, Becker and Lui, 2012). Using this logic, the authors present a predictive model of routine dynamics (Pentland et al, 2012).

Volkoff et al's study looks at the materiality of technology in order to explore how technology mediates organizational change (2007). By studying stages of the technological implementation process, they find that the extent to which technology is embedded is central to the process of change in organizational elements, including routines, occasioned by the appropriation of technologies. The material properties of technology are significant in how organizational routines change (Volkoff et al, 2007).

Leonardi draws on Leonard-Barton's model of mutual adaptation to argue that technologies and organizational routines are imbricated (2011). By applying this metaphor to organizational routines and technology, Leonardi draws attention to their inseparability, claiming that when people work with flexible routines and flexible technologies they choose whether to change routines or technology during implementation. They make this choice predicated on perceptions of affordance or constraint, which are developed based on past experience: when users have perceptions of constraint they change technologies, when they have perceptions of affordance they change their routines (Leonardi, 2011). This study challenges the depictions of technologies as inflexible, instead emphasizing the opportunities workers have to materially change the properties of technology. Leonardi states that the flexibility of technology is a result of its inherent material properties but because of its context of use (Leonardi, 2011).

Labatut, Aggeri and Girard's recent paper explores the interplay between the disciplinary effects of technologies and actors' performances in changes to organizational routines (2012). Using an unusual research setting, the authors draw on data collected in a comparative longitudinal case study of genetic selection technology used in the French sheep breeding industry. They find that routines and technologies have a close relationship that influences the development of institutional and organizational change (Labatut, Aggeri, and Girard, 2012).

5. Practice and routines

5.1 Practice ontology

A practice perspective is being used to study a range of organizational and management research streams including strategy (Whittington, 2007, 1996; Jarzabkowski 2004); institutional change (Smets, Morris, and Greenwood, 2012); technology and organizations (Kaplan and Orlikowski, 2013; Barrett et al, 2011; Orlikowski, 2000) and organizational routines (Pentland and Feldman, 2005; Feldman, 2000).

Researchers are encouraged to take a practice perspective in their studies of technology and organizations, to study the everyday activity of organizing (Feldman and Orlikowski, 2011). By studying everyday practices, scholars observe how the material is enacted in situ (Orlikowski and Scott, 2008).

In employing a practice lens, scholars adopt "the notion that social life is an ongoing production and thus emerges through people's recurrent actions" (Feldman and Orlikowski, 2011: 1240). They share a common ontology, informed by past social theorists (for example Bourdieu, 1990, 1977; Latour, 1987; Giddens, 1984). This ontology is underpinned by the three core interdependent principles: firstly that actors and agency are central; secondly that relations are mutually constitutive; and thirdly that dualisms are rejected as a way of theorizing (Feldman and Orlikowski, 2011).

The first of these principles emphasizes the centrality of actors and agency. It holds that "everyday actions [are] consequential in producing the structural contours of social life" (Feldman and Orlikowski, 2011: 1241). Therefore organizational researchers working in the practice perspective often use ethnographic techniques and close observation to observe people's situated actions at work (for example

Feldman and Orlikowski, 2011; Bechky, 2006; Howard-Grenville, 2005; Feldman, 2000; Orlikowski, 2000).

The second principle is one of mutual constitution. Mutual constitution underpins Giddens influential structuration theory, where it explains the enabling and constraining effects of structure and agency (Giddens, 1984). This implies that:

> "Structures (e.g. routines, institutions, and other social orders) are the product of human action, yet human action is constrained and enabled by these very structures"
> (Parmigiani and Howard-Grenville 2011: 421).

The third principle rejects dualism as a way of theorizing. In doing so it rejects the notion, prevalent in organizational studies, that phenomena are driven by opposing, conflicting forces (Farjoun, 2010). For example in March's well known organizational learning theory, firms are advocated to balance the tension between exploration and exploitation (March, 1991); in Transaction Cost Economics, firms face the choice to make or buy (Williamson, 1985); in institutional theory firms are constrained by institutions while needing to adapt and respond flexibly to environmental change (DiMaggio and Powell, 1983). Practice theorists draw instead on the notion of dualities (Giddens, 1984) seeing apparently opposing forces such as stability and change as "fundamentally interdependent – both contradictory and complementary" (Farjoun, 2010: 203).

5.2 Practices and organizational routines

Practices and organizations routines are closely related concepts; indeed the two terms are often used interchangeably. For the purposes of this thesis, theories of the practice perspective of organizational routines are drawn on to illustrate the role and relationship of these two terms (Pentland and Feldman, 2005, Feldman and Pentland, 2003; Feldman, 2000; Pentland, 1995; Pentland and Reuter, 1994).

The study of organizational routines has been recognized well before the practice perspective was developed. Early studies established their importance in organizational life. Scholars found that organizational routines enable efficient decision-making (Simon, 1947). They act as simple rules allowing organizations to react to the environment (March and Simon, 1958). Routines facilitate decision-

making and searches by providing procedures, rules and patterns of behavior in increasingly turbulent environments (Cyert and March, 1963).
Nelson and Winter's seminal work of the early 1980s, An Evolutionary Theory of Economic Change, profoundly influenced subsequent studies of organizational routines (1982). This work emphasized the centrality of studying routines in our understanding of organizations. They show that all behavior in organizations is based on routines, describing them as the "regular and predictable behavior patterns of firms" (Nelson and Winter, 1982: 14).

Levitt and March argue that organizational learning is based on routines (1988). They hold that routines are apparent in a range of objects and actions in organizations - including forms, rules, procedures, conventions, strategies and technologies to structures of beliefs, frameworks and cultures. Organizational routines exist independently of the individuals that enact them - they are more than a sum of their parts. As routines are based on past experiences, they act as repositories for organizational memory but run the risk of becoming "competency traps" (Levitt and March, 1988).

Routines influence the range of feasible behavioral options that an organization can adopt and therefore an organization's absorptive capacity (Cohen and Levinthal, 1990). In drawing on the psychological distinction between procedural and cognitive memory, Cohen and Bacdayan conceive of routines not as behaviors but as stored capabilities, or procedural memories (1994). Their experimental study shows that routines can lead to suboptimal behaviors: individuals and groups persist in using routines, despite the presence of better, alternative courses of action (Cohen and Bacdayan, 1994).

A retrospective view of research on organizational routines describes them as either following a capabilities or a practice perspective (Parmigiani and Howard-Grenville, 2011). Broadly speaking, research following a capabilities perspective takes the organization as its primary unit of analysis and seeks to show how routines contribute towards organizational goals. In contrast, research using a practice perspective, or performative view of routines, takes a micro level of analysis and explores how routines are enacted by individuals and the consequences of this enactment (Parmigiani and Howard-Grenville, 2011). This distinction is helpful in interpreting the abundance of studies of organizational routines in the management literature. Taken together, this research shows that routines are central in our understanding of organizational life; they are a ubiquitous and integral part of organizational life (Becker, 2008). The roles played by routines are varied and significant: they enable coordination; create a truce; focus cognitive attention; reduce uncertainty; and are portrayed as either driving change or leading to inertia (Becker, 2004).

The capabilities perspective views routines as the building blocks of organizations and their capabilities (Zollo and Winter, 2002; Eisenhardt and Martin, 2000; Teece, Pisano, and Shuen 1997). Empirical studies using a capabilities perspective often portray routines as unchanging, potentially leading to inertia and core rigidities (Leonard-Barton, 1992). Routines are depicted as stable and habitual (Gersick and Hackman, 1990) as potential sources of inertia in firms (Adler, Goldoftas, and Levine, 1999). Organizations have limited capacity to change routines (Hannan and Freeman 1984). Any change in routines is shown as coming from exogenous sources (Gersick and Hackman, 1990).

In contrast, the practice perspective sees routines as mechanisms for understanding organizational change (Parmigiani and Howard-Grenville, 2011; Pentland and Feldman, 2005; Becker et al, 2005; Feldman and Pentland, 2003; Feldman, 2000). Routines are components of organizations and organizing that enable researchers to view actions or elements at micro levels. The endogenous performance of the routine is seen as a source of generative change (Pentland and Feldman, 2003; Feldman, 2000).

5.3 The practice perspective of organizational routines

The practice perspective of organizational routines is a theory of routines as practices (Feldman and Orlikowski, 2011). It was developed in the mid- 1990s and early 2000s (Pentland and Feldman, 2005; Feldman and Pentland, 2003; Feldman, 2000; Pentland, 1995; Pentland and Reuter, 1994). It portrays organizational routines as effortful accomplishments; individuals enact routines by mindfully selecting their performance from a repertoire of available actions (Pentland, 1995; Pentland and Reuter, 1994). Thus attention is brought to the potential for endogenous change in routines (Parmigiani and Howard-Grenville, 2011).

Feldman's study of organizational routines was influential in establishing this perspective (2000). In her ethnographic study of a student-housing department of a large state university, Feldman observes five routines of "mind-numbing stability", namely hiring, training, budgeting, moving students into residential halls and closing them. In contrast to extant literature, Feldman found these routines constantly changing through individual actors' performances. Thus she observed a generative process of change in the enactment of routines, created through the "mutual constitution and recursive interaction between the actions people take and the patterns these actions create and recreate" (Feldman, 2000: 102).

From this study, and drawing on the earlier work of scholars, the theory of routines as practice continued to develop (Pentland, 1995; Pentland and Reuter, 1994). The generative process driving routine change is expanded in Feldman and Pentland's later paper, Reconceptualising Organizational Routines as a Source of Flexibility and Change (2003). Here they present a core definition of organizational routines, which is used in this study, as: "a repetitive, recognizable pattern of interdependent actions, involving multiple actors" (Feldman and Pentland, 2003: 96).

As illustrated in Figure 3, they describe the routine comprising an ostensive element, which is the "abstract, generalized idea of the routine" and a performative element, which involves "specific actions, [taken] by specific people in specific times and places" (Feldman and Pentland, 2003: 101). The ostensive provides "resources for guiding and accounting for action", and the performative "recreates, maintains and can change the ostensive" (Feldman and Pentland, 2003: 101). The performative represents the routine in practice; the ostensive represents the routine in principle (Feldman and Orlikowski, 2011). The relationship between these two parts of the routine is generative and provides an opportunity for ongoing change that is endogenous to the routine itself (Feldman and Pentland, 2003).

In a paper published two years later as part of a special edition of Industrial and Corporate Change, Pentland and Feldman consolidate their generative change model, as shown in Figure 3 (2005). They add artifacts to their existing model, describing them as “the physical manifestations of the organizational routine” (Pentland and Feldman, 2005: 797). They enable and constrain change in organization routines and their range is practically endless. Pentland and Feldman also identify the Darwinian algorithm of variation, selection and retention as driving generative change in routine performance. By exploring the relations between these three elements, researchers can gain a better understanding of sources of stability, rigidity, innovation, flexibility and change in organizational routines (Pentland and Feldman, 2005).

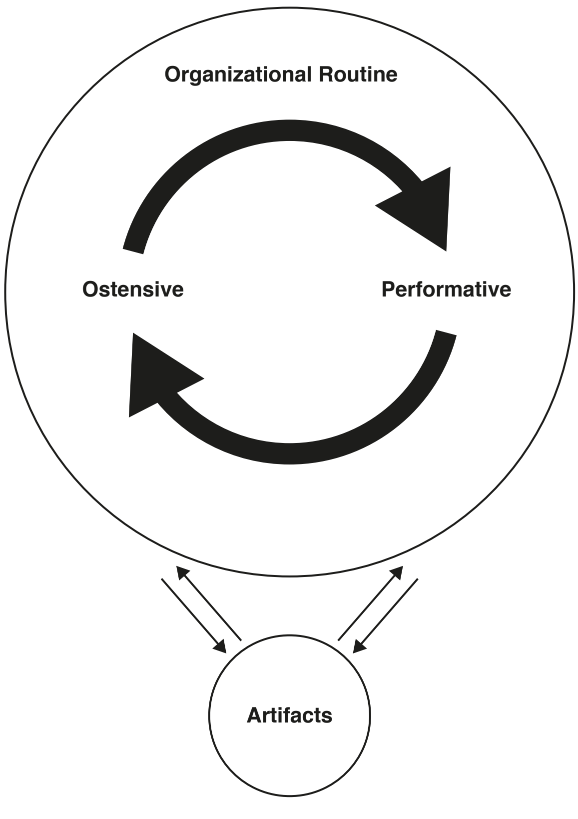

Figure 3: The practice perspective of organizational routines, reproduced from Pentland and Feldman 2005.

Many scholars adopted this theoretical model in studies of routine dynamics and organizational change (Becker, 2005). For example, variation in routines performances was found to signify particular variance and change (Pentland, 2003); routines differ in their flexibility (Howard-Grenville, 2005; Feldman, 2003); routines are changed by rules (Reynaud, 2005) and standards (Lazaric and Denis, 2005); they are transferred in product development (Bresman and Zellmer-Bruhn, 2013); and artifacts play a key role in routine creation and dynamics (Cacciatori, 2012, 2008; D'Adderio, 2012, 2008, 2003).

6. Context

6.1 The situation of action

This section describes theory relating to the second research question in this study, which addresses organizing for technological implementation in complex operations. It builds on the hypotheses put forward in the first research question – that routine dynamics play an important role in technological implementation - but adds to it by introducing the context of technological implementation, embedding this process in a specific operational and organizational context.

Both of the theoretical lenses adopted here – namely practice theory and sociomaterial perspectives of technology and organizations – emphasize the importance of the context of actions. In practice theory, as described by mutual constitution, everyday actions are consequential in producing structures and structures are equally consequential in producing everyday actions (Feldman and Orlikowski, 2011; Giddens, 1984).

The context of actions is a key guiding principle in the practice perspective of organizational routines and critical in understanding endogenous change. (Pentland and Feldman, 2005). It drives the process of variation, selection and retention that accounts for routine dynamics (Pentland and Feldman, 2005).

Context is also central in sociomaterial theories. Practices are located, embedded or nested within wider institutional and social contexts (Orlikowski and Barley, 2001). They are constrained and afforded by organizational rules and routines (Scott and Orlikowski, 2014). Through practices and structure, changes in boundaries are afforded and constrained, as is apparent in actions. Practices catalyzed by technological change can shift occupational and professional boundaries (Mazmanian, Orlikowski, and Yates, 2013; Barrett et al, 2011).

Thus recent studies adopting sociomaterial perspectives have viewed practices as nested in context. Similar to earlier sociotechnical notions of technological systems (Hughes, 1987), technological fields are aggregations of all organizations that influence the development, use, regulation or exploitation of a technology; they focus attention on the reciprocity between practice and wider structures (Whyte, 2010; Granqvist, 2007). Technology is used within a wider ecology of practice (Whyte, 2011). Technology starts a complex pattern of innovations across distributed networks of practice (Boland, Lyytinen, and Yoo, 2007). Historical context is important, with technological implementation and use dependent on users' perceptions of technology that, in turn, are based on past experiences (Leonardi, 2011). Technologies have a fundamental influence on the co-evolution of institutions and organization (Labatut, Aggeri, and Girard, 2012). The material properties of technologies are significant in affecting change (Volkoff, Strong, and Elmes, 2007).

6.2 Complex operations

In studies of technology and organizations, complexity is an important contingency. As with Woodward's earlier typology of technologies, which identifies three types of technology classified according to its complexity (1958), so the development, use and regulation of complex technologies is attracting the attention of sociomaterial researchers (Mazmanian, Orlikowski, and Yates, 2013; Barrett et al, 2011; Leonardi and Barley, 2010; Whyte, 2010). However little attention has been paid to organizing for technological implementation in complex operations.

Such settings are described in a theoretical framework of knowledge processes – that is knowledge about how to produce a desired result - which vary across a range of work settings (Edmondson, 2012). Edmondson's knowledge process spectrum illustrates this, showing a range of knowledge about how to produce a desired result. As illustrated in Figure 4, at one extreme of the process knowledge spectrum are routine operations, as found in fast-food restaurants, at the other are innovative operations, for example in pioneering research and development laboratories. In routine settings, process knowledge is mature and uncertainty is low. In innovative settings, process knowledge is immature and uncertainty is high (Edmondson, 2012).

Complex operations lie in the middle of the process knowledge spectrum. They comprise "well-understood processes, novel situations and unexpected events" (Edmondson, 2012: 37). They can be seen in settings such as hospitals, consultancies, architecture and engineering firms (Edmondson, 2012). Actors performing complex operations both draw on existing routines and create new ones or adapt existing routines, in order to enact old and new tasks. This implies that processes of organizing for technological implementation in complex operations will involve significant change.

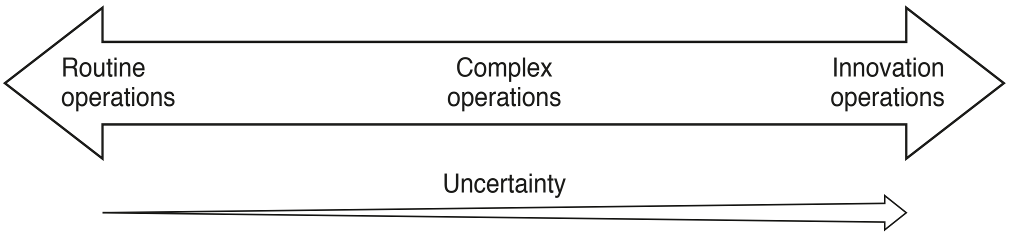

Figure 4: The Process Knowledge Spectrum, adapted from Edmondson, 2012

6.2.1 Organizing to Learn

The knowledge process framework implies that the process of organizing is contingent on the setting; a good fit between operations and the wider organization creates an enabling relationship, and vice versa (Edmondson, 2012). When applied to organizing for technological implementation, this framework shows how the actions of firms and users are mutually constitutive, existing within a wider ecology.

Thus the process of organizing in the firm should match the operations in it, be they routine, complex or innovative. Organizing to learn is an approach that is suitable for complex operations. It operates on two interacting levels: at user and organizational level. Together, the firm and individual user level enable new routines to be created in complex operations.

Collective learning, facilitated by leadership, is central to approaches of organizing to learn. Collective learning is a form of organizational learning, that occurs when “individuals express their opinions and beliefs, engage in constructive confrontations and challenge each other's viewpoints” (Zollo and Winter, 2002: 341).

Learning is intrinsic to routine dynamics and vice versa: organizational learning is based on routines (Levitt and March, 1988) and organizational routines evolve through a process of learning (Nelson, 1995). Deliberate learning drives the evolution of a firm’s dynamic capabilities, and in turn its operating routines (Zollo and Winter, 2002); firms learn and adapt their routines in response to technological change (Massini, Lewin, Nunagami, Pettigrew, 2002), and learning serves to reduce uncertainty in innovating routines (Pavitt, 2002).

Specifically, learning plays a key role in how technologies are used: vicarious individual learning is important (Leonard-Barton and Deschamps, 1988). Routines develop as technologies are used at work (Leonard-Barton, 1988; Edmondson et al, 2001). The nature of the technology affects the learning curve observed, with radical new technologies resulting in longer periods of learning (Aiman-Smith and Green, 2002).

When implementing complex, interdependent technologies, such as BIM, users should employ ‘learning by using’ approaches (Rosenberg, 1982). Learning by using creates new information that can be fed back into the hardware and user environment. It therefore describes a cyclical process of adaptation that involves changes to both the user environment and the technology. Recent research shows that the flexibility of technologies, apparent in their material properties and their context of use, influences how users change it during implementation (Leonardi, 2011).

Collective learning has been studied at varying levels of aggregation, both within and between organizations. Inside organizations it occurs in teams (Edmonson et al, 2001; Edmonson, 1999), departments (Dougherty, 1992), and across organizations (Zollo and Winter, 2002; Pavitt, 2002). Between organizations, producers of technologies can be involved in collective learning, thus benefiting from valuable information generated when technologies are used (Baldwin and von Hippel, 2011; von Hippel, 2005, 1976); collective learning in projects can create wakes of innovation that spread across networks of firms (Boland, Lyytinen, and Yoo, 2007).

7. Chapter summary

This chapter has established that the relationship between organizations and technology is significant. The most recent approach used to study this relationship is sociomaterial. Scholars adopting this stance study dynamic practices enacted when using technology.

The practice perspective of organizational routines is selected as a suitable framework to use in order to study how users' evolving practices and routines influence processes of technological implementation. Like sociomaterial perspectives, the practice perspective of organizational routines views them as sources of generative change. This change is driven by changing performances of the routine and it driven by the mutually constitutive relationship between elements in it.

By combining the practice perspective of organizational routines with Edmondson et al's process model of technological implementation, technological implementation is shown to be a circular, ongoing process as opposed to a linear, finite one. Empirically, it provides a fine-grained account of how BIM is being implemented. It unpacks this process and shows how this implementation evolves over time.

Building on this, technological implementation is embedded in distinct context – that of complex operations. The approach of organizing to learn in such settings reveals the generative relationship between organization and user in technological implementation. Theoretically by adopting this framework, the role of organizations and relationship between organization and user when implementing technologies is elaborated. By adopting an organizing to learn approach, firms in the construction industry can speed and aid the implementation of technologies.

Chapter 3: The UK construction industry and BIM

1. Introduction

This chapter presents the empirical setting and process studied in this thesis, namely the implementation of BIM at a design firm working in the UK construction industry.

As shown in Table 8, this is an interesting and appropriate empirical setting in which to study the research questions of a) how do organizational routines and practices influence processes of technological implementation in firms and b) how can firms organize for technological implementation in complex operations?

In considering the first research question, in the construction industry work is heterogeneous and situated in a complex ecology (Whyte and Sexton, 2011). This chapter describes multiple nested elements in this ecology; the industry, its institutions, firms, and individual actors. It highlights recent change initiatives and the potential for conflict between these elements.

The second research question is concerned with processes of organizing for implementation. Previous studies of technological change indicate that implementation is slow in the industry (Whyte and Bouchlaghem, 2002; Gann, 2000; Bouchlaghem and Liyanage, 1996). However the process of implementation is critical, as the construction industry often imports and adapts technologies from other sectors (Salter and Gann, 2003; Whyte, 2003; Whyte and Bouchlaghem, 2002; Currie, 1989).

Recent studies have focused on how practitioners use technologies in the construction industry. Studies of digital infrastructure, including BIM, show that individuals juggle multiple and often conflicting demands in their work (Dossick and Neff, 2010). Consqequently hybrid practices, comprising digital and traditional ways of working, are often used in project settings (Harty and Whyte, 2010; Whyte, 2011). This line of research holds much potential for generating insights into technological implementation in the UK construction indsutry.

This chapter proceeds as follows. It describes the UK construction sector from multiple levels – the industry, its firms and individuals. Insitutions, processes and change are addressed in this discussion. Technological change in the industry is described generally and implementation of technology discussed specifically. Building Information Modeling (BIM) is presented and its use from 2000 to present day discussed.

Research questions	**How do practices influence processes of technological implementation?**	**How is technological implementation organized in complex operations?**
Empirical setting	Construction sector – nested levels of industry, institutions, firms, projects and users. Resistant to change: problems with embedding change.	
	Practices and routines evolve in a complex ecology. This ecology of practice includes many conflicting norms and values..	Operations in the construction industry are complex. They involve a mixture of old and new tasks.
Technology	Building Information Modeling: "Database with drawings" Generic system of technology imported and adapted for construction industry.	
Technological implementation	Technological implementation is vital for the construction sector as technologies are imported. However it is currently a slow and unsatisfactory process. Recent research viewing technological implementation from a practice perspective offers promising insights into this.	The process of technological implementation occurs differently in complex operations, where old and new tasks collide. Organizing for technological implementation is a critical capability for the construction industry, and firms working in it, to develop.

Table 4: Overview of the research setting

2. The UK Construction sector

Construction is one sector in a wider economic system in the UK. Sectors refer to an aggregation of organizations that share a common line of business (Whyte, 2003). Sectorial analysis is widely used by economists and business scholars to examine innovation and production activities. The economics of the construction sector in the UK have been the subject of much research in the last 50 years (see Chang, 2015 for a review).

There are narrow and broad definitions of the construction sector (Pearce, 2003). As shown in Figure 7, the narrow definition of the sector refers to on-site assembly and repair of buildings and infrastructure and is usually the domain of main and sub contractors (shown in box 4, Figure 7). This narrow definition of the construction sector is used in official statistical measures (using the Standard Industry Classification code 45).

The broad definition of the sector extends to include the entire supply chain involved in the building process. It encompasses on and off site activities, design, construction, and management and post occupancy activities. Thus it incorporates boxes 1-6 in Figure 7, including the supply chain for construction products and professional services such as architecture, engineering design, management and other specialist consultants.

For the purposes of this study, the broad definition of the construction sector is used.

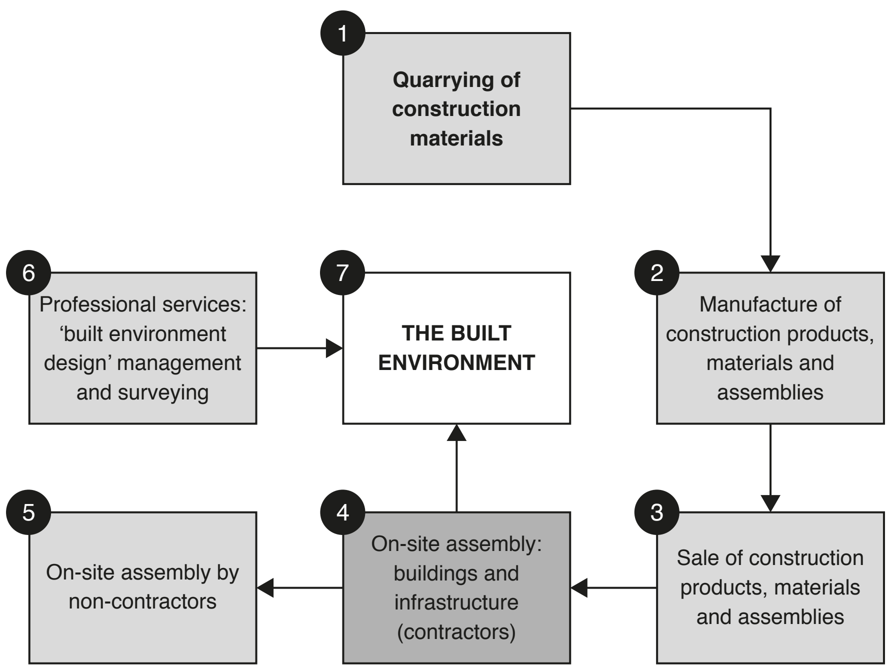

Figure 5: The structure of the UK construction sector, adapted from Pearce, 2003.

2.1 The industry

In the UK, the construction industry includes firms and institutional bodies involved in the production of the built environment. As shown in Figure 8, the construction industry impacts settings beyond the built environment. Thus it generates significant economic, social and environmental value for the UK (HMSO Digital Built Britain, 2014; Pearce, 2003). Using the narrow definition of the industry, it accounts for some 7% of the UK's GDP in 2011 (Office for National Statistics, 2011). Using the broad definition of the industry, this figure doubles (Pearce, 2003). In 2014 the industry provided employment for more than three million people in the UK (HMSO Digital Built Britain, 2014).

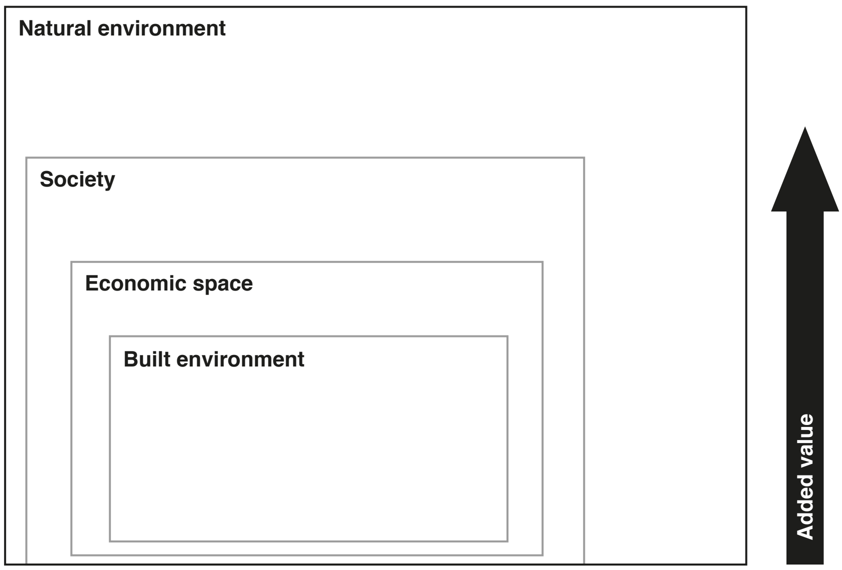

Figure 6: The construction industry in context, reproduced from Lorsch 2003.

The construction industry works in a number of markets including major projects, infrastructure, general building, housing, heritage and repair and maintenance (Pearce, 2006, 2003; Saxon, 2002). As shown in Figure 9, projects in these markets are grouped by their value, using three categories up to £1m, £1-£20m and over £20m. The proportion of projects falling into these categories varies. By definition major projects are over £20m and include elements of civil and building projects. Infrastructure comprises civil engineering projects, the majority of which are worth over £1m. The general building sector comes next, accounting for some 25%

of the value of the industry's projects. Finally projects in the housing, heritage and repair and maintenance sectors are proportionally of equal value. Together these sectors account for some 60% of the value of the industry's projects, with repair and maintenance alone accounting for 40%.

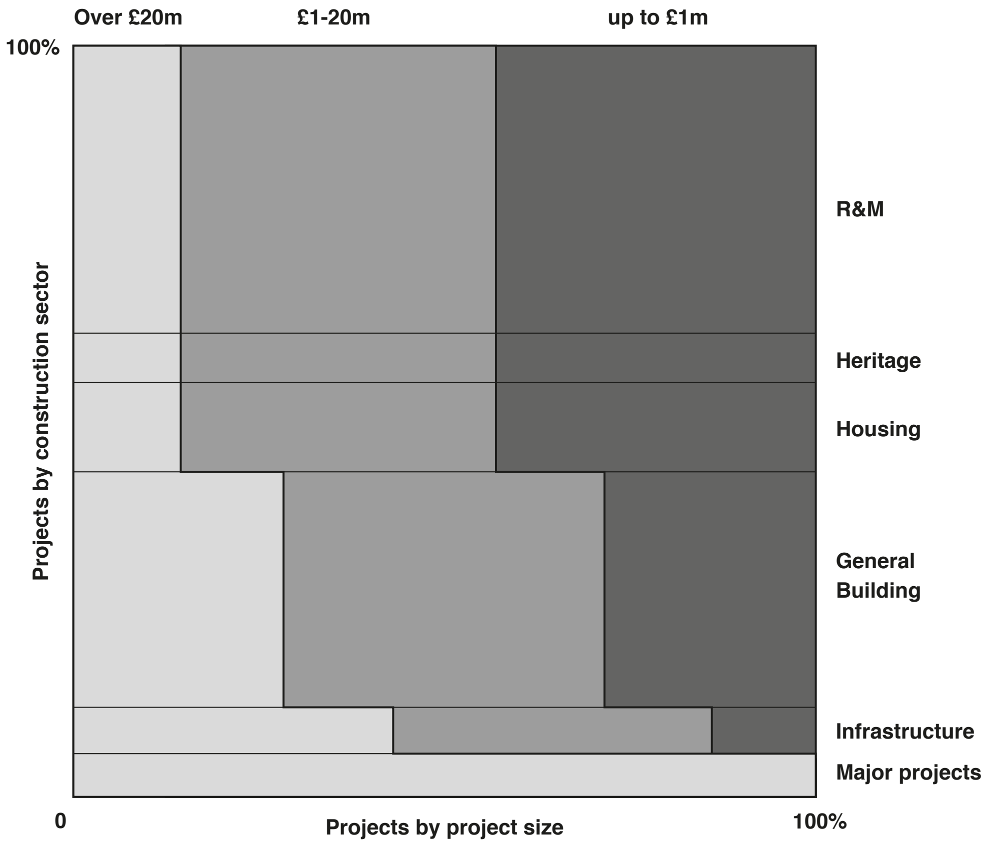

Figure 7: Markets in the construction industry, reproduced from nCRISP 2004.

2.2 Firms

The construction industry comprises many firms that vary significantly in size and capabilities. They deliver a range of services across a number of markets.

This study focuses on one type of organization in the construction industry that offers professional services, as shown in Box 6 in Figure 7. The construction professional service firm is a prominent yet under-researched organizational form in the industry (Connaughton et al, 2015; Connaughton and Meikle, 2012).

Construction professional service firms are measured by the Office of National Statistics using Standard Industry classifications 71 (architectural and engineering activities, technical testing and analysis) and 74 (other professional, scientific and technical activities). Using this definition, construction professional service firms undertake design, management and surveying activities.

Two prominent streams of research draw attention to and describe different aspects of construction professional service firms. Both of these theoretical perspectives are useful in understanding the organizational setting for this research.

The first views such settings as Professional Services Firms (PSFs). The nature and influence of knowledge in PSFs is an overarching theme in these studies (Alvesson, 2004, 2001; Starbuck, 1992; von Nordenflycht, 2011, 2010). The second describes them as project based firms (PBFs), thus drawing attention to the relationship between temporary projects organizations and permanent parent organizations, and how resources and capabilities are created and transferred between them (Brady and Davies, 2004; Davies, 2005; Gann and Salter 1998, 2000). Most studies use these theoretical perspectives separately. However recent studies have combined them to generate insights into how knowledge can be managed in firms that are both project based and deliver professional services (Manzoni, 2011; Criscuolo, Salter and Sheehan, 2007).

Turning first to studies of Professional Service Firms (PSFs). They are distinct organizational forms which first attracted the attention of management researchers and sociologists in the 1960s, as they became the worksetting of choice for many professionals (Raelin, 1991). They comprise salaried professionals who carry out their craft collectively, rather than in private firms (Raelin, 1991). Where research had previously focused on the individual professional and his or her affiliation with a profession, the role of the collective corporate organization needed to be addressed in order to develop a more accurate conceptualization of the professions.

PSFs are said to have three defining characteristics, each of which generates challenges for collective organizing in firms. First, knowledge intensity, which gives rise to the opaque qualitity of services rendered (because of the assymetry of expertise between the client and PSF) and the "cat-herding" problem of managing PSFs (discussed below). Second, low capital intensity which increases employees bargaining power with management. Third, conflict between professional and commercial norms and values (von Nordenflycht, 2010).

The core competence of PSFs is knowledge. Knowledge resides and is deployed in the individuals that are employed in the PSF; therefore the value of human capital in PSFs is high, as is the power of those that possess this knowledge (Maister, 2007).

PSFs are seen as examples of knowledge-intensive firms (KIF) (Alvesson, 2004, 2001; Starbuck, 1992). Scholars consider the challenges facing PSFs as representative of those facing KIFs and their managers more widely. Managers should create conditions under which professionals have the capacity to "learn how to learn" (Argyris and Schön, 1977).

The challenges of managing PSFs form the basis of an influential practitioner-focused work, first published the 1990s (Maister, 1993). It likens attempts to manage PSFs to herding cats because of the autonomy of professionals and their resistance to management control (Maister, 2007). For managers of professional service firms in the construction industry building long-term relationships and trust with external collaborators is particularly valuable (Smyth, 2011).

Managers of PSFs face two main challenges. First is that professional services are highly customized, therefore routines are difficult to create. Management principles derived from industrial organizations are based on standardization of repetitive tasks and often cannot be applied in PSFs. Second quality is difficult to manage collectively as many professionals deal with clients individually and directly. In light of this, managers of PSFs are encouraged to see their role as:

> "A delicate balancing act between the demands of the client marketplace, the realities of the people marketplace and the firm's economic ambitions." (Maister, 1993: 3).

Managers are advised to adopt a portfolio approach to managing their projects, developing a range of profitable routine projects through to more experimental "brains projects" (Maister, 2007).

The second influential body of literature relating to the organizational setting of this research focuses on its project intensity. Project based firms (PBFs) are permanent organizations whose employees enact much of their work within temporary projects organizations (Lundin and Söderholm, 1995). They differ from traditional function and matrix organizations, offering the flexibility to meet the demands of dynamic environments and create complex products (Davies and Hobday, 2005; Salter and Gann, 2003; Gann and Salter 2000, 1998). They are similar to Mintzberg's adhocracies in his description of the major organizational forms, as the dominance of temporary project teams means they are flexible and agile (Mintzberg, 1979).

A variety of empirical settings is testament to the increasing prevalence of PBFs, with research using data gathered from advertising, software as well as design and construction firms (Brady and Davies, 2004; Grabher, 2002; Salter and Gann, 1998; Defillippi and Arthur, 1994). A rich stream of research has been generated through this perspective, addressing issues such as project and organizational learning (Prencipe and Tell, 2001); cross boundary working (Dodgson, Gann and Salter, 2007); innovation (Salter and Gann, 2003; Gann and Salter 2000, 1998) and organizational and project capabilities (Brady and Davies, 2004; Davies and Brady, 2000).

The transfer of resources and capabilities between permanent and temporary organizations is a dominant theme. Gann and Salter's 2000 study into the management of innovation in firms producing complex products and services illustrates this. They find that project-based, service-enhanced enterprises offer specific challenges relating to innovation management. Such firms can only reproduce technological capabilities by integrating project and business processes in the firm (Gann and Salter, 2000). Later work showed that PBFs simultaneously pursue exploitative and explorative strategies in order to facilitate this replication process (Davies and Brady, 2000; Brady and Davies, 2004).

Recent research into project based organizing emphasizes the need for research to consider context, both historical and temporal (Lundin et al, 2015. Projects are nested in a wider ecology (Grabher, 2004, 2002; Engwall 2003). A mutually constitutive relationship exists between elements in this ecology that change and are changed by multiple levels, individual and institutional (Grabher and Thiel, 2015).

Scholarly interest is increasing in studying practices in projects (Lundin et al, 2015). Such a perspective offers the opportunity to capture the reality of project work, while generating insights into their wider context. Research using a practice perspective to explore the "interface between organizing as a routinized activity and organizing as a reflective, possibly innovative practice" would be of particular value (Lundin et al, 2015: 229).

2.3 Heterogeneous actors

In contrast to homogeneous policies, the construction industry comprises a diverse group of actors working across occupational and organizational boundaries in changing, institutionalized settings.

These individuals are drawn from an array of disciplines, from traditional design professions such as architecture and engineering, to contractors and their subcontractors. New and specialist disciplines, such as project managers, environmental designers and information managers, often supplement these traditional roles as the complexity of construction increases. Many of these new disciplines take a significant role in the team and are gaining professional status (Konstantinou, 2015; Kelly, Edkins, Smyth and Konstantinou, 2013).

Interdependencies between the disciplines are pronounced. Construction processes rely, to a greater or lesser extent, on coordination and communication across all stages. The need for individuals in the construction industry to collaborate effectively is becoming more pronounced. The advent of technologies such as BIM is increasing the urgency to improve collaboration. Despite this, the construction industry continues to struggle to collaborate (Wolstenholme, 2009).

This is partly explained by the disparate norms and values held by each member of the construction team. Each discipline has markedly different norms and values. They can create conflict, making sharing ideas across these thought worlds difficult (Dougherty, 1992) and leading to the non-spread of innovations (Ferlie, 2005).

Work in the traditional professions of architecture and engineering are highly institutionalized, reinforced through lengthy training and professional bodies. Foundational research in institutional theory by DiMaggio and Powell finds that the institutionalized nature of such traditional professions leads to strong forces of isomorphism being exerted on them (1983). Therefore traditional professions, such as those found in the construction industry, often struggle to change and adapt. Shared norms and values influence such traditional professions strongly. For example, the architect is said to be an extreme example of a professional who sacrifices economic gains for aesthetic (Pinnington and Morris, 2002). In stark contrast to this are contractors, who are perceived as following adversarial, cost-driven ways of working (Wolstenholme 2009; Egan 1998; Latham 1994).

Role and hierarchies in the construction team are changing. Reflecting the findings of scholars studying the changing work and role of professionals (for example Abbott, 1988), these changes hamper collaboration and contribute to adversarial behaviors between team members. The causes of such changes are varied. They are partly macro-economic: the industry enjoyed a post-war building boom but market demand declined significantly in the late 1970s. In parallel, increasingly complex products were demanded by clients (Gann and Salter, 2000), global competition was growing, and new technologies were having a profound effect on the processes and products of the industry (Gann, 2000; Whyte 2002).

Changes in roles and hierarchies also reflect a wider societal shift in professional markets. When the Royal Institute of British Architects (RIBA) was established in 1864, architects assumed a rarified, privileged position in the team. They were defined as 'gentlemen unconnected with any branch of building as a trade or business'. Under this traditional hierarchy, architects worked directly with and on behalf of clients; engineers assisted architects and developed their designs into buildable solutions; contractors were kept distant from the client – their sole role was to build the architect's design.

However much has changed over the last 100 years. Today's architect is a "virtually unrecognizable figure" compared to an "older generation of practitioners familiar with a lofty gentlemanly and professional status" (xii, Allinson, 1993). Engineers work in huge range of specialisms, beyond traditional structural and civil engineering. Contractors work directly for the client and supply them with design as well as construction services. Architects and engineers are often subcontracted to the main contractor.

This shift was catalyzed by the deregulation of the architectural market. Reflecting widespread changes to the traditional professions, mandatory fee scales for architects were abolished by the RIBA in 1986 (Symes, Eley and Seidel, 1995). The ban on advertising architectural services was lifted three years earlier in 1983. However, unlike medicine and law, architects did not secure a monopoly on their services: therefore while the title of architect remains protected, the services they supply do not.

2.4 Processes and institutions

In the construction industry, building projects generally follow institutionalized, standard processes, laid out by industry bodies such as RIBA in its Plan of Works (Sinclair, 2013) and the Construction Industry Council's (CIC) in its Scope of Services (CIC, 2007).

These process maps demonstrate the historic split between design and construction. For example in the RIBA's Plan of Works, illustrated in Figure 10, the first five of eight stages involve design processes, moving from conceptual, to detailed, to technical design. The sixth stage relates to construction, with the seventh involving handover and close out of the building. The final stage refers to the building in use. Traditionally architects and engineers undertake the first five of these processes, while contractors and their subcontractors undertake the later processes of construction. Increasingly other specialist consultants and newer disciplines are also involved, such as project and design managers, IT consultants, as needed.

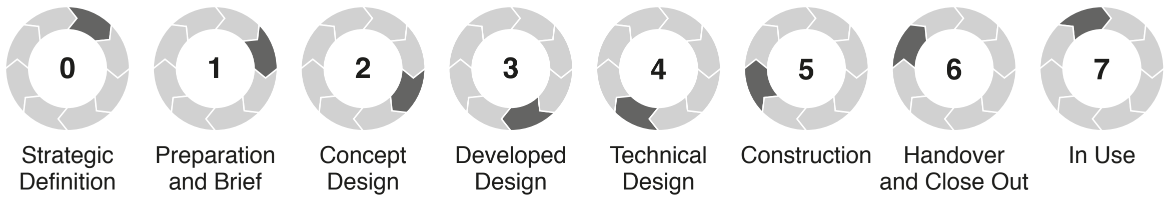

Figure 8: Royal Institute of British Architects Plan of Works 2013

The roles and responsibilities of each member of the team however are dependent on the nature of the contract and type of procurement used. As discussed in the previous section, these have changed considerably since the 1980s. Approaches to procuring buildings reflect these changes.

Traditional procurement methods dominated in the UK from the 1800s to the late 1970s. They placed the architect as design lead, as shown in simplified form in Figure 11. Under these traditional arrangements, the client directly appoints the architect to act as its main advisor. The client then appoints the engineer and contractor, often with considerable guidance from the architect.

New forms of contract introduced in the 1980s changed this hierarchy dramatically. For example, as shown in Figure 12, under Design and Build, clients directly appoint contractors who then subcontract architects and engineers. Also in the 1980s, Private Finance Initiatives became popular vehicles for securing private funding for major public sector projects, bringing cost savings and encouraging innovation (Ive, Edkins and Millan, 2000; Ive and Edkins, 1998). Such changes led to a number of major contracting firms becoming involved in the

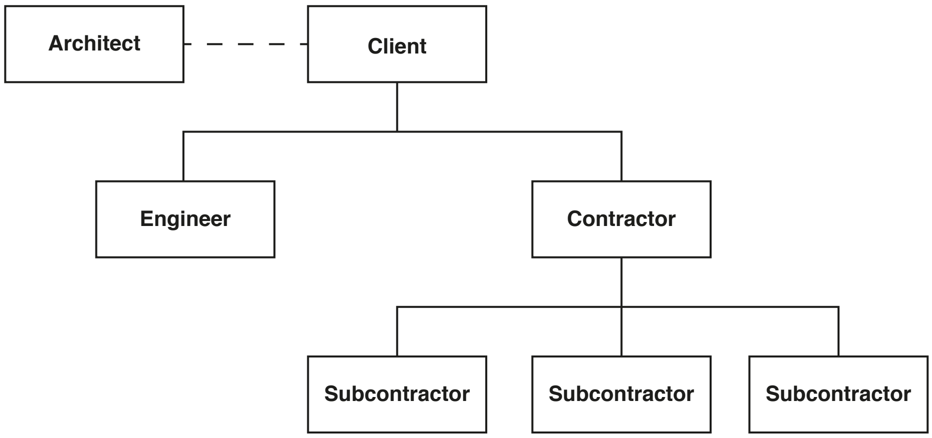

Figure 9: Typical traditional procurement contract structure

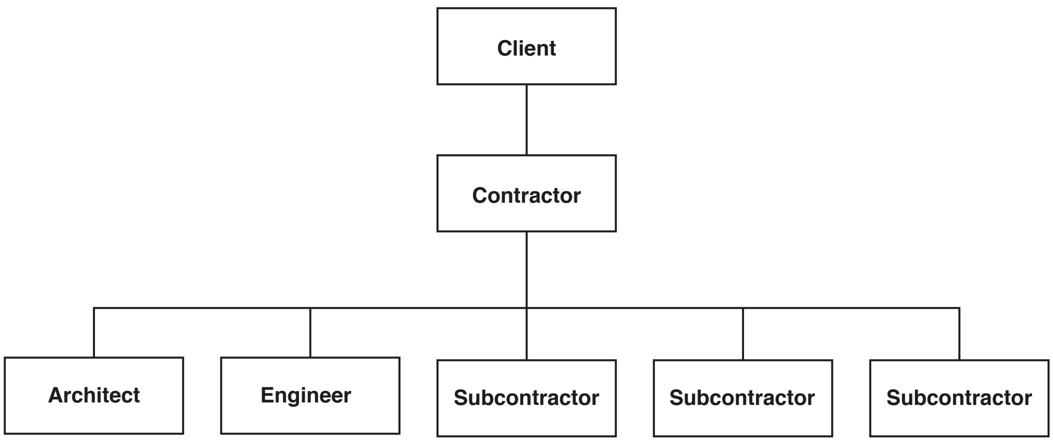

Figure 10: Typical Design and Build contract structure

servicing and financing of the built environment, and created lasting institutional reform (Winch, 2000)[3].

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[3] There are now four main methods used for procuring buildings in the UK: traditional, design and build, management and integrated (www.jciltd.co.uk/procurement, 20.11.2015). Standard forms of

2.5 Change and policy

A number of firms seized the opportunities created by these changes. They developed the capabilities required to deliver the complex, major projects that were increasingly prevalent in the construction industry. These projects are high-tech, capital intensive engineering projects of a significant scale and duration, which require firms to work collaboratively (Davies and Hobday, 2005; Hobday, 2000, 1998; Miller et al, 1995).

Firms working on major projects often supply complex capital goods and services (Hobday 1998). They are examples of new organizational forms, such as project-based, service-enhanced firms that can deliver these complex products and services (Salter and Gann, 2003; Gann and Salter, 2000, 1998). Increasingly the role of traditional design professionals such as architects and engineers are being minimized, with a growing need for systems integrators, who can manage networks of interorganizational collaboration involved in complex, often large, projects (Davies 2004).

Research captures the innovations and experience gained in such projects. For example at Heathrow Terminal 5 new capabilities and business models were developed through systems integration (Davies, Gann and Douglas, 2014, 2009). The project provided substantial insights into how mega projects should be managed (Brady, Davies and Gann, 2006). An innovative digital infrastructure was developed at Terminal 5 (Whyte, 2013; Harty and Whyte, 2009). Underpinned by a single model environment, this digital infrastructure enables coordination across occupational and project boundaries (Whyte and Harty, 2012). In the 2012 London Olympics, the project's visible physical legacy is matched by a less apparent legacy in individual careers and learning (Grabher and Thiel, 2015). Crossrail is changing the way complex projects are being delivered in the industry, through evolving project management processes (Whyte, Statis and Lindvist, 2015).

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contract match these approaches, with the Joint Contract Tribunal (the issuer of standard contracts in the construction industry) currently producing 14 different types of contract.

While the influence of major projects is substantial, only a small number of firms in the construction industry have the capabilities to work on them. Therefore a limited group of firms recurrently works on major projects. For example, firms working on Heathrow Terminal 5 include design consultants Arup, contractors Laing O'Rourke, AMEC and MACE, architect Rogers Stirk Harbour and Partners, under the leadership of an experienced client, the British Airports Authority. All of these firms went on to work on subsequent major projects such as the London 2012 Olympics and are current working on Crossrail.

However, the emergence of this elite group of firms serves to emphasize the notoriously fragmented nature of the construction industry (Pearce, 2003). This is evident in the range of work the industry does and the variety of organizations that it comprises which range from large multidisciplinary consultancies and contractors to numerous small and medium enterprises (Pearce, 2003).

As a whole, the construction industry is viewed as underperforming, failing to deliver for its clients and the national economy (Cabinet Office, 2011). Driven by the economic and social value of the industry, the UK Government attempted to remedy its underperformance through a series of policy interventions in the 1990s. It therefore commissioned the Latham and Egan reports, published in 1994 and 1998 respectively. Both reports emphasize the need for greater industry integration and collaboration in order to improve industry performance. The *Latham Report* condemns existing industry practices as adversarial, ineffective, fragmented, and incapable of delivering for clients. It advocates partnering and collaboration, and emphasizes the need for teamwork in the industry (Latham, 1994). The *Egan Report* develops these themes and emphasizes the importance of developing integrated project processes. It identifies five key drivers for change in the construction industry: committed leadership; a focus on the customer; integrated processes and teams; a quality driven agenda and commitment to people (Egan, 1998).

The reports' recommendations were translated into the "industry improvement agenda". Government invested in the implementation of this agenda through a number of existing and new industry bodies. A range of initiatives and lobbying activities were carried out including a series of Demonstration Projects, which served as examples of how aspects of the improvement agenda could be realized in reality; developing industry KPIs in order to benchmark projects and organizations; and establishing networking clubs to help drive the industry improvement agenda at regional level.

However, the industry has proved resistant to change. A decade after the publication of the Egan Report, Andrew Wolstenholme reviewed progress on the industry improvement agenda, working with industry body, Constructing Excellence (2009). His report concludes that there is limited evidence of industry change and improvement, and that the changes called for in the Latham and Egan reports have not been embedded in the industry. Examples of current industry work illustrates that commitment to Egan principles is often skin deep. Apparent improvements in performance made during the improvement agenda were not lasting and had failed to penetrate most supply chains (Smyth, 2010).

Adversarial behaviors persist, with many firms continuing to try to avoid or exploit risk in order to maximize their own profits, rather than finding ways of sharing risk and collaborating genuinely. These conclusions are echoed in forewords written by Sir Michael Latham, Sir John Egan, and the Minister for Construction at the time, Nicholas Raynsford (Wolstenholme, 2009).

Despite this apparent lack of success, UK government continues to attempt to intervene in and improve performance in the industry. Most recently it has attempted to accelerate the uptake of BIM, as discussed in detail in section 4.3 of this study.

3. Technological change

The products and production of the built environment have experienced extensive technological change since the mid-1900s (Whyte 2013, 2003; Salter and Gann, 2003; Gann, 2000). Since this time, a number of ICTs have been incorporated into existing work.

The transition from using paper-based drawing to Computer Aided Drafting (CAD) to create visual representations of projects marks the beginning of this process. The capability for coordinating geometric information was first developed by MIT in the 1960s. General CAD applications were introduced in the construction industry in the 1970s and were in common use in design firms by the 1980s. Personal computers made this technology economically viable for most design firms (Gann, 2000). 2D drawing was supplemented and eventually replaced by 3D CAD based on solid modeling techniques.

A growing body of evidence indicates the potential of ICTs to drive change and improve the efficiency and effectiveness of industry. Yet the implementation of technologies remains problematic for the producers of the built environment (Gann, 2000). Studies of attempts to implement CAD reinforce this view, finding that the diffusion of technologies was unexpectedly slow in the industry (Bouchlaghem and Liyanage, 1996). They concluded that:

> “The slow rate of adoption and apparent inability of design and construction to derive benefits from ICTs indicated that the sector was not particularly successful in its investment in new process technologies.” (Gann, 2000: 155)

As most of the technologies used in the construction industry are imported from elsewhere, technological implementation is critical. The construction industry does not generally create or invent new technologies but imports generic technologies (Whyte, 2013a, 2003; Whyte and Sexton, 2011). This is demonstrated in Pavitt’s influential taxonomy of sectorial innovations, which identifies construction as a project-based sector, thus differentiating it from the manufacturing sector (Pavitt, 1984; Whyte, 2003). These generic technologies have similar, but not identical applications across different sectors and industries (Rosenberg, 1963). Therefore the specific context for the adoption of generic technologies is significant.

As the importance and difficulty of technological implementation in the construction industry became apparent, studies in the late 1990s employed alternative levels of analysis. Research drew attention to the institutional setting. Henderson's study of the introduction of CAD at project and organizational level attributed problems with adoption of CAD to institutional influences, namely the disparate social worlds of design and construction (1999). The adversarial culture of the industry impedes implementation, as does the "engineer's paradigm", which describes how technical skills are prioritized over managerial considerations, such as innovation (Prie and Janszen, 1995).

Research into technological implementation in the construction industry views this process from an organizational perspective, using the firm as the primary unit of analysis. The outcome of firms' efforts to implement ICTs was often far removed from the benefits envisaged (Salter and Gann, 2003). Research identifies a number of causes of this: it is related to a lack of organizational learning of new technologies; senior staff were proving resistant to using new technologies; that the myriad of software systems available made investment decision difficult for SMEs and that the rapid rate of obsolescence of technologies deterred investment and adoption (Gann, 2000). The project-based nature of firms working in the industry also impedes the diffusion of innovations such as technologies (Gann and Salter, 2000).

Currie's study of managers' decisions to invest in CAD found that when investments were integrated into the overall corporate strategy, implementation was more successful than investments made as ad hoc responses to business pressures (1989). Later research identified the individual user as critical in the process of technological implementation in firms. In a comparative study of the introduction of CAD and virtual reality technology, Whyte finds that a lack of end user involvement in the implementation process hinders take up (2002). Thus this is an additional characteristic of Currie's model of ad hoc technological implementation (Whyte, 2002).

The important role played by users in implementation of technology is emphasized as studies found a substantial gap existing between the organization's intended use and actor's actual use of technology, between strategy and reality (Gann, 2000). Salter and Gann's study of 2003 finds that engineering designers rely heavily on traditional forms of communication for problem solving, on face-to-face conversations with colleagues, despite the introduction of new technologies (Salter and Gann 2003). The finding of this research concurs with the view that new technologies may increase the need for personal face-to-face communication (Nightingale, 1998).

Recent practice-based research finds that this gap remains and that technologies are still being unevenly and differently incorporated into pre-existing work (Harty and Whyte 2010). Actors continue to employ hybrid practices, using both digital and traditional ways of working (Harty and Whyte 2010, Whyte 2011, 2013). This promising vein of research continues in studies exploring the use and implementation of BIM.

4. Building Information Modeling

The ICT currently being implemented in the construction industry is Building Information Modeling (BIM). It brings together existing ICT technologies that have been widely used to improve the production of the built environment by the construction industry including computer aided drafting, databases, and the internet.

The following discussion of BIM follows the broad definition of technology used in this study as comprising three systems: mechanical (hardware), human (skills and human energy) and knowledge (abstract meanings and concepts) (Collins et al, 1986). It describes and defines BIM and discusses the advantages its offers to the industry. Implementation of BIM and efforts to accelerate rates of adoption are then discussed.

4.1 Definition and background

A number of definitions of BIM exist, each of which emphasizes different aspects of BIM. A commonly used definition is provided by the Construction Project Information Committee (an industry body with cross industry membership), which describes BIM as:

> "The digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition."
> (www.cpic.org, accessed 10th September 2015)

This definition draws attention to the main feature of BIM. At its core is an accurate digital model of the built asset with associated data. It incorporates the design, construction and management of built assets (Azhar, 2011, Bew and Underwood 2010, Eastman et al 2011). Building Information Modeling involves developing an accurate digital model that is shared across organizations and project stages. Importantly information is embedded in every object in the model, thus digital models created within the BIM framework are commonly described as "a database with drawings". This common model forms a knowledge repository or manual of the built asset and can be used for its entire life cycle, after maintenance for operation purposes.

Building Information Modeling evolved from early product modeling technologies developed in the 1960s, which subsequently gave rise to 3D solid modeling technologies (Eastman et al, 2011). These technologies were developed in the 1980s with the creation of object-based parametric modeling technology, which enables objects to automatically update in relation to other objects. Parametric modeling forms a technological basis for BIM and distinguishes it from previous technologies (Eastman et al, 2011). Industrial sectors such as manufacturing and aerospace saw the huge potential benefits of using such parametric modeling technologies, for their integration and analysis capabilities and their potential to reduce errors and automate processes (Eastman et al, 2011). Early industrial applications of parametric modeling demonstrated this value, for example in the significant cost savings achieved by Boeing in the design, fabrication and assembly of the 777 aircraft and the John Deer Company in the construction of tractors. Parametric modeling is now in standard use in large aerospace, manufacturing and electronics companies (Eastman et al, 2011). Such modeling technologies were imported into the construction industry to form BIM.

BIM can be used in various ways as shown in Bew and Richard's 2008 BIM maturity index (Figure 13). The maturity index describes different levels of BIM maturity, ranging from Levels 0 to 3 and the key features of each level.

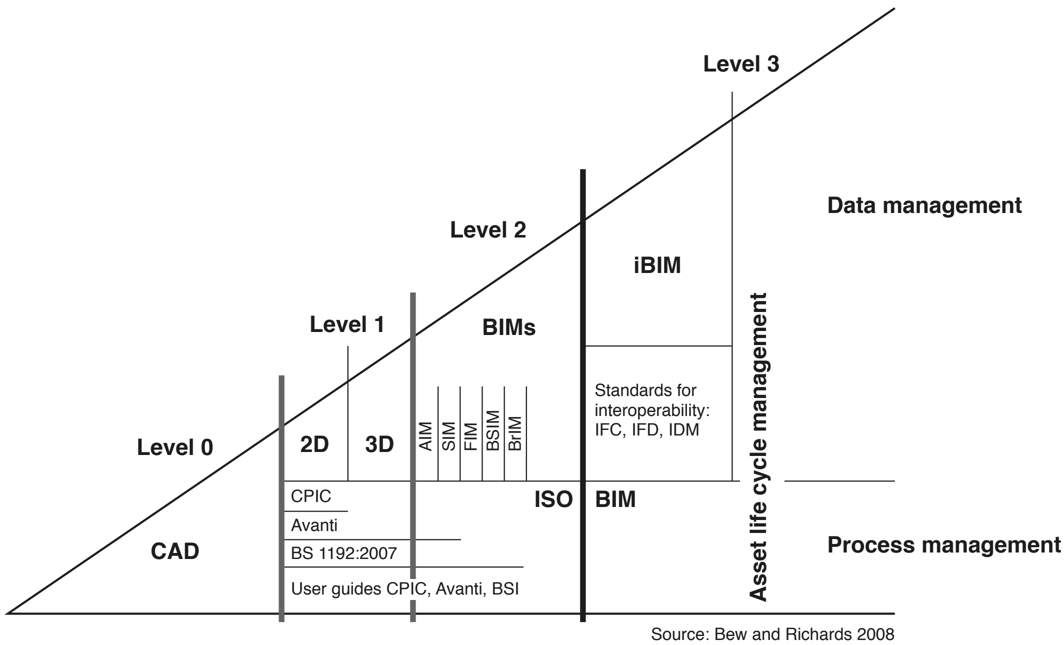

Figure 11: BIM Maturity Index, reproduced from Bew and Richards, 2008,

Level 0 BIM describes 2D CAD use, without collaboration. A Common Data Environment is used for Level 1 but drawings are produced using a mixture of 3D and 2D drawings. Little collaboration exists between parties at Level 1, with each publishing and maintaining their own data. Level 2 involves higher levels of collaboration amongst the team, with all parties using 3D CAD but not necessarily a single, shared model. Data has a degree of interoperability, with information shared in common file formats using an agreed schedule of data drops. Each organization generally compiles its own federated model and carries out checks on it. At Level 2, the common model may be used for 4D (construction sequencing) and 5D (cost information) purposes. "Open BIM" is achieved in Level 3, where full collaboration occurs between all parties. A single, shared project model exists which can be accessed and modified by all parties in real time.

4.2 Collaboration and interoperability

Using BIM demands both software and process changes (Bew and Underwood, 2010; Eastman et al, 2011). Collaboration and interoperability lies at the heart of these changes. This is succinctly explained by American body the National Building Information Modeling Standards (NBIMS)[4], who state that:

> "A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder." (NBIMS, 2010)

Although NBIMS is a USA based group, its emphasis on the fundamental importance of collaboration and its impact in all stages of a built asset's lifecyle is central to international applications of BIM, including the UK setting studied in this thesis. The necessity of collaboration brings the need for interoperability. Along with parametric modeling, interoperability is a critical technical foundation of BIM (Eastman et al, 2011). Interoperability is often used to refer to the ability to exchange data reliably and easily between software applications, creating a shared data-rich model.

A myriad of specialist software has been developed to support the different disciplines and related processes that are found in the construction industry. An industry consortium, The Industrial Alliance for Interoperability (now BuildingSmart) was established in 1994 to address software interoperability. It developed Industry Foundation Classes to define data representations of building information for exchange between software applications (Eastman et al, 2011). Industry Foundation Classes (IFC) are platform neutral, open file specifications that are not controlled by software vendors. The IFC model is an official international standard (ISO 16739:2013) used by many private and public sector clients internationally. BuildingSmart develops and maintains IFCs in line with its mission to standardize processes, workflows and procedures for BIM (www.buildingsmart.org/about, accessed 11th September, 2015).

Other standards have been developed to aid technical interoperability. In the USA, OmniClass is used in the construction industry as a classification system for organizing and retrieving information. In the UK, Uniclass has been developed as an equivalent classification system, which is regularly updated, enabling electronic data to be stored and accessed in a standard way. The second standard is Construction Operations Building Information Exchange (COBie), with COBie UK 2012 available in the UK. It standardizes the process of sharing information between the construction team and the owner.

While the ability to exchange data via integrated software has received significant industry and academic attention, less attention has been paid to the need to integrate products and processes to achieve interoperability. This wider view of interoperability is complex but crucial as Eastman and colleagues describe:

> "To achieve interoperability successfully, organizations must address technological issues of connecting systems and applications, as well as how the connection between the business processes of each organization enables or hinders the establishment of the technical bonds, along with compatibility of the employees' values and culture of trust, mutual expectations, and collaboration, which overall has to be supported by informal or formal contractual agreements between the companies, which "institutionalizes" the collaboration."
> (Eastman et al, 2011: 588)

In an industry like construction that struggles with collaborative working, this is a key challenge in using BIM.

4.2 Barriers to uptake

The promise of BIM for the construction industry is high. It has the potential to address many of the problems experienced in the construction process (Eastman et al, 2011). It offers efficiency gains and quality improvements across the life cycle of built assets. They include greater accuracy, faster processes, improved cost control and environmental performances, automated assembly, better customer services and more accurate lifecycle data (Azhar, 2011).

Reliable, data-rich models could enable better decision making, better consideration of design and construction alternatives, and improved cost, energy and lifecycle analysis (Mihindu and Arayici, 2008). Design and construction could be better aligned with operation and asset management, specifically by extending the process through the handover period. It enables sophisticated energy analysis to be carried out in design stages, thus improving sustainable design standards across the Built Environment (Dowsetti and Harty 2013).

However despite this potential, as with previous technologies introduced to the construction industry, the reality of implementation is far removed from aspirations. Significant adoption of BIM in the UK Built Environment still has not occurred (Bew and Underwood 2010).

The reasons for this sluggish rate of adoption have been considered at multiple levels. At industry level, a fragmented supply chain, slow consolidation and low investment in the industry have hindered the take up of BIM (Bew and Underwood 2010). At organizational and project level, barriers to BIM adoption are both technical and managerial (Azhar, 2011). They include resistance to change, skepticism as to the value of BIM, problems in adapting existing workflows and behaviors, a lack of training, and a poor understanding of roles and responsibilities (Arayici et al., 2011). Lack of clarity on the distribution of benefits is also hindering adoption of BIM (Gu and London 2010).

BIM is viewed as an “unbounded innovation” requiring collaboration between many firms for implementation to be successful (Harty, 2005). Interoperability between organizations and processes is vital in its use (Eastman et al, 2011). Yet practitioners in the industry continue to struggle with the collaborative, integrated nature of BIM-enabled working (Gu and London 2010). The implementation of BIM requires attention to be paid to the interactions within a range of actors and between actors and the technological artifacts (Harty, 2005).

4.3 Standards and policies

Various initiatives have been taken at institutional and policy level aimed at accelerating adoption rates of BIM. The most significant of these in the UK is Government mandating the use of Level 2 BIM on all public sector projects in 2016 (Government Construction Strategy 2011).

Published in 2011, the Government Construction Strategy identifies Building Information Modeling as key in embedding collaborative and integrated working in the industry. In contrast to past policy interventions, this strategy leverages government's powerful role as the largest single client of the construction industry in the UK – accounting for some 40% of work carried out by the industry in 2010 – to drive industry change through the use of BIM while reducing Government construction spend by a targeted 20%.

A number of institutions have also attempted to accelerate adoption rates by producing standards and frameworks that enable BIM working. For example, international standard, COBIE, which is aimed at improving interoperable working, has been adapted and COBIE-UK 2012 produced. The British Standards Institute issued PAS1192, Parts 2-5 between 2013-15. Part 2 lays out guidance for producing collaborative information focusing on project delivery. It describes the Common Data Environment and how this shared model should be used across project teams. Part 3 was published a year later in 2014 and is concerned with the operational phase of the built asset, specifying how an asset information model should be created and used across the lifecycle of the built asset. PAS1192 Part 4 was also published in 2014 in order to define a methodology for the transfer between parties of structured information relating to Facilities, including buildings and infrastructure. PAS 1192 Part 5 was published most recently in 2015 and provides guidance on the safety and security implication of digital built assets.

Changes have also been made to institutional frameworks. Following a substantial consultation process, the RIBA published a new Plan of Work in 2013 that accommodates BIM working. The previous Plan of Work dated from 1963 and was widely used in the industry to map the building process. RIBA's new Plan of Work supports the use of BIM and aims to promote integrated working. The Construction Industry Council published a BIM Protocol in 2013, which is a supplementary legal agreement that can be incorporated into contracts and calls for all parties to specify their roles and to agree a common information standard.

Substantial information resources have also been made available, including the BIM Task Force in the UK. Supported by government, this group carries out a huge range of activities targeted at different parts of the industry by region, market and supply chain. For example, groups exist for parts of the supply chain that are early in the adoption process including manufacturers and facilities managers, dealing with adoption issues that are specific to them. Construction clients are also provided with bespoke advice, and detailed guidance in creating Employer Information Requirements is readily accessible. The NBS has recently made a digital National BIM Library available, which allows designers to download standard BIM objects, both generic and produced by specific manufacturers (www.nationalbimlibrary.com, accessed 23rd November 2015).

A vast range of events, publications and conferences devoted to all aspects of BIM and targeting parts of the supply chain have been held. This creates awareness and knowledge of BIM yet also induces challenges to keep up to date and manage the "information overload". (Many users I interviewed for this study referred to this, without prompting, with a significant number lamenting the volume of information available and the resources required to keep up to date with it. One leader said many of his more junior staff were suffering from "BIM boredom" because of the sheer volume and prevalence of the information.)

4.4 Research

These policy initiatives and new standards appear to have succeeded somewhat in accelerating the rate of BIM adoption in the UK (National Building Specification survey, 2015). Increased rates of adoption have provided numerous opportunities to study the use and application of BIM. The growing prevalence of BIM in project work presents opportunities to explore how it is being used in greater detail.

Recent research of BIM uses a wide range of methods and designs: single case study, interview-based research (Whyte, 2013, 2011), comparative case studies (Azhar, 2011); and action research methods conducted via a Knowledge Transfer Partnership (Arayici et al, 2011). It draws on a variety of empirical contexts, for example UK hospitals (Sebastian, 2011) , major transport hubs in New York and London (Hartmann and Fischer, 2007; Whyte, 2011), and commercial buildings (Dossick and Neff, 2010).

Scholars have studied BIM use in different disciplines across project stages. For example in design stages, BIM promises better informed decision-making, and design development (Azhar, 2011). It offers a paradigm shift in design work, by fundamentally changing the way that architectural representations are made (Eastman et al, 2011). This shift has led to concerns, particularly amongst the architectural profession, on how BIM is used during early concept design stages: that the technology will drive standardization of design (Aish, 2005); that the visual representations created in BIM design software imply a level of completeness inappropriate to early design stages and that BIM design software privileges novice designers, who often have a good technical grasp of the software but limited professional experience.

After concept design is completed, collaboration and integrated working are particularly important as architects and engineers work together (Eastman et al, 2011). At this stage the shared model has greatest potential to enable better detection of clashes between designed building elements and allowing these to be rectified (Eastman et al, 2011). However as Dossick and Neff's study finds, architects and engineers experience multiple competing obligations at individual, organizational and project level which can undermine collaboration (2010).

In construction phases, research considers how BIM tools are used on-site. Hartmann and Fischer study how 3D and 4D applications of BIM are used during the construction phase of a large transport hub in New York (2007). They show how construction teams use the model to generate and share knowledge during a constructability review of the project (Hartmann and Fischer, 2007).

During stages involving data handover, digital infrastructure such as BIM helps inform better decision-making (Whyte, Lindvist and Ibrahaim, 2012). Because interoperable information is being handed over to asset construction or management of the built asset, opportunities are created for delivering and operating built assets (Whyte et al, 2012).

As BIM starts to be used in post occupancy phases, studies have begun to explore its application after construction. Research looks at how BIM can support facilities management in different areas (Becerik-Gerber et al., 2011). Studies explore how BIM is used in maintenance, repair and rehabilitation (Hallberg and Tarandi, 2011).

Researchers have adopted a practice perspective in viewing how BIM is implemented and used (Whyte 2013, 2011; Harty and Whyte, 2010). Central to this research is the recognition that using BIM involves process and practice change (Eastman et al, 2011). Such research recognizes the contrast between the theory and reality of BIM (Dossick and Neff, 2010) and aims to unpack the "complex universe of interactions and interdependencies between processes, roles and actions which are an integral part of practitioners' daily work" (Moum, 2010: 587). Practice research builds on earlier insights that called for attention to be paid to the interactions within a range of actors and between actors and the technological artifacts in order to understand BIM implementation (Hardy, 2005). It studies these interactions, and changing and new roles "in the wild". Common to these studies is a focus on the embedded nature of practices, acknowledgement that they occur within an ecology (Harty and Whyte, 2010).

For example research adopting a practice perspective finds that architects and engineers develop different relationships with the shared model and that institutionalized divisions of labor differ significantly between architects and engineers (Whyte, 2011). In institutionalized project settings, professionals draw on diverse cultures, meanings and values (Whyte, 2011). These norms and values are deeply engrained. Digital representations and expressions are shaped by norms and ideals of different professional cultures (Whyte and Ewenstein, 2007).

The changes wrought on professional roles are particularly notable (Jaradat, Whyte and Luck, 2013). The entrenchment of professionals is seen as a major barrier to adoption of BIM (Harty and Laing, 2010). Some professionals see BIM as threatening their autonomy, expertise and interdependence (Jaradat et al, 2013).

BIM-enabled working is causing and will continue to cause significant changes in the relationship of project participants (Eastman et al, 2011). Traditional borders between the groups have become blurred: there is a different configuration of the team (Sebastian, 2011). New occupational groups are being created as BIM is adopted, such as information managers and BIM coordinators (Sebastian, 2011). Roles are changing between the contractor and designer (Taylor, 2007).

These role changes are creating conflict between occupational groups who develop different understandings of deliverables and how they are achieved (Hartmann and Fischer, 2007). New technologies disrupt shared frames and power struggles amongst occupational groups become explicit. People use new technologies to reassert professional status and differences, and revisit previous distinctions and divisions (Dossick and Neff, 2010; Orlikowski, 2000; Barley, 1986). Amid these accounts of conflict, research identifies a more sinister application of BIM, the "dark side of BIM" (Davies and Harty, 2012). This research argues that BIM is a potential source of power and conflict in the construction industry (Davies and Harty, 2012).

Research also shows how digital objects such as BIM are creating new opportunities in engineering design (Whyte and Lobo, 2010) and visual design work (Ewenstein and Whyte, 2009; Whyte, Ewenstein, Hales and Tidd., 2008; Whyte and Ewenstein, 2007). Organizing takes place through interactions between people and objects as specific time and places. This use of BIM for coordination happens across multiple sites (Whyte and Lobo, 2010). As digital infrastructure creates different types of visual tools, individuals use these tools for managing knowledge between projects, for stepping between exploration and exploitation (Whyte, Ewenstein, Hales and Tidd, 2008). By using theoretical approaches such as Actor Network Theory, studies find that technologies are unevenly incorporated into existing social structures (Harty and Whyte, 2010).

Innovation studies also emphasize the embedded nature of practices and processes involved in the construction industry (Boland, Lyytinen and Yoo, 2007). Recent research in the use of 3D digital modeling by architect Frank Gehry's firm finds a complex pattern of innovations started by a new technology. Thus researchers working in the built environment are urged to look at networks of innovations, rather than vertically integrated firms (Boland et al, 2007).

Chapter 4: Research design and methods

1. Introduction

This chapter discusses the methodology, design and research techniques used in this thesis. These are derived from the study's research questions and theoretical frameworks, as illustrated in Table 4.

Methodologically, this thesis is guided by the principles of process research. It is thus based on models of reality that are complex, interdependent and iterative. Following Langley's recommendations, it combines deductive theory-driven methods with inductive data-driven methods (1999). Engaged Scholarship offers a method for studying commercial organizations (Van de Ven, 2007). The ethics of conducting research in such settings are reviewed.

Qualitative research techniques are used to produce a single embedded case study. A longitudinal study of BIM implementation at a large firm in the construction industry, Design Partnership, is developed. The process of implementation is viewed at multiple levels: users, firm and industry. To build thick descriptions of this process, data are drawn from a number of sources – interviews, archived information, internal meetings and seminars. This data covers a 15-year time period therefore retrospective and contemporaneous data sources are used.

Quality criteria suitable for qualitative research are applied to ensure the rigor and "truthfulness" of this study (Lincoln and Guba, 1985). These data are analyzed using the principles of the Gioia Methodology combined with a temporal bracketing strategy, as befits process research (Langley 1999). Different levels of analysis are used for the two research questions: data relating to the use of BIM are collected and analyzed for the first question. Additional data relating to the wider ecology of practice are used for the second question.

The analysis of this case contributes to our understanding of technological implementation; it helps explains the divergence between existing theory and contemporary phenomenon. It contributes to theory by proposing alternative theoretical explanations of empirical observations, gained by addressing this study's research questions of a) how do organizational routines and practices influence processes of technological implementation in firms? and b) how can firms organize for technological implementation in complex operations?

Research questions	**RQ1.** How do organizational routines and practices influence processes of technological implementation in firms?	**RQ2. How can firms organize for technological implementation in complex operations?**
Theoretical framework	Practice perspective of organizational routines	Knowledge Process Framework
Methodological approach	Process research Combination of inductive and deductive reasoning (Langley 1999)	
Research design	Longitudinal data collection Single embedded case study (Design Partnership)	
Method	Emphasis on studying practices over time. Participant observation: deeply embedded,	Emphasis on situation or context of action Participant observation methods
Data collection	Semi structured , user interviews; internal meetings, seminars and training events	Data collected for RQ1, plus semi structured interviews with firm leadership and externally. External and internal meetings, seminars and training events.
Data analysis	Unit of analysis = events (temporal bracketing strategy) Level of analysis = users' practices and routines	Unit of analysis = events (temporal bracketing strategy) Level of analysis = users, firm and industry (embedded)

Table 4: Methodologies and research design and methods used in this study

2. Methodologies

2.1 Process research

Process research generates insights into "how and why things emerge, develop, grow or terminate over time" (Langley, Smallman, Tsoukas, Van de Ven, 2013: 1). Unlike variance studies which focus on, and sometimes quantify, the effect of different variables, process studies explain how a sequence of events leads to an outcome (Van de Ven, 2007).

The ontological underpinnings of process research are found in process metaphysics, which argues that “things” are reifications of processes. Thus attention is drawn to verbs, as opposed to nouns: to organizing, rather than organizations (Weick, 1979).

Accordingly change is a constant theme in process research. A recent special edition of the *Academy of Management Journal* illustrates how process studies illuminate and refine our understanding of change at many levels (Langley et al, 2013). Studies address process change and reproduction in institutions (Lok and De Rond, 2013; Wright and Zammuto, 2013); practices (Gehman, Trevino and Garud, 2013); and routines (Bresman, 2013).

As illustrated in Figure 5, management and organizational research views processes of development and change in four ways[5]: as evolutionary, dialectic, life cycle or teleological change (Van de Ven and Poole 1995). Evolutionary views of change draw on mechanisms of variation, selection and retention as motors of change. Life cycle views of change describe the progress of an entity through biological stages in nature. Dialectical models view conflict and confrontation between entities in processes of development. Teleological models of change are purposeful enactments, accomplished through iterative development processes of goal formulation, implementation, evaluation and modification (Van De Ven and Poole, 1995).

In accordance with advice that process studies should combine deductive, theory-driven and inductive, data-driven methods, this study alternates between both approaches (Langley, 1999). This combination of methods:

> “Selectively takes concepts from different theoretical traditions and adapts them to the data at hand, or takes ideas from the data and attaches them to theoretical perspectives, enriching those theories as it goes along.” (Langley, 1999: 708).

[5] Change is the event: it is the difference in the form, quality or state of an organizational entity over time. Development is a change process: a progression of change events that unfold during the duration of an entity’s existence (Van de Ven and Poole 1995).

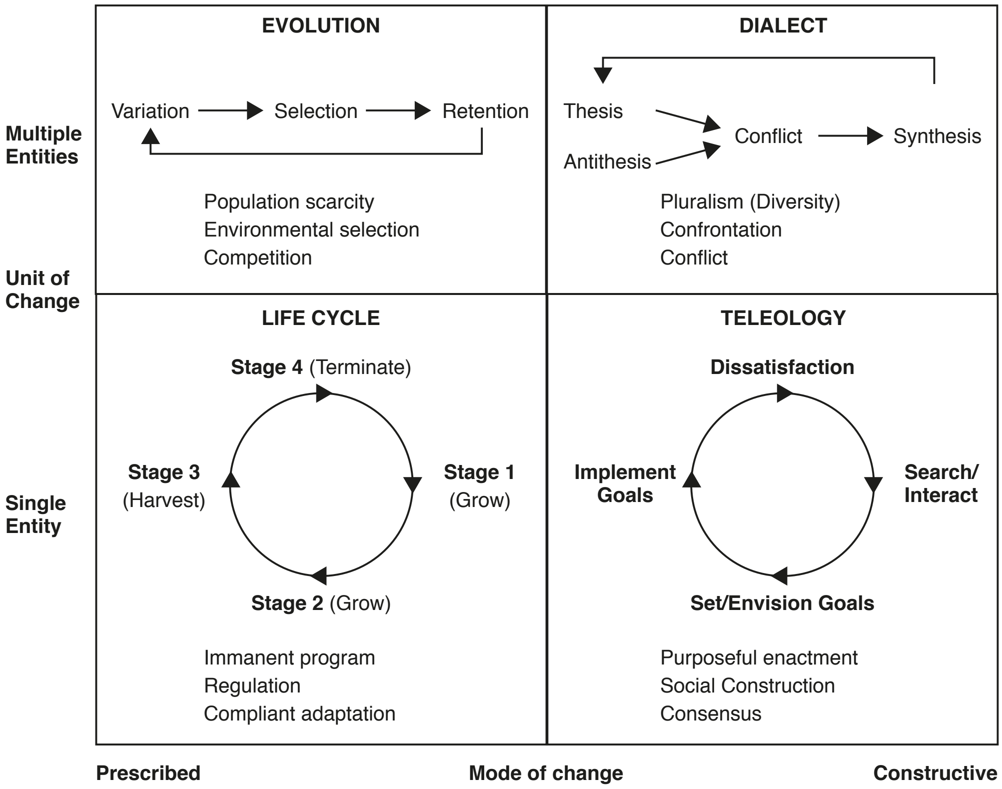

Figure 12: Four process theories of organizational development and change, reproduced from Van de Ven and Poole, 1995: 520.

As described in the introduction to this thesis, I therefore use deductive methods to identify core theoretical constructs relating to technological implementation in the construction industry and wider technology and organizations literature. Through this process, I refine my broad, experienced based research area into focused research questions and developed a research design. Methods used during data collection followed inductive methods, driven by data, thus surfacing new concepts and generating new theoretical insights (Gioia, Corley and Hamilton, 2012). Regular iteration between empirical data and theoretical frameworks during data collection guided the study's direction and helped make sense of emerging findings. For instance, interviewees' repeated references to the challenges encountered when using BIM at work, emphasized the importance of developing a practice-centric view of implementation.

During data analysis, established theories are used to code findings, informing second order codes and deriving models from the data. The contributions and limitations of this study are drawn from comparison with existing theory using deductive reasoning.

2.1.1 Longitudinal studies

Longitudinal data are necessary for process studies. This is demonstrated in Pettigrew's seminal study of change at Imperial Chemicals Industry which draws upon current and retrospective data covering 1960 and 1983 (1985).
The duration of this study enabled Pettigrew to view "dramas" or events in the process of change in situ. Thus, by using longitudinal data, Pettigrew viewed strategy as process embedded in context (Pettigrew, 1985).

While longitudinal data are central to process research, such studies generate a number of challenges for researchers in the field. One is knowing when a process begins and ends (Pettigrew, 1990). Identifying the start and end of processes becomes a greater challenge in cyclical processes of change, which are viewed as continually constituted and adapted (Gehman et al, 2013).

Another challenge lies in analyzing longitudinal process data. The sheer volume of data collected makes its interpretation a time-consuming and complex task, with researchers engaged in data analysis of process data risking "death by data-asphyxiation" (Pettigrew, 1990).

Acknowledging the messy nature of process data, Langley puts forward a number of strategies that researchers use to analyze process data (1999). Langley's description of one of these approaches to data analysis – temporal bracketing – is used in this study. As detailed in Table 2, such strategies deal primarily with phases that have clear temporal breakpoints. One or two detailed case studies are sufficient for this strategy, as long as they involve several phases (Langley, 1999).

Process and practice studies draw on similar ontological principles. These converge in theoretical approaches to gathering data. Through data collected longitudinally, as is necessary for process studies, researchers develop a fine-grained understanding of situations (Gioia, Corley and Hamilton, 2013).

Longitudinal data generates an in-depth appreciation of organizations and change, recording events as they unfold.

Strategy	Key anchor point	Exemplars	Fit with process data complexity	Specific data needs	Good Theory Dimensions	Form of Sense-making
Temporal bracketing strategy	Phases	Barley (1986) Denis, Langley and Cazale (1996) Doz (1996)	Can deal with eclectic data, but needs clear temporal breakpoints to define phases.	One of two detailed cases is sufficient if processes have several phases used for replication	Accuracy depends on adequacy of temporal decompositi on. Moderate simplicity and generality.	Mechanisms

Table 6: Analysis of process data using a temporal bracketing strategy, reproduced from Langley, 1999.

This is in accord with the theoretical foundation of practice theory, wherein “everyday actions are consequential in producing the structural contours of social life” (Feldman and Orlikowski, 2011: 1241). The techniques used by practice researchers to observe people’s situated actions also record processes that evolve over time (for example Feldman and Orlikowski, 2011; Howard-Grenville, 2005; Feldman, 2000; Orlikowski, 2000).

The second point of convergence is the emphasis both methodologies place on context (Langley et al, 2013: 5). Events and actions are viewed as temporally and contextually embedded. As practice research is concerned with situated actions (Orlikowski 2007) so process research aims to “catch reality in flight” (Pettigrew, 2003,). Thus:

> “How the past is drawn upon and made relevant to the present is not an atomistic or random exercise but crucially depends on the social practices in which actors are embedded” (Langley et al 2013: 5).

2.2 Engaged Scholarship

In this thesis a practice perspective is used to view processes of technological implementation embedded in firms. Deep engagement with a commercial organization was therefore a requisite. Van de Ven’s model of Engaged Scholarship provides a suitable method as it aims to address the gap between theory and empirics, to explain “the world of practice seen in organizations and theories being debated in academe” (Van de Ven, 2007: 265).

Engaged Scholarship is a participative form of research that helps understand complex, social problems. It views research as a collective achievement – as a collaboration between academic and business organizations rather than a solitary activity (Van de Ven, 2007). It can be used in a number of ways, from researchers obtaining stakeholders perspectives in conducting a basic social science study, to undertaking a collaborative research project that coproduces knowledge on a question of mutual interest, to obtaining stakeholders involvement in designing or evaluating a policy or program, to intervening and implementing change to solve a client’s problem. The original approach to Engaged Scholarship adopted in this study was to undertake a collaborative research project to coproduce knowledge on a question of mutual interest (Van de Ven 2007).

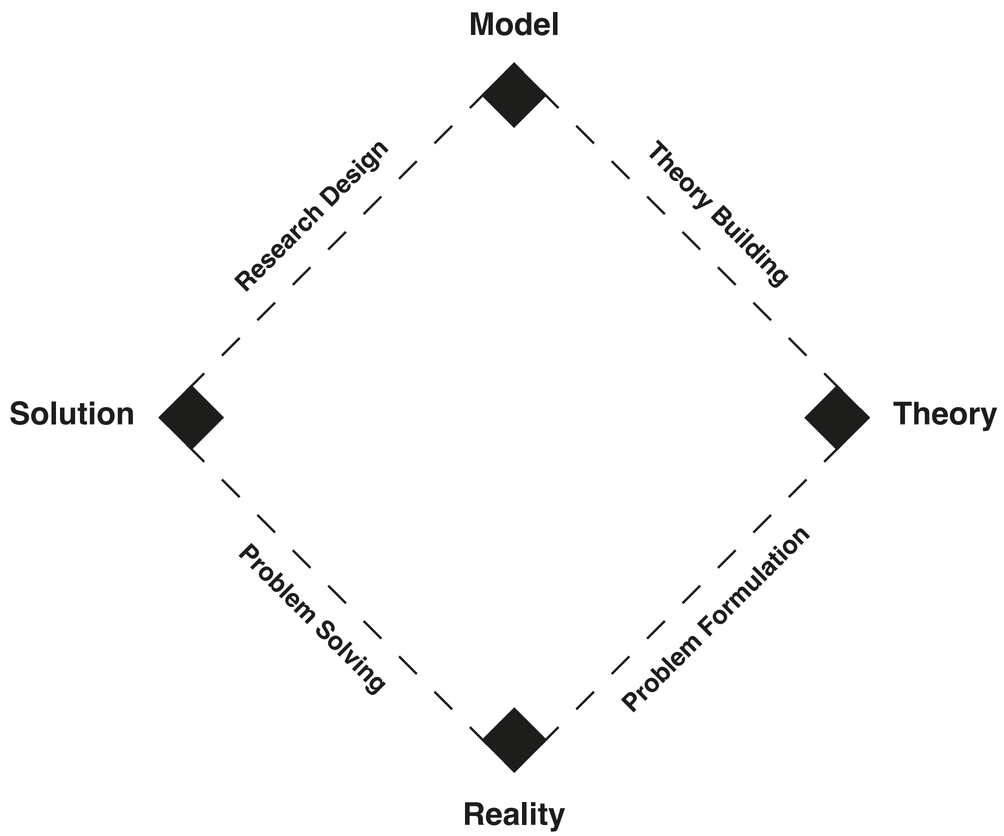

Figure 13: The four stages of Engaged Scholarship research. reproduced from Van de Ven, 2007.

As shown in Figure 6, a four-stage model illustrates the process of Engaged Scholarship. These four stages of the model are linked by processes of theory building, problem formulation, problem solving and research design. The starting point for this model varies and multiple iterations between stages are involved.

This method guided this thesis throughout. All stages - from identifying an initial research area, to refining the research questions, to data collection and analysis – were undertaken as collaborative endeavors. The experience of applying this method led to a number of findings that are discussed in detail in Chapter 8.

2.2.1 Ethics

Many of the ethical issues encountered in this study arose because of the method and setting of the study, namely undertaking longitudinal, embedded research in a commercial organization. UCL's ethical standards for research draw on three principles: that all research participants should give informed consent before providing data for research; that research involving human participants should create social benefit over harm to participants; and that all participants have the right to expect data to be treated confidentially.

During the early stages of data collection, it became apparent that a Non Disclosure Agreement (NDA) was required for research to proceed. This document was duly drawn up (and is available on request). It ensures anonymity for the firm where data was gathered (thus the use of a pseudonym) without which the organization was not prepared to grant the deep, ongoing access required for practice and process research. As data collection progresses, this proved invaluable in conducting fieldwork in the tradition of Engaged Scholarship.

As per UCL's ethical standards, all data provided through interviews is treated as confidential. As interviewees imparted potentially sensitive information about their work, this confidentiality was necessary. All participants also gave informed consent to be interviewed and were asked for consent to be recorded prior to the start of the interview.

3. Qualitative research

This study uses qualitative research techniques. It therefore has potential to be creative and revelatory, to add new concepts and insights to our understanding of situations (Gioia, Corley and Hamilton, 2013). Whilst the insights generated by interpretive qualitative research are substantial, such studies have attracted much criticism for a lack of scholarly rigor, particularly from researchers using more traditional scientific methods of research (Gioia et al, 2013). Considerable attention has therefore been paid to rigor in this study, leading to plausible and defensible research (Gioia et al, 2013).

General criteria for ensuring the quality of qualitative research have been considered and applied throughout the research. Criteria often used to judge the quality of quantitative research, including reliability, validity, replicability and generalizability, are problematic when transferred to qualitative research. Lincoln and Guba's criteria for evaluating the "trustworthiness" of qualitative research that takes place in the field are therefore used (1985). Table 6 illustrates how these criteria of credibility, transferability, dependability and conformability are applied in this research design.

Credibility refers to readers' confidence in the truth of the research (Lincoln and Guba, 1985). The credibility of this study was increased as the data was gathered over a prolonged period of time in the field (15 months), during which time numerous interviews (54) were conducted. Observation was persistent; close attention was paid to multiple influences on the BIM implementation process. Data and theoretical triangulation were achieved by collecting data from multiple sources and by testing numerous theories against the data throughout the study. Peer debriefing was achieved through regular informal and formal reviews with practitioners and scholars undertaken throughout the study.

Transferability shows that the findings have applicability in other contexts. Geertz' popularized term of "thick description" (originally developed to describe ethnographic research methods) increases the transferability of qualitative

Criteria	Principle	Suggested techniques	Application
Credibility	Confidence in the truth of the findings	- Prolonged engagement - Persistent observation - Triangulation - Peer debriefing	- Data was gathered over a prolonged period of time in the field (15 months), during which time numerous interviews (54) were conducted. - Observation was persistent, close attention was paid to the multiple influences on the BIM implementation process - Data triangulation achieved - Theoretical triangulation achieved - Regular meetings and debriefing sessions with peers – both at Design Partnership and other scholars- have been held throughout the study.
Transferability	Showing that the findings have applicability in other contexts	- Thick description (Geertz, 1994)	- Through prolonged and intensive fieldwork, the case presents thick descriptions. - As research has focused on multiple levels – user, firm and industry ecology – the phenomenon is put in context.
Dependability	Showing that the findings are consistent and could be repeated	- Inquiry audit	- The findings of this study have been discussed informally and formally throughout its course with academics and practitioners. - Interviews were held with another comparative firm to check the validity of some emerging findings.
Conformability	The findings of the study are shaped by the respondents and not researcher bias	- Conformability audit - Audit trail - Reflexivity	- A professional researcher not involved in the research process has regularly formally and informally discussed and advised on the process and product of the study. - A clear audit trail is available of all data including interview transcripts, field notes, and archived information. - I considered reflexivity at every stage of the research. Throughout I was aware of how my preconceptions, beliefs, values, assumptions and position may influence the study.

Table 7: Application of quality criteria for qualitative research, based on Lincoln & Guba, 1985.

research findings. The prolonged and intensive field work undertaken here, ensures that the case is based on thick descriptions. Because data has been collected on multiple levels, technological implementation is put in context.

Dependability draws attention to the consistency of the findings. Following Lincoln and Guba's recommended strategy of undertaking an inquiry audit, the findings of this study have been discussed informally and formally with academics and practitioners throughout its duration. A number of interviews were also conducted with another comparative firm, enabling verification of the validity of emerging findings.

Lincoln and Guba's final requirement for conformability demands that respondents, rather than researcher bias, shape the research's findings. In order to meet this requirement, I have followed their suggested strategy of developing a conformability audit. Thus professional researchers not involved in the research process have regularly formally and informally discussed and advised on the process and product of the study. A clear audit trail is also available of all data including interview transcripts, field notes, and most written information. Importantly, reflexivity was a major consideration at every stage of the research. Throughout the study I was aware of how my preconceptions, beliefs, values, assumptions and position may influence the study.

4. Case study

This thesis adopts a case study design as it is exploring a complex social phenomenon (Yin, 2009). Case studies are suitable for using when little is known about a phenomenon that cannot be explained by current theoretical perspectives (Yin, 2009). Of the four possible different types of case study design, a single embedded case study design is used here (Yin 2009). Recent research shows the insights that can be generated through single embedded case studies designs, for example in recent practice studies to show how work influence wider institutional change (Smets, Morris and Greenwood, 2012), and in studies of technological artifacts and routine dynamics (Cacciatori 2008, 2012).

This case comprises an intensive, longitudinal study of technological implementation in one firm, embedded within which are multiple levels of analysis. This single embedded case study is a suitable research design for this study for various reasons. It enables researchers to develop a deep understanding of the dynamics present within a single setting and is especially useful in studying longitudinal change processes (Van de Ven and Poole, 2002; Yin, 2009). It is suitable to use with a temporal bracketing strategy, as befits the analysis of process research data (Langley, 1999).

A potential weakness of case study research relates to generalizability, that is the ability to generalize the findings of the case to other settings (Yin, 2009; Ferlie et al, 2005). The aim of this study is to achieve theoretical generalizability, which is in contrast with deductive, usually quantitative research, which aims for statistically generalizability (Yin, 2009). Lincoln and Guba advocate increasing the generalizability (or transferability) of qualitative research by developing "thick descriptions" of settings (1985).

A potential hazard in embedded case studies is that research focuses only on the subunit without returning to the larger unit of analysis (Yin, 2009). Therefore, considerable attention is paid in this research to its organizational and institutional setting.

4.1 Selection of the case

As the aim of this research is to achieve theoretical generalizability, the selection of the case was driven by considerations of whether it could:

> "Shed empirical light about some theoretical concepts or principles, not unlike the motive of a laboratory investigator in conceiving of and then conducting a new experiment." (Yin, 2009: 40)

Therefore this case study develops intensive, "thick descriptions" of the process of implementation at one firm level over 15 year. Embedded within this are multiple accounts of BIM implementation at user, firm and industry levels. In order to preserve the anonymity of this organization (a requirement of data collection), the case is henceforth referred to using the pseudonym Design Partnership.

The firm in question, known as Design Partnership, Design Partnership is a large, well-established multidisciplinary design consultancy. It is a leading firm in the construction industry and is renowned for being creative and explorative and using technologies innovatively. Subsequent chapters of this thesis give detailed descriptions of Design Partnership and the construction industry in which it works (Chapters 4 and 5 respectively). The purpose of this discussion is to describe why Design Partnership was selected as a case study for this research.

As well as being a leading firm with an established track record in using technologies to create innovative solutions, various other empirical, theoretical and methodological reasons led to its selection. Empirically, Design Partnership generally begins its work in the early design stages of projects. The use of BIM in design stages are highly influential but not well understood. Critical decisions are made during design stages that affect the long-term construction and operation of built assets (Bew and Underwood, 2010). Despite this, our understanding of how designers use BIM in early project stages is limited (Moum, 2010).

The selection was also made for theoretical reasons. As discussed in chapter 2, the process of implementation is viewed as embedded: users' practices and routines are situated within complex organizational and institutional settings. Users play an influential role in technological implementation (Orlikowski, 1992) particularly in construction firms (Whyte, 2002). At Design Partnership, the users of BIM determine and carry out actions in complex operations, exercising considerable agency, while being constrained by institutional and organizational norms and values (Edmondson, 2012). Design firms, such as the one studied here, comprise knowledgeable agents (Giddens, 1984) who regularly deal with unexpected and complex problems in their work (Edmondson, 2012).

The richness of this embedded perspective is increased in Design Partnership, as it is a project-based firm; therefore users work between temporary project settings and the more enduring activities of the firm.. As is typical in complex operations, users in Design Partnership work in complex and pluralistic settings, where institutional, firm, project and professional demands collide and sometimes conflict (Edmondson, 2012; Dossick and Neff, 2010).

Methodological reasons also account for selecting Design Partnership as a case study. In order to observe work enacted in situ, good access to the case study organization was necessary; thus location was important. In accordance with the participant observation techniques used, the vast majority of data were collected first hand, through face-to-face interactions (rare exceptions to this are detailed in section 5 of this study). Given the duration of data collection for this longitudinal study, physical proximity was vital to enable regular access to the field.

As a result of having previously worked in the industry, I also had a senior sponsor at Design Partnership. This sponsor arranged access to the organization and encouraged individuals to participate in data collection. Through this sponsor, I was viewed as a trusted researcher in the organization. Access and quality of information supplied during data collection were greatly improved by this.

4.2 Boundaries of the study

In researching the questions posed in this thesis, the boundaries of the study needed to be defined. This helps maintain consistency between the process observed and its context. For reasons explained here, data was collected BIM implementation in Design Partnership's general building market in the United Kingdom between 2000-2015.

4.2.1 Temporal boundaries

It is important to put meaningful temporal boundaries around longitudinal studies (Pettigrew, 1990), particularly when using temporal bracketing strategies for data analysis (Langley, 1999). The empirical process studied in this thesis is the implementation of BIM in Design Partnership. When entering the field, it proved challenging to identify the boundaries and nature of the implementation process, both at Design Partnership and in wider industry.

In order to define temporal boundaries, I iterated between empirical and theoretical data. Upon entering the field, early exploratory interviews at Design Partnership showed that the first formal organizational initiative aimed specifically at the implementation of BIM (in the geographic and business markets of its UK building business) dated from 2000. Studies in the construction industry indicated that BIM-enabled working in projects started in 2000 (Grilo and Jardim-Goncalves, 2010). Bew and Richards' BIM maturity index shows that collaborative research projects, such as Avanti and Comet, which began in 2002, mark early uses of BIM in the industry (Bew and Richards, 2008).

The end point of the longitudinal process observed is in 2015. This marks the end of Design Partnership's current strategy relating to BIM implementation. Three identifiable and distinct phases in the process were clear from the data collected between 2000-2015 (as discussed in detail in Chapter 5). Interviews at Design Partnership ceased in late 2014 as theoretical saturation had been reached (Trochim and Donnelly, 2001). At this point, interviews were not revealing new patterns or themes. Access to internal archival information and Design Partnership's offices continued into 2015, and were used to provide a complete picture of the longitudinal implementation process.

4.2.2 Sectoral and geographic boundaries

As well as imposing temporal boundaries on the study, its scope is purposely limited to specific service sectors and geographic markets. The aim of establishing these boundaries is to restrict the variables - technological, geographical and commercial - that could confound accounts of this process (Edmondson et al, 2001).

As discussed in detail in Chapter 4, the construction industry works across a range of markets: major projects, infrastructure, general building, housing, heritage, repair and maintenance (Pearce, 2003). Design Partnership reflects this diversity and operates in most of these markets, with the exception of repair and maintenance, which tends to be the domain of contractors. One boundary set in this study was to restrict data collection to work enacted on general building projects in the UK. This is a substantial and significant market for Design Partnership.

While BIM is being used to great effect in other markets, the context of use varies significantly across them. These markets differ in a number of ways that mean technological implementation is best studied within one market. For instance, infrastructure is a major market for Design Partnership, involving design and construction of major road, rail and maritime projects. However, there are marked differences between infrastructure and building projects in the processes followed, the institutional and regulatory environment, and the professions involved. In infrastructure projects, BIM is often combined with other geospatial technologies.

Similarly Design Partnership works in a number of major projects[6]. The complexity, scale and duration of mega projects are pronounced; they vary significantly in their governance and purpose. Existing research shows that major or mega projects are good units of analysis for studying how firms develop capabilities in temporary organizations.

Major projects studied in the UK include Heathrow Terminal 5, the 2012 London Olympics and current work on Crossrail. These flagship projects often employ innovative solutions. For example at Heathrow Terminal 5, firms developed new capabilities and business models through systems integration (Davies, Gann, Douglas, 2009). The 2012 London Olympics has created a significant physical legacy for the city, as well as a learning legacy and impact on individual careers when viewed in its wider project ecology (Grabher and Thiel, 2015). Work being carried out on Crossrail is changing the way complex projects are delivered in the industry, through evolving project management processes (Whyte, Statis and Lindvist, 2015).

[6] The original definition of major projects given in the Pearce Report in 2003 defines major project as those worth over £20m. Given the time that has elapsed since this original definition, this figure is no longer representative of projects perceived as major or the exemplars used here. In defining major projects, I have therefore interpreted the spirit of major projects, rather than the outdated value definition.

Similarly Design Partnership's work in the housing and heritage markets, while significant, is generally restricted to its specialist consultancy in areas such as lighting, acoustic, fire engineering and product design. While BIM is used in such markets, its application and context is specific and specialist.

A further boundary in this study relates to geographic markets. The institutional and regulatory environment forms a significant element in understanding the wider context. From the comprehensive review of the evolution of BIM adoption in the construction industry, undertaken in Chapter 3 of this study, it is apparent that national government policies, formal regulations, institutional bodies and professions are influential variables in rates of adoption. National cultures also vary significantly in using BIM: exploratory interviews revealed widely different accounts of using BIM in New Zealand, Dubai, and the United States.

5. Data collection

In accordance with the Engaged Scholarship model of research, the first stage of data collection involved formulating the research problem (Van de Ven, 2007). Upon commencing data collection, a number of interviews held with senior individuals in Design Partnership showed that implementation of BIM was a key challenge for the firm. Interviews with industry leaders and policy makers, as well as secondary data sources, confirmed the widespread nature of this phenomenon.

For reasons previously described, a single embedded case study was used to research the questions raised in this study. As this study is concerned with developing situated understanding of how actors behave, data was collected in natural settings (Lee, 1999). I therefore embarked on a 15-month period of data collection, between July 2013 and September 2014. During this time, I became embedded in the organization. I had a desk, security access, intranet access and a corporate email account at Design Partnership. I was present in the London office on a weekly or bi-weekly basis.

According to the boundaries of this study, the data I collected related to BIM being used in Design Partnership's building business in the UK. This includes stand-alone engineering services and integrated architecture and engineering services. Iterations between theory and empirics during data collection focused and guided data collection throughout.

In order to build a longitudinal view of the process of BIM implementation at Design Partnership over time, I collected contemporaneous and retrospective data. Details of the approaches to data collection are discussed in section 5.1 and 5.2 of this thesis. In collecting retrospective data, I maintained a critical awareness of the validity and accuracy of the data gathered. The recollections of informants regarding BIM implementation gathered during semi-structured interviews, was particularly vulnerable to "informant inaccuracy" (Bernard, Killworth, Kronenfield and Sailer, 1984). Such informant inaccuracy potentially has significant detrimental effects on the quality of data collected (Bernard et al, 1984)

In order to minimize the impact of potential inaccuracy, I collected data from a number of sources following Pettigrew's advice for conducting longitudinal studies using retrospective data (1990). Thus I achieved data triangulation and increased the credibility of the case (Lincoln and Guba, 1985). As shown in Table 7, semi-structured interviews are the central source of data collection. Archival data sources, including intranet sites and paper-based documents were studied, and meetings, internal seminars and training events attended and noted. I also kept regular field notes during data collection, recording observations and thoughts during or shortly after data collection.

I also used interviews and wider data relating to this study's first research question, based on recently completed or current projects. The details of this approach are explained in detail in section 5.1. In contrast, I interviewed key informants and made wide use of archival data – internally and externally – to build a longitudinal view of implementation. Details of this approach are discussed in detail in section 5.2. 54 interviews were conducted in total. 34 of these involved individuals based in the focal organization, 11 interviews were undertaken in other similar design consultancies operating in the construction industry, and 9 interviews were undertaken with policy makers and implementers drawn from industry. Prior to the interviews, a note explaining the research and areas of interest were emailed to participants (see Appendix 1 and 2 for examples). This note describes the NDA and makes a copy available on request. A number of the more junior interviewees did request a copy prior to the interview. I verbally reminded them of the existence of the NDA before the interviews, which reassured subjects of confidentiality, increasing their willingness to talk about their work openly and in depth.

Interviews lasted between 40 and 90 minutes. The vast majority of interviews were face-to-face and were taped (with the interviewee's prior permission). I transcribed these recordings within one week, using this as an opportunity to recollect and make observations about the interview. In five instances it was not possible to carry out the interview face-to-face because of distance so interviews were carried out by telephone. On these occasions detailed notes were made during the interview that were written up within 24 hours.
During data collection, a number of changes to personnel were made at Design Partnership. As a result of this, my senior sponsor left the firm along with a number of other senior contacts. This occurred 11 months into the 15-month data collection period. At this stage, while a substantial amount of data had been collected, I still had a number of interviews to conduct and lines of enquiry to follow. I had not reached theoretical saturation point. With some difficulty, I managed to secure an alternative sponsor for my project and complete data collection. (Reflections on this experience are made in Chapter 8 of this thesis.)

Prior to the interviews, a note explaining the research and areas of interest were emailed to participants (see Appendix 1a and b for examples). This note describes the NDA and makes a copy available on request. A number of the more junior interviewees did request a copy prior to the interview. I verbally reminded them of the existence of the NDA before the interviews, which reassured subjects of confidentiality, increasing their willingness to talk about their work openly and in depth.

Interviews lasted between 40 and 90 minutes. Most were carried out face-to-face and taped (with the interviewee's prior permission). I transcribed these recordings within one week, using this as an opportunity to recollect and make observations about the interview. In five instances it was not possible to carry out the interview face-to-face because of distance so interviews were carried out by telephone. On these occasions detailed notes were made during the interview that were written up within 24 hours.

During data collection, a number of changes to personnel were made at Design Partnership. As a result of this, my senior sponsor left the firm along with a number of other senior contacts. This occurred 11 months into the 15-month data collection period. At this stage, while a substantial amount of data had been collected, I still had a number of interviews to conduct and lines of enquiry to follow. I had not reached theoretical saturation point. With some difficulty, I managed to secure an alternative sponsor for my project and complete data collection. (Reflections on this experience are made in Chapter 8 of this thesis.)

	Number of interviews	Meetings / seminars	Archived information	Other
RQ1: How do organizational routines and practices influence processes of technological implementation in firms?				
General	3	Launch of BIM strategy in UK (29.1.2014)	- Current strategy document - Numerous retrospective - reports (from 2000)	Field notes of observations and records of informal conversations (Books 1 and 2 – available on request)
Project Media	5	Not applicable	- Project sheet - Information on intranet - Concept report - Other internal documents and presentations	
Project University	4	Not applicable	- Project sheet - Information on intranet - Award submission - External media	
Project Experiment	6	- Project review (22.1.14) - Training event (17.10.13)	- Project sheet & report - Internal presentations - Information on intranet - NBS National BIM report 2014	
RQ2. How do firms organize for technological implementation in complex operations?				
Design Partnership	7 senior leaders 11 managers (BIM)	- Launch of BIM strategy in UK (29.1.2014) - Meeting of BIM strategy team (17.03.15)	- Background reports (retrospective since 2000) - Current strategy document - Annual reports, Design Partnership Journal (from 2000)	
Industry (inc government, institutions, academic bodies)	9	- Conferences (various) - External media (press, institutions, reports) - Websites eg UK BIM task force -		
Other firms	11	na	- Internal strategy documents (business and project) - Inter and intranet sites	
Total	54*			

* 2 interviews in Design Partnership provided data for RQ 1 and 2,.

Table 8: Summary of data sources

5.1 Emerging uses of BIM

The first question raised in this thesis asks how practices influence processes of technological implementation in firms.

As is common in embedded case studies, different data is collected for different levels of analysis (Yin, 2009). Thus data specifically relating to individuals' use of BIM in-situ were gathered. Because Design Partnership is a project-based organization, in order to observe how BIM was being used, interviews were clustered around a number of building projects.

Design Partnership suggested this strategy of accessing these accounts through projects. Consequently they identified a number of current or recently completed projects as suitable examples of how BIM was being used..

These projects provided the immediate social and temporal context for the practices and routines. Participants in interviews described how they used BIM readily using concrete project contexts, but struggled to relay these in the abstract. The temporal context of projects meant that phases of projects could be analyzed with a temporal bracketing strategy.

The projects studied for research question 1 are recent or current. Of the core projects, one (Project University) was occupied in 2013 of the implementation process, and the others (Project Media and Project Experiment) were completed in 2013, as data collection commenced. In addition to these three core projects, a further 23 projects were discussed in detail during the interviews.

As shown in Table 8, as well as the interviews, internal and external written material was drawn on and relevant internal events attended. Data from these sources provided valuable background to understanding the project setting.

Initial interviews with senior members of the team were secured. A snowballing strategy was then used to identify more actors who worked on these projects. This ensured interviewees covered a range of seniority and professional backgrounds, from project leaders to designers and technicians working in structural and MEP engineering and architecture.

In keeping with the semi-structured nature of the interviews, the questions asked were open-ended and adapted to suit the participant's occupation and experience. Interviews generally began with a brief description of interviewee's professional background, their experience using BIM and other technologies, and how they were using BIM in their everyday work. While the three core projects provided a context for relaying their work, many informants referred to and discussed at length their previous experiences, usually relating to projects, including prior technological change.

5.2 Organizing for implementation

The second question raised in this thesis focuses on context. It asks how firms organize for technological implementation in complex operations.
The data collected for research question two is drawn both from the leadership and management of Design Partnership and also from sources outside Design Partnership. This data forms a longitudinal and embedded view of the technological implementation process at Design Partnership between 2000-2015.

In Design Partnership interviews were undertaken with a number of individuals in leadership management and positions, who had particular responsibilities and interests in BIM. Prior to the interview they were sent information on it, as shown in Appendix 2b. This note was purposefully short in recognition of the time pressures experienced by such participants. They were asked to describe the current BIM implementation process at Design Partnership and its evolution. Existing written information and historical accounts provided valuable insights into this process. In particular, a number of documents provided crucial retrospective accounts of BIM implementation. As shown in Table 7, data were also collected outside Design Partnership. Nine interviews were held with policy makers and implementers, academics, and leaders of institutions in the UK. They were combined with data gathered from reports and other written sources to provide a view of BIM implementation in the construction industry and its evolution. Other external interviews were undertaken with similar design consultancies in the construction industry in the UK. These interviews validated the process model developing from data collected in Design Partnership, thus improving the external validity of the case study (Yin, 2009).

6. Data analysis

Constant iterations were made between data collection and analysis, therefore data collection involved analysis and data analysis involved additional data collection. The balance shifted as the study moved between the phases. As the study shifted and data analysis became the prevalent activity, two approaches informed my approach. The first, a temporal bracketing strategy, is discussed earlier as a suitable strategy for analyzing process data (Langley, 1999). It involves identifying clear temporal break points and phases in longitudinal research. Three phases of implementation at Design Partnership were clearly evident in my data, driven by different firm strategies and reflected in changing industry and user actions.

The second draws on the Gioia Methodology, which seeks to bring qualitative rigor to inductive research (Gioia et al, 2013). A basic assumption of the Gioia methodology is that participants are viewed as "knowledgeable agents"; that "people in organizations know what they are trying to do and can explain their thoughts, intentions and actions" (Gioia et al, 2013: 17). Thus they distinguish between first order data – that is informants' views – and second order data. Primary coding is undertaken in-vivo – in interviewee's language – then secondary coding is undertaken using scholarly terms drawn from theoretical concepts. From these stages a model is then developed. I combine this with a temporal bracketing strategy in order to analyze the data (Langley, 1999).

A software application, HyperResearch, was used to assist with data analysis. This software helped with data management, and was used as a database for data storage and interrogation. Considerable care was made to ensure that this software was used appropriately, minimizing its interpretative role in data analysis. Therefore all transcripts were read a number of times before coding. Both primary coding of in-vivo term, and secondary coding of theoretical terms, was undertaken manually before being entered into HyperResearch.

Data analysis for research question one focused on identifying how routines developed in the context of project work. First order codes were identified from the interviews and grouped by common themes to be developed. Second order coding drew on theoretical concepts relating to the development of routines in technological implementation. In turn these informed the conceptual model presented in chapter 6. Data analysis for research question 2 incorporates a wider data set. Coding followed a similar process to previously described. From this, a conceptual model was derived as presented in chapter 7.

As well as theoretical comparison, throughout data analysis, emerging findings were reviewed and refined accordingly. This formed an explicit part of the method used in this study, following the methodologies of Engaged Scholarship (Van de Ven, 2007). For example, emerging findings were fed back regularly to my original research sponsor at Design Partnership. This took place largely through regular monthly meetings held over the course of this study. Invaluable guidance and comments were made at these meetings on challenges of data collection, and considerations of findings. This advice included both insights into the use of BIM at Design Partnership, as well as relevant activities and contacts at industry and institutional level.

One-to-one feedback from academics, including my supervisory team, provided invaluable guidance. For example, in the final stages of data collection, a senior academic pointed out the need for more data on the role of technology developers in the BIM implementation process. This prompted me to interview other comparable firms in the construction industry about their experiences vis-a-vis technology developers. Therefore a number of external comparative interviews were undertaken with a similar firm to Design Partnership to validate a number of findings. Thus the research was refined and its quality improved.

Presentations and feedback on my research at conferences provided methodological, theoretical and empirical guidance in this study. For example, presentations at seminars on research ethics at UCL drew my attention to this vital area. In presenting my experiences and receiving feedback on them, I was able to articulate an accurate description and reflection of ethics in this study. Similarly, a presentation at the 2015 International Research Network on Organizing by Projects conference emphasized the importance of focusing on process and practice theories and methodologies. Attendance at other industry conferences and reviews of media and reports on BIM were vital in keeping up-to-date on this rapidly changing phenomenon.

In presenting the findings of this thesis, particular attention has been paid to developing accurate visual representations of processes. The art of drawing processes diagrammatically is challenging (Langley et al, 2013). However it is also crucial: process research focuses attention on the arrows rather than the boxes of diagrams representing variance studies.

Accordingly I use visual representations extensively to present the findings of this study in Chapters 5, 6 and 7 of this thesis. Having drawn these representations, I worked with a Graphic Designer to translate these diagrams into suitable reproducible electronic diagrams. Throughout this thesis, diagrams reproduced from the work of other scholars are stylistically differentiated from visual representations developed through this thesis. These are purposely shown in sketch form, as befits their conceptual nature.

5. Summary

In discussing the methodology and research design used in this study, this chapter has described the explanatory, inductive approach employed to address this study's research questions.

The longitudinal case study of technological implementation in one organization, Design Partnership, developed provides this study's single, embedded case study design. Data drawn from a number of sources collected using qualitative methods, covers a 15-year time process of implementation.

This chapter has described the different levels of analysis and data used to address this study's two research questions. Chapter 4 describes the setting for data collection in detail. It shows that implementation in firms working in the construction industry is an interesting and important setting to develop our understanding of technological implementation.

Chapter 5: A longitudinal view of implementing BIM at Design Partnership

1. Introduction

This chapter is the first of three presenting the findings of this thesis. It describes the focal organization for this research, Design Partnership and presents a longitudinal overview of BIM implementation at it.

Design Partnership is a large multi-disciplinary consultancy working across a number of markets in the construction industry. It provides a range of professional design services to the construction industry. The work of these design professionals are enacted in projects. Complex operations dominate work in the firm. Design Partnership has a reputation for creativity and innovation amongst clients, collaborators and its own staff.

Retrospective and current data are used to build a longitudinal model of the process of BIM implementation in Design Partnership's building business in the UK between 2000 and 2015. Using a temporal bracketing strategy to analyze these data, three distinct phases are apparent. Contemporary data relating to the current phase of the implementation was collected between 2013-2014. Retrospective data on the first two phases of implementation (2000-2005 and 2005-2013 respectively) were collected from interviews and archival sources.

The first of these phases occurs between 2000-2005. During this time Design Partnership adopts a "hands-off" approach to implementation, based on its experience of adopting technologies in the past. At the end of this Phase, the use of BIM remains restricted to certain BIM enthusiasts practicing in isolated "islands of automation". In the second phase, between 2005-2013, Design Partnership learns how to implement BIM. The potential of BIM becomes apparent, as does the huge challenge faced in implementing BIM across the organization. During the final phase, between 2013-2015, a strategic shift takes place at Design Partnership. The firm aims to provide an "infrastructure of support" for practitioners using BIM. This change reflects and is supported by wider industry changes, including the provision of numerous institutional standards.

2. Design Partnership

The focal organization studied here is a large, well-established multidisciplinary design consultancy operating in the construction industry. It is referred to in this study using the pseudonym Design Partnership. During its evolution, Design Partnership has been involved in many landmark projects in the built environment sector, earning itself a well-deserved reputation for design excellence in many business and geographic markets.

A prominent engineer founded Design Partnership nearly 70 years ago. It has since expanded from providing structural engineering consultancy to offering multidisciplinary design services in architecture, engineering, management consulting and other specialist consultancy services. This range of services enables Design Partnership to provide complex goods and services to their clients in a number of markets including aviation, highways, rail, energy, water, management consulting, planning and architecture.

In the UK construction industry, Design Partnership represents a leading firm in terms of its size, scope and reputation. Its growth has been mainly organic, punctuated with occasional strategic acquisitions (Connaughton, Meikle and Teerikangas, 2015). It operates from 90 offices in 38 countries spread across its five global regions, the Americas, Australasia, East Asia, Europe and UKMEA. In 2014, it employed around 11,000 staff and had a turnover of £1048m.

Design Partnership is a construction professional services firm (Connaughton and Meikle, 2012). A significant number of staff working at Design Partnership come from traditional building professions such as architecture, engineering (of various disciplines) and planning. On one hand, its professional workforce operates within multiple, highly institutionalized settings (DiMaggio and Powell, 1983). On the other, many employees at Design Partnership gain substantial individual satisfaction from acting autonomously and innovatively (Abbott, 1988).

Design Partnership portrays a number of characteristics of professional service firms, described in detail in Chapter 4 of this thesis. It is knowledge intensive, the value (and therefore power) of human capital is high, and professional and commercial norms and values often conflict (von Nordenflycht 2010). The "cat-herding" problem of managing professionals is keenly felt at Design Partnership (Maister 2007). The autonomy of professionals and their resistance to management control is a constant challenge; command and control approaches to management are poorly received and rarely attempted. As Maister advocates, the managers of Design Partnership perform a "delicate balancing act" between commercial demands and those of employees.

Design Partnership is also an example of a project-based firm (PBF). It is dominated by temporary project teams, and is therefore an agile organization (Mintzberg, 1979). It is sufficiently flexible to meet the demands of dynamic environments and has the capabilities needed to create complex products (Davies and Hobday, 2005; Salter and Gann, 2003; Gann and Salter 2000, 1998). It developed these capabilities through its highly skilled and innovative workforce.

Design Partnership's current portfolio of work comprises some 10,000 projects. These vary in scale and nature, thus creating a portfolio of project work:

> "You need a portfolio of large and small projects: of ones that are cutting edge and ones that are more business as usual. Commercially you have to keep cash flow going so you need cash cows. From a commercial point of view you need a portfolio." (Senior Business Leader, Design Partnership)

While Design Partnership is involved in innovative and routine operations, most of its operations are complex. As shown in Figure 14, applying Edmondson's Process Knowledge Spectrum framework to Design Partnership's works reveals a number of implications of the dominance of complex operations for the firm. Old and new tasks collide within and between projects, resulting in the combination of mature and emerging knowledge (Edmondson, 2012).

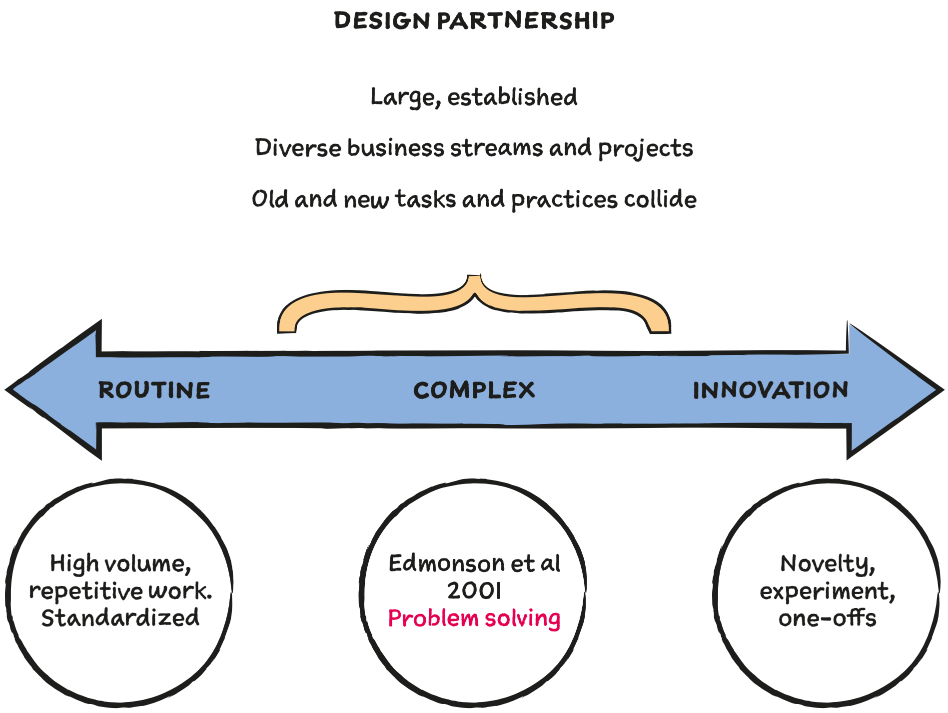

Figure 14: Complex operations in Design Partnership

Design Partnership has developed a reputation externally for its capabilities in complex operations. It balances innovation and creativity with pragmatism, always seeking to operate within the constraints of reality. As one of its business leaders said, "we build buildings for people – we are socially engaged". The capabilities rely partly on Design Partnership's ability to attract and retain skilled professionals. The firm has a strong reputation for undertaking challenging work on complex projects, which is a major attraction for professionals, who seek to use their creativity and professional expertise on a daily basis. Many practitioners working at Design Partnership are enthusiastic about being involved in complex projects. As an interviewee put it:

> "If a client approaches you and says 'I'd like the same airport as Chek Lap Kok [the airport in Hong Kong] please', then there is no role for us. However if a client says I want a zero carbon airport, then that is interesting, then we can unleash the whole of our multidisciplinary skills."

3. Implementing BIM at Design Partnership

This thesis draws on data collected in Design Partnership's general building division in the UK from 2000. The reasons for establishing these boundaries are discussed in detail in Chapter 3.

The longitudinal process presented of BIM implementation to date occurs over three distinct phases at Design Partnership, identified through data analysis using a temporal bracketing strategy. As shown in Table 9, data used were drawn from Design Partnership, wider industry and interviews with other similar firms. Sources of data include interviews, meetings, internal and external written accounts and extensive field notes.

Data provided both contemporary and retrospective accounts of BIM implementation. This longitudinal process shows the different approaches taken to BIM implementation between 2000-2015, as shown in Figure 15. Three phases are shown, with initial implementation efforts achieving "islands of automation" through to the current strategy that aims to provide practitioners with an infrastructure of support. The first two phases were identified primarily from retrospective data, the third from contemporary data.

The implementation process is illustrated in context. Therefore events in Design Partnership are related to external events initiated by government, institutions and academic bodies. These include policy interventions, standards and macro economic events such as the major economic recession. Academic studies detailing the use of BIM on major projects, such as Heathrow Terminal 5 and the London Olympics, in which Design Partnership was involved, are described. These studies provide valuable wider insights into how Design Partnership developed capabilities in technological implementation.

	Number of interviews[7]	Meetings / seminars	Archived information	Other
Design Partnership	7 leaders 11 managers (BIM)	- Launch of BIM strategy in UK (29.1.2014) - Meeting of BIM strategy team (17.03.15)	- Background reports (retrospective since 2000) 3 –D Document Transition Report (2005) - 'Lets get serious about our digital future', BIM implementation strategy, 2013 - Current strategy document and launch - Design Partnership journal esp. edition 2/2012 (special edition on UK projects)	- Field notes - (Books 1-3) - External reports on innovative uses of ICT at Design Partnership. - Criscuolo, Salter and Sheehan, 2007 Dodgson, Salter and Gann, 2007
Industry (Inc. government, institutions, academic bodies)	9 interview with individuals from government,	- Conferences various (virtual and real) - External media (press, institutions, reports) - Websites wg UK BIM task force		
Other firms	11 at 'Construction Ltd'	na	- Construction Ltd internal strategy documents (business and project)	

Table 9: Data table

The process of implementation followed by Design Partnership is discussed in detail with relation to the data in sections 3.1 to 3.3. As illustrated in Figure 15, three phases are apparent in Design Partnership's BIM implementation. As

[7] Details of individual interviewees are protected by the anonymity clause given in the NDA. These are available on request.

explained with reference to the data in section 3.1, in the earliest phase, beginning in 2000, Design Partnership took a hands-off approach, assuming BIM would be implemented by evolution. The outcome of this approach was that "islands of automation" were achieved, and the use of BIM was isolated to a few projects and used by a number of technological enthusiasts. As one senior business leader and Mechanical, Electrical and Plumbing (MEP) engineer commented during an interview,

> "my enthusiasm for digital working is very strong and deep-seated. I was drawing 3D services when I was 25!"
> (Excerpt from an interview with Design Partnership senior leader)

However, during these early days, as explained during an interview with a manager from Design Partnership adopted a ' bottom up approach' to implementation, establishing an online skills network intended to help these enthusiasts connect.

As explained in greater detail to the data in section 3.2,, in Phase 2, between 2005-2013, Design Partnership learnt progressively how to implement BIM. The complexity and implications of the technology were brought into sharp relief through a number of internal initiatives. Externally, attention began to focus on the potential of BIM during this period, moving from the significant effect of a major economic recession. The government mandate for all public sector projects to use BIM Level 2 by 2016, and its publication of the 2011 Construction Strategy, were significant catalysts for this resurgence in interest. A number of institutional standards and policies were rewritten and many firms in the industry focus on ensuring they would be able to meet the 2016 deadline.

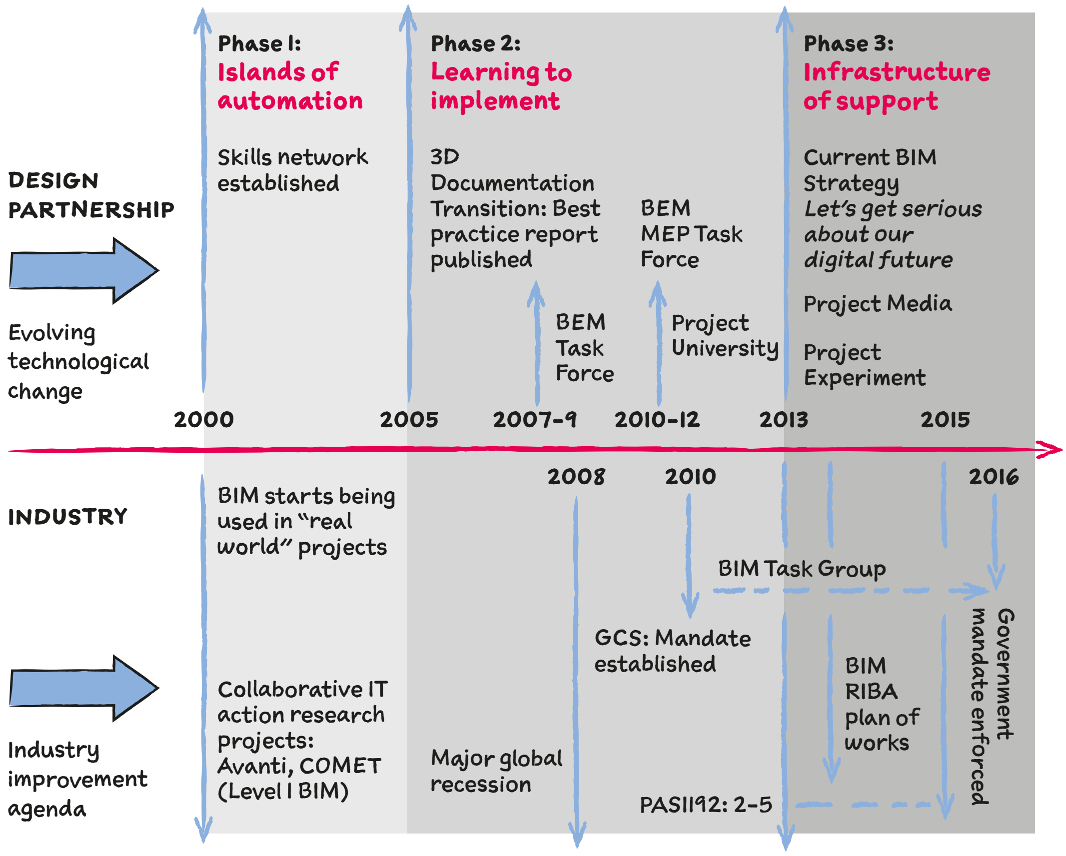

Figure 15: Three phases of BIM implementation at Design Partnership

During the current phase, Phase 3, Design Partnership adopts an approach aimed at providing an infrastructure of support for its practitioners. Design Partnership develops a different relationship between firm strategy and the work of users. When issues arise at user level that constrain the use of BIM, they are addressed by the organization with leadership support. The actions of users are an ongoing source of change, which are responded to at organizational level, and vice versa. Substantial variation between individuals use of BIM is anticipated and accommodated.

The impact of this shift is considered in detail in the subsequent chapter of this study. The external standards and processes introduced by external bodies add additional support for using BIM in everyday work.

3.1 Phase 1: Islands of automation

The first phase identified in this study starts in 2000 and extends to 2005. It marks the initial adoption of BIM in the built environment industry and at Design Partnership. In 2000, BIM was being used on *real world* projects (Grilo and Jardim-Goncalves, 2010). Through action research projects in the UK such as Avanti and COMET, the use of collaborative digital technologies in live projects was being explored.

These research projects made useful practical contributions to developing collaborative standards and work processes. They demonstrated the potential that BIM held for improving the efficiency of work and quality of output in the UK built environment industry. However they also hinted at the scale of the disruption that BIM-enabled working would bring to the industry. As well as learning to use new and complex software, behavior, cultures, standards and processes would need changing. The challenges of using a collaborative technology like BIM in an industry that remains stubbornly adversarial became apparent (Wolstenholme, 2009; Government Construction Strategy, 2011). As one senior business leader at Design Partnership commented:

> "The collaboration agenda didn't really happen – it's so embedded in the industry its basically a very litigious industry that makes its money on claims. They cannot get around the idea that you do not make money on claims."
>
> (Exert from interview)

Before 2000, Design Partnership had adopted new technologies with minimal organizational intervention. For example, the transition from paper based to digital drafting, using Computer Aided Drawing, was achieved through evolutionary methods. Based on this past experience, the firm initially took a similarly hands-off strategy to implementing BIM. It employed a bottom up approach that foresaw individual BIM enthusiasts driving BIM implementation across Design Partnership. As a member of the current BIM implementation team recalls:

> "We had an evolution about 10 years ago to 3D drawing but it was still only physical objects that we were looking at. So it was a relatively easy transition and one born out of necessity: if you were doing something really complicated it made sense to do it in 3D. We thought that the evolution to BIM was going to be similar."
>
> (Exert from interview)

A limited number of such individual enthusiasts had been using 3D technologies for some time at Design Partnership. As one senior business leader and Mechanical, Electrical and Plumbing (MEP) engineer commented:

> "my enthusiasm for digital working is very strong and deep-seated. I was drawing 3D services when I was 25!"
>
> (Exert from interview)

The knowledge and skills of these early adopters were substantial, far in advance of many in the firm and industry.

During this time Design Partnership did establish an online skills network that connects individual early adopters of BIM, effectively creating an online community of practice. The firm had established skills networks in other areas of their business, connecting global communities of practice through a moderated online network. The original manager of this network commented on its purpose, saying:

> "What you need is a community of questioners and practitioners…the [skills] network always linked together the doers and the needers. There are two sides to digitalization of work – one is to make things faster, cheaper, safer (efficiency) and the other is to make things you couldn't do before. "
>
> (Exert from interview)

The remit of this skills network has evolved in name and scope over the years, partly because of the emerging nature of its focus, from an initial title of visualization, to 3D skills, to virtual design skills to its current guise as the Digital Environment Skills Network. While it grew slowly initially, its membership has since expanded to 1500 people in the past 15 years. This early mechanism has endured well and proved adaptable.

During this period, research set in Design Partnership showed how engineering designers were using ICTs in their work. Whilst it found evidence of some engineers' enthusiasm about the potential of ICTs, most were still relying on traditional interactions, talking to other designers to develop innovative ideas, solve problems and assess the quality of their work (see also Salter and Gann 2003).

This finding is reflected in limited implementation of BIM that had occurred in Design Partnership at the end of Phase 1. BIM remained resolutely the domain of these technological enthusiasts; the islands of automation in the firm had become more pronounced (cf. Gann 2000). The dominant perception of BIM in Design Partnership was that BIM is an irrelevance: as one senior business leader at the firm explained,

> "most people felt that BIM was nothing to do with what Design Partnership does".
>
> (Exert from interview with leader of Design Partnership.)

This view was shared by leadership, as shown in its debates as to whether to outsource BIM.

During this initial phase, a lack of engagement amongst leaders and practitioners in Design Partnership led to minimal progress in implementing BIM. Without the organizational and institutional structures in place, the isolated innovations of technological enthusiasts working in islands of automation were unable to advance technological implementation. The hands off approach adopted by leadership proved insufficient to progress implementation of BIM.

3.2 Phase 2: Learning to implement

The second phase in this process occurs between 2005 and 2013. During this time the BIM attracted significant organizational and institutional attention as policy makers, business and industry leaders realized its potential but also the challenges that implementation adoption presented and the scale of change needed.

Early in this phase, from 2007, the industry experienced the impact of a major economic recession. Its effects were severe and construction output plummeted sharply (Construction Industry Council, 2009). Survival became a struggle for a number of organizations, many of which made significant staffing cuts to stave off financial crisis and bankruptcy (Construction Industry Council, 2009).

Understandably, BIM implementation took a backseat during this time, but attracted attention once again with the publication of Government's 2011 construction strategy. In it, Government uses its position as procurer and client of 40% of the Built Environment industry to drive through BIM adoption by mandating its use on public sector projects from 2016. It also draws attention to the cost and time savings that could be generated through the use of BIM. In an industry struggling with profitability and efficiency, this was an attractive proposition.

The effects of this mandate can be seen at institutional level. The need for new industry standards and processes was recognized, and institutions began preparing new standards that enabled BIM working and adapting existing routines. These are described in detail in Chapter 4 of this study.

At Design Partnership, technology was permeating almost all aspects of work. Interest grew in the use of new technologies and their potential to aid design processes and outputs. Designers at the firm were seeing opportunities to begin using BIM in their work. A number of external studies and internal reports from the time show the variety of ways in which technology was being used. For example, one study provides a detailed account of Design Partnership's development of an electronic knowledge management system, or an expert 'yellow pages' (Criscuolo, Salter and Sheehan, 2007). It focuses on the benefits such technologies can bring to firms, and discusses the importance of managing knowledge in professional service firms (Criscuolo et al, 2007).

Published in the same year, Dodgson et al's study looks at the use of simulation technologies in Design Partnership, and shows how these technologies can foster innovation in inter organizational projects; technology is shown to be an important boundary object, enabling communication and coordination between team members working across boundaries (Dodgson et al, 2007).

The use of 3-D structural analysis software enabled Design Partnership to design an innovative and complex diagrid structure for the roof at a major transport exchange in London (Design Partnership Journal 2/2012). On the same project, simulation technology was used to design lighting, to model for pedestrian flow, and to plan for construction logistics (Design Partnership Journal 2/2012). At another high profile project in London, geotechnical technology was used to model ground excavations in a historically important site before construction. The proximity of the building to St Paul's Cathedral and the London Underground system created a complex set of challenges for designing and constructing the foundations. Modeling technology was central in meeting these challenges (Design Partnership Journal 2/2012). Also in the City of London, designers of the 225m Leadenhall building made extensive use of 3-D CAD modeling software to design the structure of the building's frame. These models were later used during construction by the fabricators to manufacture the steel elements accurately and quickly (Design Partnership Journal 2/2012). (All data gathered from internal firm journal.)

In parallel, the challenges of adopting BIM at project level and firm-wide implementation became apparent. As a business leader of Design Partnership recalled implementing BIM routinely across the firm was going to require more deliberate organizational intervention than previous technological changes:

> "We thought that the move to BIM was going to be like the evolution to CAD and 3D modeling – that we'll figure it out - but because BIM is about taking all the separate activities that we do and putting them together, it's a much bigger deal… We understood that it [implementing BIM] is significantly different to technological changes that happened before. It would be a gradual process of adoption and it wouldn't be easy."
>
> (Exert from interview with leader of Design Partnership.)

Managers recognized that the scale of the task involved in implementing BIM at Design Partnership meant that: "the evolutionary model was not going to cut it". BIM implementation required changes reaching far beyond the IT department. As a Director in Design Partnership explained, the magnitude of the change and level of disruption to the organization meant that:

> "Almost every member of staff needs to be told what it [BIM] means and that it's going to change their job description – it is that disruptive."
>
> (Exert from interview with leader of Design Partnership.)

Design Partnership struggled with the collaborative demands implicit in using BIM. A senior business leader describes this saying:

> "We realized BIM enabled working affects the way we communicate with collaborators and that's the difference – everything we do with BIM is open book and you have to decide very clearly what you've done for internal processes and what it is you share with clients and collaborators."

He went on to explain that this created a great challenge for Design Partnership and other firms operating in an industry where:

> "The collaboration agenda didn't really happen – it's so embedded in the industry its basically a very litigious industry that makes its money on claims. They cannot get around the idea that you do not make money on claims…. You know there are surveyors whose whole purpose is to review your document and look for holes in it and then make claims."
>
> (Exerts from interview with leader of Design Partnership.)

A series of business initiatives undertaken during this phase informed this shift in approach. The first of these is an internal report published by Design Partnership in November 2005, entitled 3D Documentation Transition. As one of the authors of the reports states:

> "We realized that the whole thing [implementing BIM] was about organizational change, as well as being dependent on technology."
>
> (Exert from author of '3D Documentation Transition at Design Partnership.)

In this report the use of 3D modeling, an important stepping-stone to BIM-enabled working, was mandated on every project. The report is based on studies of 40 projects that exemplify innovative working using early applications of BIM, namely 3D documentation. This early "discovery" phase provided opportunities to gather and share data and knowledge about use of 3D on projects. Interviews were undertaken vertically in project teams, and information was collected about lessons learnt, efficiency savings, and how the project was selected.

It was envisaged that an implementation phase would follow on from the report's findings and recommendations. During this phase, the lessons learnt should have been disseminated and introduced to all of Design Partnership's offices. However Design Partnership decided not to fund the implementation phase, for reasons that are unclear. Instead uptake of the 3D documentation target was monitored periodically across offices.

During an interview with the report's author, he explained that it emphasized the variance in applications of BIM found across Design Partnership's offices and disciplines. For example, it discusses in detail the range of discipline-specific software available for 3D documentation in the building sector and the challenge of achieving interoperability between them. Software issues are linked to the 3D capabilities and outputs in the disciplines. Structural engineering is described as being ahead of building services (or MEP engineering) in its use of BIM. This is put down, in part, to the lack of software suitable for MEP (Design Partnership, 2005).

This variance led to many BIM-related initiatives springing up across the organization. In an effort to provide strategic coordination for them, Design Partnership established an internal Built Environment Modeling (BEM) task force in 2007 comprising senior leaders from across its geographic and business markets. The acronym BEM indicates its wider remit incorporating a number of emerging and related technologies including Building Information Modeling, Geographical Information Systems, virtual reality, parametric modeling, and design optimization.

The BEM task force operated for two years until 2009 and published a number of vision statements. Leading on from this, regional working groups were established to develop the current organizational strategy, launched in 2013. Additionally a task force was put in place to address the many specific issues facing MEP engineers adopting BIM. Major advances were made in MEP software and BIM abilities, both in Design Partnership and more widely. The current MEP software was suitable for modeling, but couldn't perform more advanced analysis:

> "It was okay for 3D modeling but in terms of linking services, linking the pipework to the plant rooms and so on. It wasn't really intelligent. So you couldn't play with flow rates or connect things up. It was disjointed."
> (Exert from interview with MEP engineer at Design Partnership.)

The focus on improving staff's technical abilities in using complex BIM modeling and analysis software was echoed in the wider organization as more staff were trained in its use. Additionally towards the end of Phase 2, advanced users of BIM were offered intensive training in association with a leading university.
During Phase 2, implementation of BIM in Design Partnership remained patchy, limited to "pockets of people who could see the light". However the emergence of formative early practices and routines are evident. Many of these were enacted by a growing group of practitioners who began using BIM in their everyday work, learning from these experiences.

Some experiences were negative, and could be deemed a failure. For example, a number of regional offices in Design Partnership decided to take advantage of the low workload resulting from the recession to develop their 3D modeling capabilities. However a lack of experience meant that this was not a success:

> "They created these amazingly detailed models, but they cost a fortune, a lot more than they were meant to. It was a disaster. It stopped that region doing more modeling for years because they burnt their fingers so badly."
> (Exert from interview with manager at Design Partnership.)

However, lessons were learnt from these ventures that have been well used.. Namely, that learning happens on projects, modeling has to be necessary, therefore reinforcing the importance in Design Partnership of employing a learning by using approach (Rosenberg, 1982) to BIM adoption.

More positive formative experiences using BIM in everyday work were also described. For example, one engineer talked about the first time he used BIM software [REVIT in this example] on a project in Central London; this experience was instrumental in standardizing the use of BIM software in project teams:

> "Back in 2006 I had a project that I was leading and we had the opportunity to use REVIT – people had seen it but it hadn't been used on a real project. We decided that it was worth going for on a complex project – mainly because it was a project needeing some 3D software. It was a big learning curve but we've been using it ever since."
> (Exert from interview with project engineer at Design Partnership.)

The acquisition of software skills ran in parallel with the introduction of novel organizational routines. For instance, experiences gained on Project University (discussed in detail in Chapter 6 of this thesis) show that the early stages of projects and team formation are important and that BIM both enables and makes demands on ongoing communication and coordination. It shows that these routines are formed through collective learning, extending beyond organizational and disciplinary boundaries.

3.3 Phase 3: Infrastructure of support

The third phase of BIM implementation at Design Partnership occurs between 2013 and 2015. Over this time, the technological and organizational fields begin to align with users actions and enable and embed change. As one interviewee put it, BIM adoption had become a "do or die" situation for Design Partnership.

> "It's a very different climate in 2013 compared to 2005. Instead of BIM being a nice-to-have it is a must-have."
> (Exert from interview with leader at Design Partnership.)

This sense of renewed urgency reflects wider changes. The Government mandate was laid out in the GCS report in 2010. Institutions began publishing policies and standards that were formed during Phase 2, facilitating the use of BIM.. Standards were introduced with the publications of documents such as PAS 1192-2 (British Standards Institution, 2013) that laid out the specific requirements for achieving Level 2 BIM. The professional institutions aligned their routines with the use of

BIM: for example, in 2013 the Royal Institute of British Architects published a new Plan of Works to accommodate BIM-working (at all levels) in its project stages; the Construction Industry Council also published guidance in 2013 that lays out collaborative protocols for using BIM.

Reflecting this, a step change occurred at Design Partnership in its approach to implementing BIM. Its Chairman launched its current strategy at its 2013 general meeting, indicating clearly that the implementation of BIM had become a key strategic issue for the business. The objective of the strategy is to standardize BIM across Design Partnership with all work being routinely undertaken in a "BIM fashion" by 2014. The overall aim of this strategy is to accelerate the spread of implementation of BIM in Design Partnership. This strategic shift indicated that BIM was no longer the domain of a few technical enthusiasts but involved every member of staff in the organization

The strategy was launched at an internal firm event on 29.1.14, where the head of Design Partnership's UK business described adopting BIM as a 'do or die situation for the firm" (from Launch of BIM strategy in the UK, 29.1.14). In a later interview the leader of the strategy group in the UK describes the task of this team as:

> "pushing BIM through all our work. To take it from something optional to something we do every day".
> (Exert from interview with manager at Design Partnership.)

A global team has therefore been put together to implement this strategy across Design Partnership's business sectors and regions. Senior staff have been recruited internally and externally with expertise in using BIM to implement this strategy. Considerable resources have been dedicated to the current strategy supported by senior leadership. It aims to create an infrastructure of support to enable users to adopt BIM in their work. As a member of the team implementing the BIM strategy put it:

> "We need to change our projects appropriately but urgently – we need staff to keep calm but act now. We are trying to tell people how BIM will help them personally in their work."

(Exert from interview with manager of 2013 BIM implementation strategy at Design Partnership.)

A range of mechanisms is being used to provide this infrastructure of support. For example, users are provided with information and guidance, explaining the abundant terminology that surrounds BIM and detailing guidance in using BIM. Focused training is delivered that caters for different disciplines and levels of seniority. Existing organizational routines are adapted to incorporate BIM working, for example virtual design reviews are added into standard project reviews; extensive guidelines are available on producing BIM execution plans as part of the briefing process.

The BIM task force is setting measurable targets and putting in place a number of quantifiable measures to measure progress at all levels that are linked to individual and business performance and reward. Targets include the number of projects with BIM execution plans and virtual design reviews, and rates of staff training. Following discussion at a meeting of Design Partnership's strategy team on 17.3.15, a survey has been developed, based on the BIM Project Execution Planning Guide developed by Pennsylvania State University's Computer Integrated Construction Research Group, which measures various dimensions of BIM use on projects (CIC Research Group 2011). Human Resources are developing individual performance measures of BIM relating to different job functions, production, management and leadership, which will be used for future recruitment and performances reviews.

Importantly, the current strategy recognizes and tries to accommodate variance in BIM use, highlighted during Phase 2 of this process. This variance is apparent in a number of dimensions in Design Partnership. For example different business and service streams have different requirements that are fulfilled by a range of BIM software platforms:

> "Our business streams work in different ways – they serve different clients and markets. And how BIM is implemented differs in each of those areas – the scale of the issues, the software platforms and so forth. "

(Exert from interview with manager of 2013 BIM implementation strategy at Design Partnership.)

Integrating BIM across the disciplines is a major challenge for Design Partnership. This is because there are markedly different uses of BIM building design. This is well illustrated by the differences in use of BIM between structural and MEP (or building services) engineers. As an experienced MEP engineer explained:

> "In structures, if you have a steel structure, it's just detailing that the contractor needs to do. In building services, we often do not specify the equipment: for example we say we need a pump that has a certain performance specification but we don't tell the contractor from which manufacturer … And if you imagine that goes right through building services to every single piece of equipment – it is a fundamental problem around transfer of information. Traditionally this has been addressed by redoing the drawing but in BIM if we are to take the maximum advantage we shouldn't be doing redrawing. So that is a big issue that needs to be resolved. "

(Exert from interview with senior MEP engineer at Design Partnership.)

Accordingly different practices and routines are developing across the two disciplines. For example, building services engineers keep all layers of the BIM model turned on while designing to avoid clashes, while structural engineers tend to work with them turned off. As one structural engineer explains:

> "I find that when you're building the structure it's easier just to work from the grid and then you switch on the other stuff for coordination to make sure that you do clash detection. Structural engineers set the building to the frame, they set the geometry of the building. Building services are then fixed to the structure."

(Exert from interview with senior structural engineer at Design Partnership.)

The current strategy also recognizes that groups within the business have specific requirements in using BIM. For example project leaders are identified as of particular importance in the implementation process because:

> "They are on the front line with clients and need to know exactly what they're agreeing to. They are making some very big decisions on behalf of the company about whether we're going to do 'BIM' on a project. "

(Exert from interview with manager of 2013 BIM implementation strategy at Design Partnership.)

Project leaders are faced with a number of critical issues that they feel are constraining BIM use. For example, “cost is a big topic: no one is ever going to pay us more for BIM. We have to get the efficiencies out of it ourselves.” Liability is also a great concern:

> “Typically it will still be part of our base services to do 3D modeling so it’s the sharing of that that we give out but with a disclaimer that says don’t rely on it, use it at its own risk.” As are contracted deliverables: “People need to know what they can use the models for and rely on. But we’ve got to get the aspect right of not over or under modeling.”

(Exert from interview with manager of 2013 BIM implementation strategy at Design Partnership.)

While these issues remain problems for leaders,, they are being addressed through targeted project leadership training. This combines technical knowledge of BIM with business issues such as how to specify BIM in contracts, managing the cost and liability issues in using BIM, and how BIM is used collaboratively. The UKMEA BIM working Group in 2012 for project leaders, addressing these specific issues and providing guidance for dealing with them, produced a detailed handbook.

The strategic shift in BIM implementation that has occurred during Phase 3 at Design Partnership is apparent. The effects of providing this infrastructure of support are described in more detail later.

4. Overview

This findings presented in this chapter provide an overview of Design Partnership, focusing on their complex operations.

Drawing on contemporary and retrospective data, a longitudinal process model of BIM implementation in the firm is shown. This presents three phases of implementation. The firm and industry actions are described through these phases.

The following chapter looks at practices and routines enacted during the most recent phase of implementation, under the infrastructure of support created in Phase 3. Chapter 7 then draws upon the longitudinal model presented here to illustrate different approaches that have been taken to organizing for implementation.

Chapter 6: Implementing technologies: evolving practices and routines

1. Introduction

This chapter is the second of three presenting the detailed findings of this thesis. It addresses the study's first research question, which asks how organizational routines and practices influence processes of technological implementation in firms. Data drawn from projects during the course of projects at Design Partnership is presented. The practices observed here are clustered around three recently completed projects. As practice studies demand observations of situated actions, these projects are current or recently completed, drawing on contemporary rather than retrospective data.

The chapter begins by presenting a conceptual model that describes a staged process of technological implementation. This model builds on Edmondson et al's 2001 process model of technological implementation, developing it to fit the theoretical, methodological and empirical setting of this study. It describes a generative process of routine development in technological implementation using four practice stages of forming, preparing, enacting, and reflecting. Collective learning and leadership enable this generative process.

The remainder of this chapter shows the derivation of this model from the data. It illustrates how this model can be applied to the context of this study, the process of implementing BIM in building projects is illustrated. Detailed descriptions of how BIM is used in three project case studies illustrate how these practices and routines develop, evolve and vary across the project stages. Finally, a cross case comparison of these stages across the three projects shows how practices and routines evolve together and the relationship between them. Factors that enable this evolution in each of the four stages are discussed.

2. Evolving practices and routines

The practices observed here are enacted over the life cycle of three core projects at Design Partnership. In turn these practices form the basis for constantly changing organizational routines. The practice perspective of organizational routines emphasizes the generative, cyclical nature of this process. By viewing practices and routines developing in project contexts, their evolution and embedded nature becomes clear. Distinct stages within the projects are evident and were analyzed using a temporal bracketing approach to analysis.

Edmondson et al’s 2001 model for establishing new technological routines (Figure 16) provides the basis for a conceptual model showing the process of implementing technologies in organizations (Figure 17). Edmondson and her colleagues show that new and adapted organizational routines are needed to use new technologies (2001). They present a model that illustrates this process, involving four stages. This model is developed here to reflect the different empirical setting used in this study, and the theoretical and methodological frameworks drawn on.

The empirical setting of this study affords a view of implementation taking place over a longer time . While Edmondson et al look at how new technology is implemented in cardiac surgery: a specific disruptive technology (MICS) that is used over the course of hours (2001). In contrast, the projects studied here are of significantly longer duration, evolving over months and years. This enables observations of how practices and routines are created during different stages of projects and how they evolve over time.

The terminology is also adapted for this study. The original model refers to one of the stages as “trial*s*” described as “involving initial uses of the technology for actual work” (Edmondson et al, 2001: 697). Such trials are common in the setting of this study in the medical profession. This is not the case in the construction industry, where technology use develops iteratively within and between projects. Thus the third stage is named ‘enacting’*.* This is commonly the longest stage in construction projects, and often involves unexpected events that bring the need for collective problem solving. The theoretical framework used here also differs from Edmondson et al’s study. By using the practice perspective of organizational routines, routines are not seen as set but are viewed as incrementally changing through iterative processes, driven by changing performances, or the routine in practice (Feldman 2000, Pentland and Feldman, 2005).

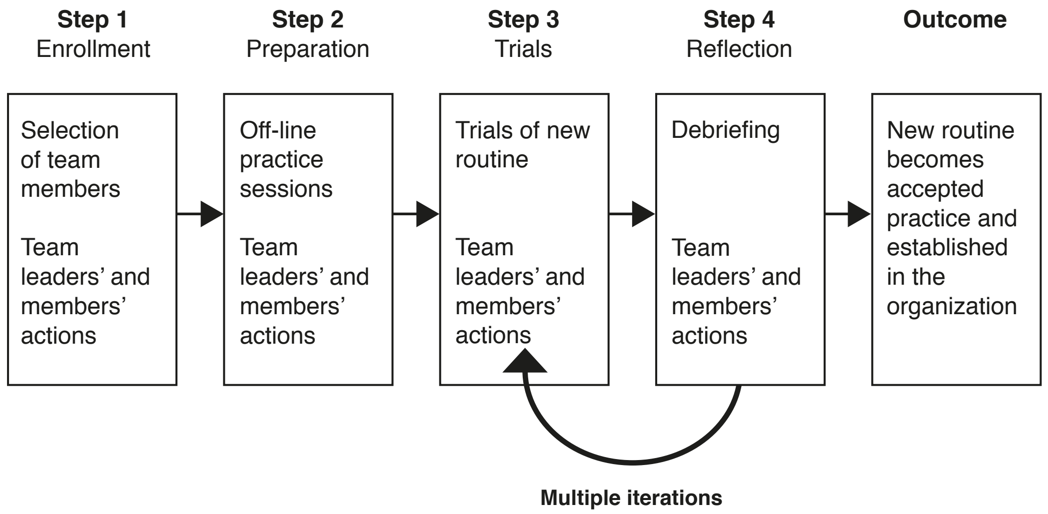

Figure 16: A process model for establishing new technological routines, reproduced from Edmondson et al, 2001: 697.

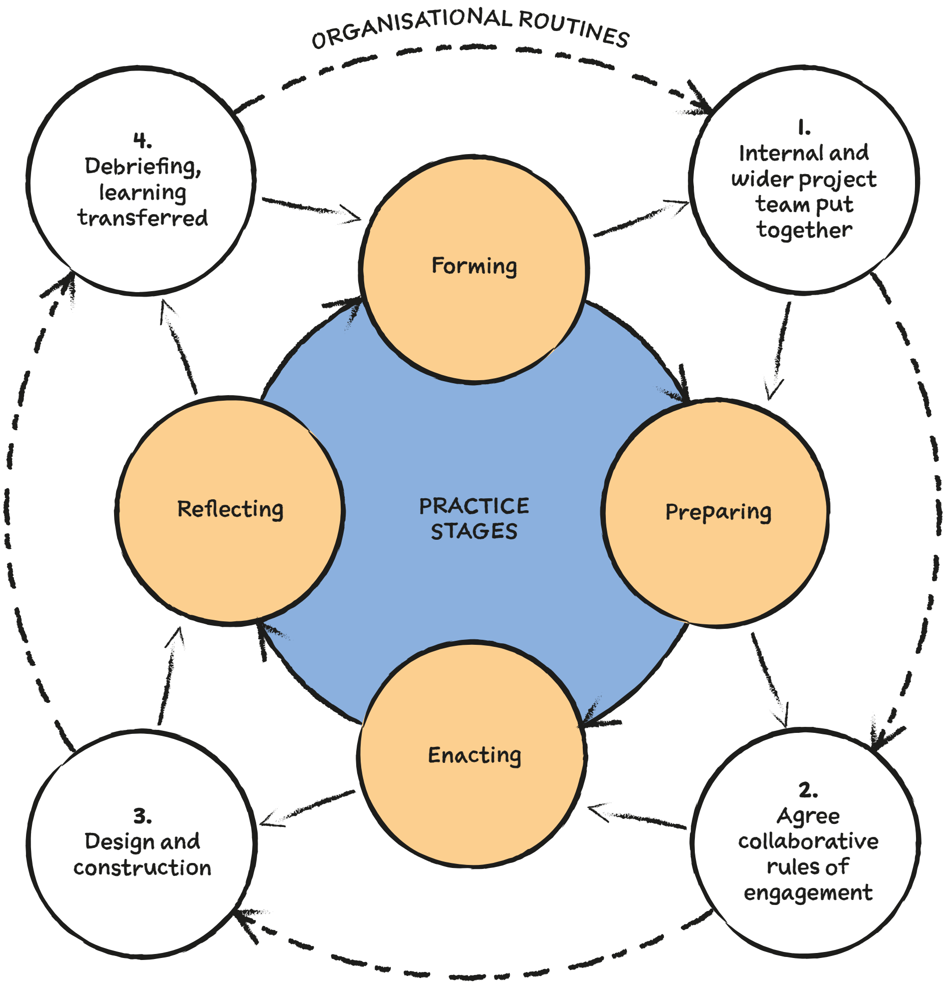

Figure 17: The process of implementing technologies in practice

Edmondson and colleagues' model shows the development process of new routines being established through a linear and finite process; it describes how new technological routines become accepted and established in the organizations as an outcome of this process. In contrast the model developed here shows the process of technological implementation as circular and iterative, driven by constantly changing routines.

Following the methodological implications of process studies, the titles of the stages are changed from nouns to verbs. This is in keeping with Weick's view that organizational scholars should think more in verbs rather than nouns, or in term of actions rather than outputs (Weick 1969).

Thus the conceptual model presented here, and shown in Figure 17, shows different stages encompassing different activities involved in the process of technological implementation. The *forming* stage includes putting together the team, both internally and more widely across the project team; *preparing* describes how the team briefs and sets collaboration protocols before the project starts; *enacting* describes designing and building the project; and *reflecting* describes a post project stage in which the team learns from their experience and applies this learning to future work and routines. As with Edmondson et al's study, collective learning and leadership play an important role in enabling this process. The nature of these enablers varies across the process stages, as discussed in Section 5 of this chapter.

3. Implementing BIM in building projects

Figure 18 illustrates how this conceptual model can be applied to describe the staged process of BIM implementation that occurs in building projects. It shows the four practices stages of forming, preparing, enacting and reflecting linked with the types of routines created and supported by an example institutional process, in this case the RIBA Plan of Works, 2013. Further details on the derivation of this model are shown in the remainder of this chapter, with reference to data collected on 3 core projects at Design Partnership.

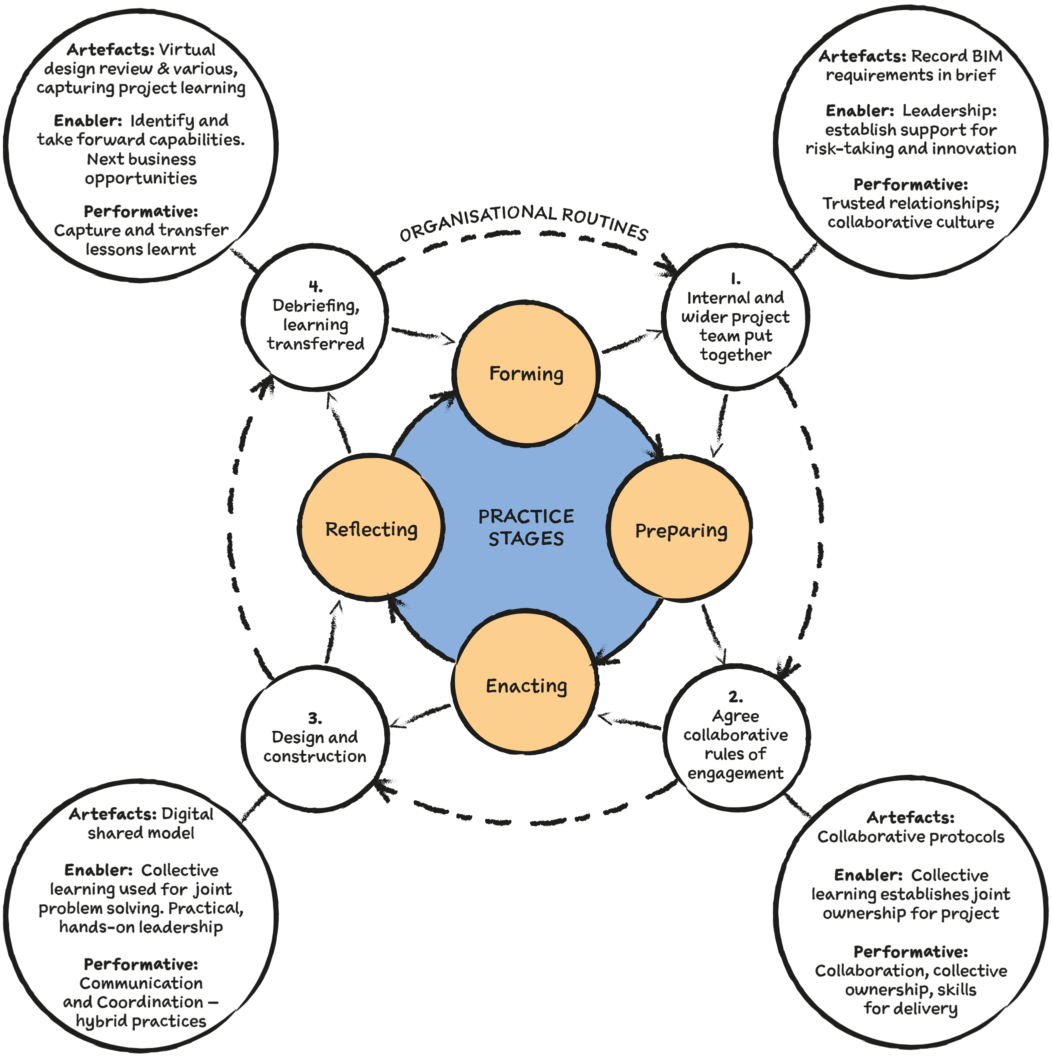

Figure 18: Implementing BIM in building projects

In applying the practice perspective of routines, multiple ostensive and performative elements of routines become apparent. Artifacts represent the ostensive element of the routine, or the routine in principle (Feldman and Pentland, 2005; D'Adderio 2013). A number of artifacts are apparent in the process described here, including the BIM brief in forming stage, the collaborative protocols in the preparing stage and the digital model in the enacting stage. A range of artifacts are used during the reflecting stage, including project sheets and presentations, aimed at capturing and transferring the lessons learnt on the project.

Performative elements, or the routine in practice, influence and are influenced by these artifacts. In forming stages of the process, multiple performances establish trust and collaboration. In preparing stages, performances establish collaboration, joint ownership for the project and develop skills needed for delivery. Performances aimed at improving communication and coordination dominant the enacting stage. During the reflecting stage, performances are aimed at capturing and transferring lessons learnt on the project.

Leadership and collective learning enable the process. They can be seen in this context in various guises. For example, collective learning is apparent when preparing for the project in establishing joint ownership for its successful delivery. Collective learning in the enacting stage is directed towards joint problem solving, during the reflecting stage collective learning enables lessons learnt and capabilities to be identified. Leadership internally and in the project team establishes support for innovation during forming stages of the project; it becomes more practical during hands-on stages. It is vital during reflecting stages of the project in transferring capabilities and lessons learnt on the project and looking for new business opportunities.

4. Practices and projects

Data collected on the three core projects illustrate the derivation of this model in detail. In addition to this data, a wider group of 23 referent projects, were discussed in detail in the course of interviews. The projects studied here are current or recently complete. They reflect uses of BIM taken during Phase 3 of Design Partnership's implementation process.

The core projects are discussed here using the four stages of forming, preparing, enacting and reflecting.

4.1 Project University

Project University was completed at the beginning of Phase 3 of the implementation process – where an infrastructure of support was created. Design Partnership started work on Project University in the middle of 2007 and the building was opened early in 2013.

The client is a large UK university, with some 25000 students, studying in 8 different campuses spread across the city. The building reviewed here provides additional accommodation for the University's Faculty of Media and Performance Arts and Faculty of Technology, Innovation and Development along with the city's Institute of Art and Design. Project University has recently won a prestigious architecture award and achieved the top rating for environmental design in buildings.

Design Partnership provided MEP engineering design on the project, along with specialist engineering services including fire, acoustics, lighting, communications, transportation, security, and highways engineering.

4.1.1 Forming

The project team was assembled in 2007. Design Partnership had worked with this client repeatedly for over 20 years, as had the architect. The existing working relationship between clients, architect and engineer was a key criterion in the team's selection.

The client was clear that it wanted 3D modeling from the outset of the project. While physically consolidating the built facilities in its campus, it was also aiming to achieve virtual consolidation. After the project was delayed, owing to a location clash with a major piece of national infrastructure, the client specified more ambitious BIM targets while retaining the original design team. Unusually for this time, BIM was a contractual deliverable; the design team was bound to use BIM and to hand over to the client a virtual model that matched the physical facility.

The Design Partnership team was led by a project manager who had some experience in using BIM and was enthusiastic about its potential. This project manager played an instrumental role early in the project, but stepped back from the project after the critical early stages, when more junior engineers took over his role. Design Partnership's local leadership team was strongly supportive of this project, reflecting their enthusiasm for using BIM. Their ongoing support was instrumental in ensuring the success of the project.

4.1.2 Preparing

The challenge of using BIM was considerable for all members of the wider project team; they were inexperienced in using BIM, many of the institutional standards that have been published in recent years were unavailable and BIM software available at the time was notoriously "clunky and unreliable". Many members of the team felt that using BIM for the first time on such a large, high profile project was risky. Indeed, one organization in the team initially had two internal teams working on the project in order to mitigate the perceived risk, one working in BIM and one using traditional processes. (They dropped this approach after the scheme had been through planning and their internal team only used BIM modeling.)

However from early project stages a strong sense of collaboration existed amongst all team members, following the leadership of the client. From the outset of the project, the client established a strong commitment to learning collectively in the team. This is perhaps the most striking aspect of actors' accounts of working on Project University. As one team member recalls, "we were all feeling our way. All participants were making significant efforts to make it work."

The client was instrumental in establishing this approach early in the project and supported the whole design team in their learning curve. Tangible evidence of their commitment can be found throughout the subsequent project stages. For example, they funded an initial workshop to help elaborate how BIM was to be used and financed ongoing external IT support for all members of the wider project team.

Because learning was undertaken collectively, extending across organizational and disciplinary boundaries, routines for using BIM were developed together from the outset of the project. For example, the team developed a BIM brief and collaboration protocol at the start of the project. This specified criteria for uses of BIM, for example it stipulated how data were to be managed including schedules for data drops and guidance around software use. It was drawn up at a two-day workshop, funded by the client and run by IT consultants, who were then available to help the wider project team implement this brief.

As described in the subsequent section, these collaboration protocols did not remain unchanged but evolved with demands. On reflection, team members felt the collaboration protocols should have included more detail on issues such as levels of development, roles and responsibilities of the team. However, the protocol itself and the process of collectively creating it were important early steps in preparing the team for subsequent stages.

4.1.3 Enacting

The enacting stage was challenging for all project team members in a number of areas. They quickly realized that communication and coordination across the project team in Design Partnership and beyond was critical, even more so when using BIM.

It became clear that using BIM both creates challenges and opportunities for communication and coordination. For example, the 3D model was used at all project meetings for discussing design and construction issues, rather than 2D drawings. It proved a markedly more effective tool for these types of discussions, allowing team members to get a 3D view of how the building was progressing quickly.

However this also created a problem across the team. While the collaboration protocol specified that the team exchanged models every two weeks, this was leading to issues around workflow and communication: the design team often had to wait for other organizations to design and it was difficult to communicate changes in information exchange. As an architect working on the scheme recalls:

> "Our main problem was around communicating changes in information exchange. We were exchanging models every 2 weeks. This created delays as we were waiting for other team members to design elements."

Similarly, if the architect made a significant change in the design, for example by moving the ceiling grid, there were substantial delays in communicating this to other members of the team as data drops were made bi-weekly, and BIM software had restricted functionality to communicate these changes. This resulted in inefficiencies and clash detection became a major ongoing issue for the team.

Therefore the collaboration protocol was adapted to reflect user experience, and a routine was developed to resolve this. As a member of the design team explained:

> "We decided to streamline the process – to put placeholder elements in the model which acted as generic elements that identified zones. So we didn't have to wait for other members of the team to design."

Despite this, coordination and clashes persisted in creating challenges throughout this enacting stage. Project University was carried out before the advent of institutional standards, such as PAS 1192 and the CIC protocol, and specialist technologies, such as clash detection software (specifically NavisWorks Clash Detection) that help resolve issues around coordination and communication in contemporary projects. As these standards and technologies were unavailable, team members often relied on traditional methods of project communication to try and mitigate some of the more serious coordination issues. For example, colocation and other forms of face-to-face contact were found to be invaluable for day-to-day informal communication. The project's lead MEP engineer says Project University showed that:

> "Coordination issues are potentially big problems – BIM doesn't answer the need for coordination. If anything the basics of design coordination are more important when working with BIM because they are flagged up quickly."

The team found that in the wider project team, professional boundaries were in a state of flux. While some aspects of professional roles remained broadly intact –

that, for example, the architect still did the setting out and designing – using BIM was changing the boundaries between the professions. A number of unresolved questions arose because of this emerging situation. For example, how should architects communicate with engineers when using BIM? Who is responsible and when?

Inside Design Partnership, it became apparent during this project that engineer and technician roles were changing significantly in using BIM. As modeling became a more highly valued skill, the technician took on more of the engineer's role. A member of the Project University team commented that there had previously been a "Berlin Wall" between the technician and engineer, but that as the use of BIM becomes more widespread, technicians increasingly work on design problems that were traditionally the domain of engineers:

> "Now technicians are greatly improving their knowledge of buildings – they're asking engineering questions and getting more involved in project management roles."

4.1.4 Reflecting

While many aspects of using BIM on Project University were challenging, and some remained unresolved, for organizations in the wider project team and individuals in Design Partnership's team it proved a formative project in building BIM capabilities. Business leaders were vital in ensuring this transition was made in Design Partnership, in creating a link between learning and capabilities that had been built on Project University to the business.

This is reflected in all organizations in the wider project team. For example, the client has progressed to using the BIM model for facilities management purposes. The architect is now using BIM in all its work and has developed an industry reputation for its capabilities in using BIM. The main contractor is working on Phase 2 of this development and has invested in BIM 360 Air, a cloud-based computing system used by the whole team; the MEP engineer is working with Design Partnership on another major project for an automotive client, collocated at their offices in order to enable ongoing communication.

For Design Partnership, the experienced gained in Project University established a number of significant issues and approaches to using BIM that have informed its current strategy The importance of early project routines was made clear from the collaboration protocol put together by all project members.
The team was formed from individuals and organizations that were familiar with each other and had an established working relationship.

The importance of strong leadership was clear at a number of levels: from the client, and internally in Design Partnership at project and business levels. This leadership provided the infrastructure of support to enable collaborative working, using BIM. This collaborative working proved sufficiently robust to allow changes to be made as the project progressed.

As team members were carrying out this project, it became apparent that the use of BIM demands higher levels of communication internally and between members, with more rigorous attention being paid to coordination, especially in areas such as clash detection. The lack of standards and the software functionality available at the time meant that more traditional forms of coordination were used.

Finally an unresolved issue emerged around changing roles, both between professionals in the wider project team and internally between the engineers and technicians in Design Partnership. This is an ongoing shift, as the lead MEP engineer reflects:

> "Engineer's and technician's roles are changing enormously and significantly. Using BIM, the technician is taking on more of the engineer's domain. "

4.2 Project Media

Design Partnership started work on Project Media during Phase 3 of the BIM adoption process, in October 2013. The client is a major media organization which has commissioned a considerable level of repeat work, and has become Design Partnership's largest grossing client today.

The client wanted a bespoke building for a training academy, which is currently housed in a small room in the studios. It set an ambitious timeframe for the project, which was completed in September 2014. The original brief called for a temporary building, although this changed during the project and the building is now permanent. Timber construction was chosen early in the project, when the building was still envisaged as temporary, as it is easily demountable. For speed of design and construction, the building has a relatively simple orthogonal geometry, with forms repeated across its four floors.

The division of Design Partnership working on Project Media offers architecture, structural, MEP and public health engineering services. It provided these integrated services through the design phase of Project Media, working in a co-located team based in its offices in London. During construction it worked with the main contractor who are also providing detailed MEP engineering and a specialist timber fabricator.

Since Project Media, the client has decided to use BIM for all its new building projects, with the long-term goal of building an “asset bank” of their properties. They decided to use BIM after Project Media was started, and documented this aspiration, although no detailed BIM execution plan was shared with Design Partnership.

4.2.1 Forming

The speed of the project is extraordinary in the UK building industry: from producing a project brief in October 2013, the building was in use in under a year in September 2014. Design Partnership was commissioned on the project in October and released a concept design report in November. The size of Design Partnership’s team on the project fluctuated according to project stage, during peak times the team comprised eight people, scaling down after design development was completed.

Early forming activities were driven by the speed of the project and the need for the project team to work quickly and collaboratively. This contributed substantially to the client's decision to use this division of Design Partnership for this project. As a senior MEP engineer working on the project explained:

> "Because we are integrated we are well-placed to do a super fast building. We all sit together and we can just get things done without having the backwards and forwards that you might normally get and the more contractual relationship you usually have."

Design Partnership's leaders chose to drive BIM use on this project. Specifically, they decided that engineers would do all the modeling on Project Media while designing, a role previously performed by technicians and a first for Design Partnership. Internally, some team members had concerns about the risks of using BIM in this way on a project with such challenging timescales. However, as the same MEP engineer commented, past experience had taught them that:

> "There was never going to be a perfect project [to use BIM] – there was always going to be an excuse. So we just did it and it was hard. But it's given us a lot of things to talk about and to understand."

This sums up the strong commitment this division of Design Partnership has to using BIM and learning from these experiences. They had already built substantial BIM capabilities over time by using this approach; from the first time they chose to model an entire project using modeling software on a major London development, to their current work developing a data rich BIM model for a major automotive manufacturer.

This dynamic process of learning on projects is strongly supported and encouraged by the leader of this business division, himself an early adopter of BIM technologies. Practitioners are encouraged and supported to learn and innovate with regards to BIM on every project. During the interviews, actors who had worked on Project Media generally showed a determination to learn from the experience and use these in future work.

Senior engineers, enthusiastic and experienced in using BIM, led the selected team. Technicians were used during times of peak workflows, but the junior engineers and architects were, for the most part, novice users of BIM.

4.2.2 Preparing

Because Design Partnership's team on Project Media "hit the ground running", preparation time was extremely limited. They had just six weeks to produce a concept design. A formal kick off meeting was held at the beginning of the project that established some internal collaboration and coordination guides from the outset of the project.

As the team is small, co-located and integrated, collaboration and management of data is easier. Individual team members were, for the most part, familiar with each other, and had established routines developed from working together on past projects.

There was enthusiasm amongst the team for the coming challenge. While many were facing a steep learning curve with regards to BIM use, they described this as an opportunity, complementing the formal training they had received. As a recently qualified engineer explained:

> "The training courses seem quite useful at the time, but you forget it quickly if you don't use it. You need to link things together; otherwise it's just discrete bits of learning."

4.2.3 Enacting

Past experience had established that communication and coordination was particularly important when using BIM. During Project Media, this was pronounced because of the intense pace of the project.

The project team learnt not to rely on the model to coordinate, and that face-to-face communication was still a valuable means of communicating and coordinating work. The project leader explained:

> "The model is a tool that helps you coordinate but actually you should be talking to each other first … you shouldn't rely on the model to miraculously do your coordination."

This was demonstrated early in the project, when the site coordinates were entered in error without communication between the team. This mistake was uncovered during a conversation in a design meeting and subsequently resolved. However it took time, a scarce resource, and could have been avoided.

The co-location of the team helped enormously to facilitate informal ongoing communication amongst team members, this was particularly important on such a fast-paced project, which used BIM in a novel way for the first time. The team's physical proximity meant that discussion between members was readily available. Illustrating how this led to problems being collectively solved, a lead engineer recalled:

> "We did have a lot of discussion about how people model things. For example, how you do tapering elements. If you've got a steel element, you just tell it what beam it is, you tell it from the library, whereas in concrete (and particularly in foundations where you've got pits and funny shapes) you have to make design decisions about where one element stops and another starts. So do you model a slab to the side of the wall or do you model a slab all the way through? There was that sort of decision to be made."

While the team learnt that the 3D model couldn't be relied on in isolation, there were instances where it proved a valuable tool. The model was used to facilitate discussion at the periodic design team meetings, where it proved a particularly valuable tool for showing the building elements and their relationship to each other. For example, during design development stages, the team was able to quickly identify from the model that the timber structure was getting very large, therefore the architects were able to increase the floor height to mitigate the proportional effects and allow more room in floors and ceiling voids for services.

In communicating with the client, Design Partnership also used both the 3D model and physical model. During the project, it was crucial that the client took timely and well-informed decisions in order to meet tight deadlines. The project leader is convinced of the value of this hybrid approach:

> "We did use the 3D model, but we also developed a scaled physical model to use in design meetings. I think there will forever be a space for both."

On the strength of 3D models she explained:

> "Virtual models allow you to talk about specific bits and to see problems with them – because the physical model is just architectural it doesn't allow you to see the services and raised floors and so on. A virtual model enables us to coordinate much more and see the little nooks and crannies and spot problems with clashes."

However, the team also found through that virtual models bring disadvantages in guiding client decision-making, disadvantages that are not incurred using a physical model:

> "The minute you model the design, it looks real. You can show a client a BIM image and they think it's designed whereas most of it is conceptual still. At concept stage you're reserving spaces for things and not detailing."

As Project Media moved into construction phases, other organizations became involved as well as Design Partnership. The BIM model was then used in ways that further illustrate its versatility. For example, timber manufacturers B&K used the model as the basis for timber fabrication and were able to reduce their tendering program by a week.

The contractors for the project used the model for 4D programming; effectively they developed the model to show the building being constructed. By doing so, they calculated constructability (or logistical) details that account for other activities on the site: where to site the cranes and delivery wagons and offloading the timber, and then rearranging plant as needed.

During costing stages, the model was used to clarify information with other manufacturers. For example, a senior structural engineer at Design Partnership used the model to show that the wrong calculations and price estimates had been made for concrete beams.

Work processes between the disciplines change using BIM, potentially creating efficiency gains and allowing the design team to work faster. One senior structural engineer provided an example of this:

> "Structural engineers generally fix geometry whereas the service engineers traditionally write performance specifications and get

> trade contractors to do the final installation drawings. But when using REVIT *[a 3D modeling software]*, the building service engineers have to specify more detail in their design up-front. On this project, because all the risers and cores are made out of timber panels, all of the openings for the services are cut in them. So our building service engineers predefined that so that when our model went to B&K it had all the building work in it."

However, there were instances in this project stage where using BIM had less successful outcomes. First, the team experienced considerable frustrations trying to produce suitable drawings (their contractual deliverable) from the 3D model:

> "The drawings didn't look like the professionals wanted them to look like. It's a very real problem: our deliverable is a drawing. If it looks bad then that reflects on us and it doesn't show the information we want it to. There's an uphill battle with that and people are often citing this as a reason not to use BIM."

Second, several more junior engineers, learning to use BIM and model for the first time, felt there was a lack of practical support available to help with day-to-day modeling. Support tended to come informally from asking internal BIM experts:

> "We've got one BIM MEP guy in our group, who is pretty knowledgeable about it. But if he's not around, and you've got a question, then no one has got the answer. So it's quite tricky if you just get stuck. It is quite frustrating, yeah, but on the other hand it seems hard for him just to be a question monkey."

The junior engineers expressed frustration with some project leaders, whose lack of hands-on experience of using BIM was limiting the support they could offer:

> "I guess all of our leads were trying to be as understanding as they could but they have little concept of how REVIT actually works – how long it really takes to do something or why a problem occurs or how they can solve it. They can't tell you to speed up, they can't help and they don't know how long it's going to take. They just pat you on the back!"

4.2.4 Reflecting

For Design Partnership, Project Media provided an opportunity to build on past experiences and advance their learning about using BIM in projects, in order to improve on the next project. The way in which practices evolve from projects, and the clear path that practitioners use to trace this evolution is striking. For example, taking early project routines: the need to establish protocols and produce BIM execution plan as part of the briefing was established during early projects. The lack of such formal collaborative documents agreed by the wider project team and client created problems on Project Media. Subsequently, Design Partnership used the opportunity of a new project – a sports stadium in Qatar with a client driving use of BIM on the project – in order to facilitate an initial workshop across all design team members on a new project, thus creating a collective and flexible BIM brief. The leader of Project Media explained that:

> "On future projects we will endeavor to make sure that we get the BEP [BIM Execution Plan] right at the beginning of the project. In Qatar we're going to hold a workshop and talk about what the process is with all parties. We're going to agree who is doing what, with what piece of software so that people engage and understand the effects of what they do. In the world of BIM the interdependencies are increasing, whereas before it didn't matter as much."

Similarly they were aware of the importance of communication and collaboration when using BIM from past projects, but advanced their learning about how communication and coordination happen. Design Partnership's experience on Project Media enforces their experience on Project University. A senior engineer working on Project Media observed that BIM enables better coordination but also demands more communication, explaining that:

> "The main thing we've learnt from using BIM on such a quick project is that you need to talk, to have discussions about what areas are being developed so that people aren't doing abortive work."

In particular, Design Partnership learnt how to use the 3D model and its value and limitations as a communication aid. They realized that in different settings, audiences, and project stages the virtual and physical models are perceived differently and therefore guide decision-making differently. Through their work with external organizations, they learnt about the model's flexibility, and how it can be used beyond design stages into construction.

Design Partnership's technical learning also grew on Project Media, advancing their experience of modeling and BIM capabilities. It led to their current work with a major automotive manufacturer in the Midlands. On this project, Design Partnership is working with the client and co-consultants to develop a data rich model, one that not only provides a 3D model but also has information on each element embedded in the model.

4.3 Project Experiment

Project Experiment is an exemplar BIM project funded by Design Partnership in order to "develop an engaging case study that demonstrates the real advantages of BIM" (NBS National BIM Report, 2014). It showcases Design Partnership's capabilities in BIM and provides opportunities to innovate, learn and develop these capabilities.

This was a fast project, completed in 8 weeks between September and December 2013, Phase 3 of the adoption process. During this time, an interdisciplinary team modeled a 35-storey, 170m tall building, based on the human form. Initially a member of the team was measured using a 3D laser scanner. The resulting data was used as the basis for modeling a building that incorporates architecture, structures, MEP and public health engineering. The design uses bodily systems to produce a building that takes the form of a human being.

4.3.1 Forming

Project Experiment was the idea of two BIM enthusiasts in Design Partnership. The concept gained leadership support and therefore secured business investment. As one of the originators recalls:

> "We had the idea of modeling a person into a building. Together we pitched it to the London leadership *[of Design Partnership]*, who agreed to fund it. The project is a BIM case study to push the tools as far as they could go, using a different form that people could relate to without having to know about buildings!"

Getting the right team together to realize the project was a challenge that involved compromises but was crucial to its success. Team members needed to be skilled, enthusiastic and prepared to work on Project Experiment in parallel with fee-paying projects.

At first, the leaders accessed their internal networks through the Skills Network and personal internal contacts in an attempt to build a global team in Design Partnership. However a lack of response and time pressures meant that the leaders of Project Experiment decided to approach people personally in order to build the team. This approach was successful:

> "More or less without fail everyone I approached in London did want to participate. So we built up a small team – initially it was about 15 people – which was very multidisciplinary including lighting and fire engineers."

While time pressures meant that more specialist engineering disciplines could not be included a core team was developed comprising eight people working across core engineering and design disciplines.

There was considerable variation in team member's experience of using BIM and knowledge of the software, ranging from novices to experienced users of BIM model. There was also marked variation in the approaches and outputs used by the different engineering disciplines, from well-developed mechanical and structural BIM models to a more limited use of BIM in electrical and public health engineering.

4.3.2 Preparing

Time spent preparing for Project Experiment was limited but significant. During this stage, shared ownership for the project was generated across the team. The initial project concept was developed into a realizable project: turning the two project leaders' idea into a collectively owned and deliverable scheme.

This challenging project, designing a model based on the human form, appealed to the engineers and designers involved. The team sought advice from scientists at Imperial College in London about human anatomy and mapped these into engineering systems, designing different components to correspond with bodily functions. For example, the public health engineers decided that the stomach would be a water system and the bladder would be grey water harvesting.

In parallel, the team was addressing the technical aspects of the project: how such a complex, interdependent form was going to be modeled. They decided together to work on scanned data. In partnership with an external IT company they developed a 3D scan - produced by laser scanning the body of a member of the project team- and used this as the basis for ongoing modeling.

4.3.3 Enacting

The team worked on Project Experiment in parallel with fee-earning projects; therefore the team undertook a lot of work on the project out-of-hours. Although the purpose of the project was to innovate, the project leaders chose to use what they called an "old school methodology" to manage the project. They did so because of time pressures generated as Project Experiment needed to be completed in time to present it at a conference and because the team was working on it in parallel with fee-earning work.

As with Project Media, the physical proximity of the team and co-location of the disciplinary units, helped substantially with informal communication. Formal project communication occurred through team meetings, held every two weeks, where tasks and deadlines were agreed. The team was hierarchically organized, with project leaders and heads of each engineering discipline.

Some team members proved resistant to using BIM, preferring to use more traditional methods of working with the engineer designing and technician modeling. As the project manager recalled, it transpired that some team members lacked the technical knowledge to work in BIM consistently:

> "Sometimes we said draw on the prints and we'll model it. These occasions arose because of technical limitations: because the tools are very complex and need expert knowledge to drive your way around the model. We tried to simplify that but again it has a time overhead. Even when you're working on a real project, you don't necessarily have the luxury of that time to enable better collaboration."

The same individual describes how this variation across the disciplines was reflected in the model:

> "Structurally it was fairly well developed. Mechanically it was very well developed. Electrical and public health are more geometry and

> filling out the model rather than being true BIM. That was a function of time and not having skilled people that could run off and do that element in a BIM-way on their own."

Despite this variation, leaders did push interdisciplinary working in Project Experiment, trying to improve coordination between disciplines and workflows. A leader of Project Experiment explained the potential of BIM in this area:

> "One of the huge things that's often overlooked in using BIM is what you can do to inform others. So it's not about making steel fabrication faster, it's about thinking across disciplines. For example if public health engineers include a tank in their design, these are very heavy with huge loads. Using the model, you can highlight this to the structural engineer and help them realize early on that they need to provide extra reinforcement. But quite often things like that get overlooked early in the design process. It's that mindset to check what someone else has done first before you go off and do your own thing."

This view is expanded by a project engineer, who feels that the use of BIM:

> "Is very much driven by the modeling side. It's not being pushed from a design and collaboration side. We're just thinking how can we easily model something."

A number of technical advances were made during this stage, often through collective problem solving carried out during design meetings. As the lead design explained:

> "There were instances on the project where we could have done it in an easier way. Take the structure: the way that we originally defined the structure was to trace the laser scan and join the dots: it is efficient but it's not very clever and it couldn't have coped with changes! Instead we discovered that one of the team members had enough knowledge to define a parametric structure that would dynamically reform depending on a few variables. He could probably do that a lot quicker with his technical knowledge then to have done a manual process in the first place. From a design perspective that means it's a lot more flexible and copes with design changes easily. "

Significant technical innovations were also made in MEP engineering. In modeling airflow systems, team members managed to embed formulae into the mechanical equipment families and thereby automate a vast array of calculations that rely on the total airflow:

> "We established that it was possible to use the total airflow to calculate the heating and cooling loads for each piece of equipment in the ductwork system, alongside the water mass flow rates required by this equipment to meet the calculated loads."

Not only does this innovation automate a traditionally manual process, it synchronizes calculations to the geometry of the model and links the ductwork system to the pipework system so that a change in one automatically updates the other.

4.3.4 Reflecting

After Project Experiment was completed and presented, significant resources were put into reflecting on the project. This was partly because of the nature of this project: it was experimental and funded as an exemplar project, therefore reflecting on and capturing the learning from the project was the central driver behind Design Partnership's and the team's investment in it.

In terms of improving future work, the project leader felt that more time could be spent during the project solving problems creatively rather than always being focused on individual deadlines:

> "The main lesson we learnt was that we could take the time to stand back and use the tool and we could do a lot more than was previously thought! By keeping your head down and doing work you don't see the possibilities."

On forming the team early in the project, a number of team members commented that knowing individual capabilities is critical commenting, "it would be a big help to know team member skills up front". One event that occurred during Project Experiment illustrates this well: the team needed some parametric modeling carrying out and put a global call out for someone with these capabilities. After considerable efforts and time were spent finding the right resource, it transpired that a member of Project Experiment's existing team had the skills to do this work, but that other team members and leaders were unaware of this.

Individual team members working on Project Experiment developed their technical skills significantly: one engineer now feels he has sufficient modeling skills to design straight into the model and no longer passes this work to a technician.

During the project, considerable learning was made in workflows and the importance of interdisciplinary coordination and communication. Drawing on these experiences in Project Experiment, one member of the team produced a work process diagram, based on analyzing the work flows and software interoperability over the project's duration. This concept is being taken forward and developed in using BIM for 4D programming on projects with complex logistics such as Euston Station in London.

Through a series of internal seminars and events, and written accounts, the learning from Project Experiment is being diffused across Design Partnership. Externally, it is being presented at a number of conferences and written about in publications. It is also used to demonstrate Design Partnership's abilities in BIM to prospective clients and potential employees. The response from internal and external audiences has been positive:

> "Internally we've had a lot of interest from other regions and offices that want to know what we've done and why we've done it. Externally there has been an overwhelming reaction, praising our work and saying that we're doing some really clever stuff. We've been invited to speak at other conferences, generally within the BIM community, and we've been shortlisted for a couple of awards."

The team remains adamant that further work will be done on Project Experiment, developing the existing model and incorporating more specialist engineering disciplines.

5.0 Stages of implementation

Comparison between the stages in the three projects demonstrates further the fit between the model and data, as summarized in Table 10.

5.1 Forming

The *forming* stage describes putting together the team. It occurs at individual level internally in Design Partnership and organizational level across the project team to incorporate other consultants and contractors.

Comparison across the three case studies shows the importance of existing relationships, of the trust and knowledge they bring between participants. This is evident both at organizational level, as is apparent in Project University, and individual level, as is apparent in Project Media and Project Experiment. The value of repeat relationships, working with trusted collaborators (Smyth, Gustafsson, Gansaku, 2010; Smyth, 2005), is also evident in the reflecting stage of this process model, as seen in the level of repeat work that is secured through successful projects. For example in Project Media all organizations involved went on to work with co-consultants or for the same client. This emphasizes the circular and iterative nature of this process.

Familiarity with internal individuals on the team and external partners enables team members to assess quickly and accurately the level of skill people have in using BIM. The value of this is particularly evident in Project Experiment that is markedly innovative in its use of BIM.

	Forming	Preparing	Enacting	Reflecting
Project University	*Actions* - Existing working relationship between all parties meaning routines were existing and easier to adapt. - Client specified formal BIM requirements in brief. - Original team retained despite project delay.	*Actions* - Collaborative culture established early on: '*we're all in it together'* - Collaborative BIM protocols produced - Ongoing IT support provided	*Actions* - Critical nature of communication and coordination: - Collaborative routines were adapted as the project evolved. - Traditional means of communication and co ordination - Shifting professional roles and hierarchies	*Actions* - Projects build organizational capabilities in BIM - Early project routines establish collaboration. - BIM enables better coordination but requires more communication. - Without appropriate standards and software, routines and practices remain unchanged.
	Enablers - Supportive and enthusiastic business and project leadership in Design Partnership. - Ongoing client leadership demonstrated.	*Enablers* - *Collective learning* in wider project team extended - Client *leadership* creates culture for innovation and risk taking.	*Enablers* - 3D model can enable *collective learning* during enacting stages - Traditional *leadership* roles changed.	*Enablers* - *Leadership* engaged with the project. - *Collective learning enabled* participants to work together using BIM throughout this project.
Project Media	*Actions* - Team formed quickly because of need for speed - Established collaborative relationships between team members were valuable.	*Actions* - Limited because of apparent time pressures. - No BIM execution plan was created. - Client was unclear in the brief about BIM requirements.	*Actions* - Model shouldn't be used in isolation for coordination. - Virtual and physical representations of design are complementary. - Misalignment between BIM and professional outputs.	*Actions* - Clearly learning and evolving practices for example in early project routines. - BIM can enable better coordination, but demands more communication.
	Enabler - Leadership from Design Partnership at business and project level meant team members were supported in using BIM in an innovative way.	*Enabler* - Kick off meeting at Design Partnership established internal protocols. - Leadership chose to drive forward use of BIM beyond client requirements..	*Enabler* - Problems solved through *collective learning.* - Hands-on project *leadership* is needed at this stage to support staff's work. It was lacking in this project.	*Enabler* - *Leadership* ensured that in project learning was transferred to the business. - A dynamic and evolving process of collective learning across projects is apparent.

	Forming	Preparing	Enacting	Reflecting
Project Experiment	*Actions* - Getting the team with the right capabilities and enthusiasm was critical. - Personal contacts were used to identify suitable individuals and select the team quickly.	*Actions* - A time limited but important stage - Together the team worked out how to turn an idea into a realizable project.	*Actions* - Some resistance was experienced across the team. - Major advances in inter-disciplinary working and technical challenges.	*Actions* - Take time to reflect during the project process. - Knowledge of individual capabilities and skills up front is critical. - Significant advances were made in integration of work processes.
	Enabler - *Leadership* support gained initial investment and business support for the project.	*Enabler* - Through collective learning externally the team developed shared ownership for the project	*Enabler* - *Leaders* used traditional project management methods for speed.	*Enabler* - *Leadership* played a key role in ensuring substantial internal and external dissemination of learning on Project Experiment.

Table 10: Cross case comparison of the stages of BIM implementation

During this stage, formal BIM requirements should be stated. For example, in Project University the inclusion of BIM requirements in the brief established the digital deliverables from an early stage. From the outset of the project, the digital product is conceived in parallel with the physical output.

Leadership is critical in this stage in various guises. The importance of internal leadership support in Design Partnership is apparent. For example, in Project Experiment, business leadership is instrumental in generating the support and investment needed for the project to become a reality. In Project Media, senior leadership provides the support for individuals to feel confident in taking risks and use BIM innovatively. In Project University, the early support and enthusiasm of business and project leaders enabled the team to move forward into a risky and innovative project.

External client leadership indicates a strong commitment to using BIM and to the team. At Project University, BIM is specified in the brief thus indicating its significance to the team, and the original project team was retained despite significant delays.

5.2 Preparing

The second stage*, preparing,* describes how the team developed BIM briefs and collaboration protocols before the project starts. A collective vision for the project is established, which together the team then works out how to deliver.

This is an important stage in the long-term success of the project, as illustrated in Project University, but one that can be rushed to the long-term detriment of the project, as in Project Media and Project Experiment.

For example, in Project University it was during the preparing stage that the scene was set for collaboration amongst all organizations – a vital component of the long-term success of the project. By developing a collaborative protocol together, with the investment of the client, organizations proceeded into the next stage with an established sense of collaboration, that despite a common lack of experience using BIM they were "in it together". Under strong client leadership, extended collective learning was used to establish collaboration, a theme that continued throughout this project. Practical IT support ensured that the project team had the skills needed to meet the requirements of the BIM brief.

This is contrasted with the speed of this stage in Project Media. No BIM execution plan was created and there was a lack of clarity from the client about its BIM requirements. While internally, Design Partnership, did hold a meeting before the start of the project, it is apparent that a number of time consuming problems that were experienced when enacting this project, such as changes to the brief and coordination issues, could have been resolved had more time been spent on this stage. This division of Design Partnership was able to compensate for this because of strong leadership support, existing relationships and its experience in using BIM.

While this was a rapid stage in Project Experiment that would have benefited from greater time spent establishing team member skills and working protocols, substantial benefit was gained from their limited activities. In turning a conceptual idea into a built form, the original concept was developed from the domain of two members of the project team, to being owned by the entire project team. In this way, collective enthusiasm and ownership was created that was essential for taking the project into and through the next stage.

5.3 Enacting

The third stage, *enacting,* describes designing and constructing the project. In all of the projects described here this is the longest stage, as it is in the vast majority of projects. It is also most prone to changes and unexpected events. Communication and coordination are critical in the enacting stage. BIM both creates the opportunities for better coordination, particularly between the disciplines, but demands more communication between individuals and organizations. Traditional face-to-face communication and colocation was found to be particularly valuable, particularly with fast-paced projects such as Project Media and in certain project stages as was found in Project University.

The potential of the 3D model in enabling coordination is most clear in this stage. This is apparent in Project Media, where virtual and physical versions of the model were put to different uses, to guide coordination and decision-making, and to develop 4D models and manufacture components. However the limitations of the model were also apparent in this project, as the dangers of relying on it for coordination led to early errors related to site fixing.

As other research has found, a number of traditional methods, or hybrid practices are being employed in using BIM (Whyte, 2011). As is evident, traditional ways of working remain valuable and are retained. For example, traditional communication remains valued, as do traditional project management approaches, as used in Project Experiment and the value of physical models in developing the design for Project Media. When BIM adoption is upsetting established roles and hierarchies, such as changing professional roles or internal hierarchies (as seen between engineers and technicians), actors are confused about how to handle this in their everyday work.

It seems that in the absence of the suitable frameworks people revert to traditional methods, be these institutional, organizational or technological. This is most apparent in the earliest case, Project University, where actors tried to compensate for a lack of technical functionality and industry standards by increasing their levels of communication and using traditional coordination methods.

During this stage, collective learning enables joint problem solving. This can be seen in the cases between individuals in one organization, as in the solutions to technical problems on Project Media and Project Experiment, and between organizations as seen in Project University.

The role of leadership during this stage is largely practical. A lack of hands-on leadership support led to problems in using BIM in Project Media. Conversely in Project Experiment, those disciplines that had access to experienced leaders were able to advance their use of BIM fully. The importance of leadership taken during the early process stages is pronounced during this stage: for example in the collaborative culture and support of the client in Project University, in the business leadership support in Project Media allowing individuals to take risks and innovate.

5.4 Reflecting

Reflecting describes a stage in which the team learns from their experience and applies this learning to future practices and routines. It is typically post-project, although users, particularly in Project Experiment, draw attention of integrating time for reflection during the project's enactment. It is during this stage, that the organizational capabilities developed on the project become apparent. These capabilities can help organizations win further work, speed the implementation process and form the foundation for learning on future project.

Specific lessons were learnt on each project, for example that early project routines had long-term value, that time should be taken during the project to reflect on progress during the project and that establishing of the capabilities of individual team members early in the project is critical.

Many interviewees reflected that using BIM can enable better coordination but requires more communication. This is particularly apparent in
clash detection, where disciplines bring schemes together to identify problem zones where the designs clash. While BIM makes these more apparent, ongoing communication through the process of the design minimizes these clashes in the first place. The view that the model cannot be used as a substitute for communication is strongly endorsed amongst experienced engineers.

The role of leadership is particularly prominent in this stage, demonstrating the importance of transferring lessons learnt from project team to organization and beyond. For example in Project Media, a long-standing commitment to developing BIM capabilities and evolving this across projects is evident. It was apparent that learning from Project Media was being used and developed: in two current projects in the Middle East and UK. Similarly in Project Experiment, significant resources were put into internal and external dissemination of the project. Technical learning around interdependencies of work processes was applied and is developing in Design Partnership's work at a major London mainline railway station.

6. Summary

This chapter presents a process model of technological implementation.
The derivation of this model from data clustered around three core projects undertaken recently at Design Partnership is described. It shows how the model can be applied to BIM implementation in building projects.

This model describes a generative process of routine development in technological implementation using four process stages – forming, preparing, enacting, and reflecting. Collective learning and leadership enable this generative process. The model draws on and extends Edmondson et al's 2001 process model of technological implementation, developing it to fit the theoretical, methodological and empirical setting of this study.

The following chapter draws on this model of implementation and embeds it in a wider firm and industry context. In doing so it addresses this study's second research question, which asks how firms organize for technological implementation in complex operations. It shows that despite the process view of implementation put forward here, the firm plays a central role in enabling implementation.

Chapter 7: Organizing for technological implementation in complex operations

1. Introduction

This chapter considers how organizing for implementation was achieved in Design Partnership. It addresses this study's second question, which asks how firms can organize for technological implementation in complex operations.

To do so, this chapter builds on the process model of implementation presented in the previous chapter. It embeds this in multiple nested levels, individual actors, firm and industry, and considers the mutually constitutive relationship between them. Organizing for implementation at Design Partnership involved alignment between individual actors, firm and industry. When these levels are aligned, an infrastructure of support is created that affords processes of implementation. When they are misaligned, the process of technological implementation is constrained.

By viewing organizing for implementation in complex operations such as in Design Partnership the significance of this relationship is emphasized. In such settings, practitioners draw skillfully and seamlessly on firm and institutional frameworks to provide a stable structure within which they innovate and adapt routines. The firm plays a central role in achieving this alignment, it responds to and influences exogenous change and endogenous user-led change.

The derivation of this concept is shown by applying it to the longitudinal process of BIM implementation at Design Partnership, presented in Chapter 5. The three approaches to organizing for implementation used during this process illustrate a progression from misalignment to alignment between firm and users of BIM in technological implementation.

During the current phase of implementation at Design Partnership, alignment between the firm and users creates an infrastructure of support. As described in the previous chapter, this infrastructure of support provides practitioners with the routines and standards they need to be innovative and creative in their use of BIM.

Relevant aspects of work are used to illustrate dimensions in which firm and user levels serve to constrain and afford one another. In particular, three areas are drawn upon to demonstrate its application: collaborative working, skills and training, and software development.

From this analysis, mechanisms for forming alignment between individual actors, firm and industry are identified. These include formal policies, standards and guidance, and informal approaches, such as collective learning and leadership.

2. Organizing for technological implementation in complex operations

A conceptual process model of organizing for technological implementation in complex operations is illustrated in Figure 19. The internal circle depicts the process model of implementation developed in Chapter 6. The central circle depicts the firm. The outer circle denotes the industry, its institutions, standards and policies. When these levels are aligned, technological implementation is afforded. When they are not aligned, the process of implementing technologies is impeded.

When implementation is afforded, users draw skillfully and seamlessly on firm and institutional frameworks to provide a stable structure within which they develop new practices from which new and adapted routines are derived. The firm provides an infrastructure of support for users. It plays a central role in supporting endogenous user-led change and influencing exogenous change occurring in institutional and technological fields.

The context of the implementation is significant. As operations are complex, practitioners are dealing with old and new tasks; they balance the routine and the innovative in their everyday work. In learning to use a technology such as BIM, they need routines and standards as well as the freedom to innovate and be creative in their adoption of BIM.

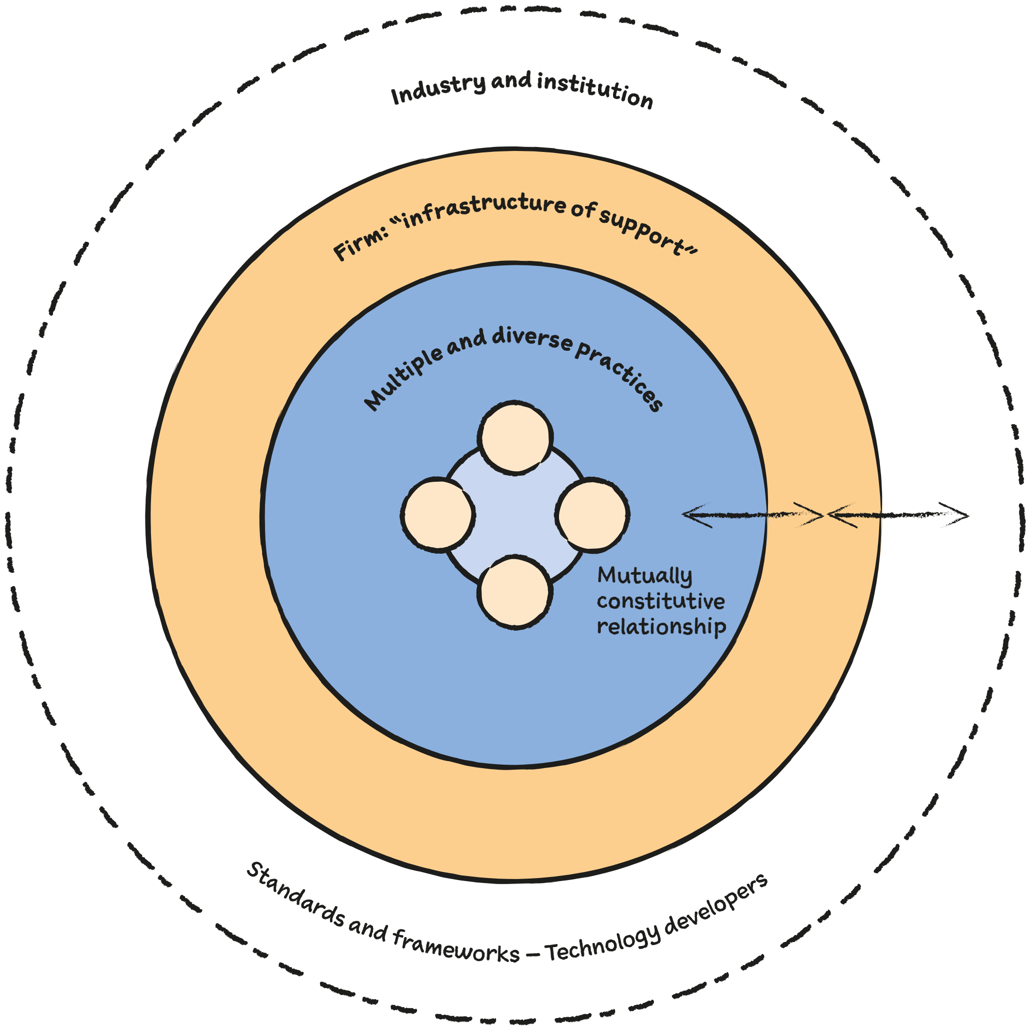

Figure 19: Organizing for technological implementation in complex operations

3. Firm and user alignment at Design Partnership

The longitudinal process of implementation of BIM at Design Partnership described in Chapter 5 describes the derivation of this model. As shown in Figure 20, the three phases of implementation show different approaches to organizing for implementation, progressing from misalignment to alignment between firm and users.

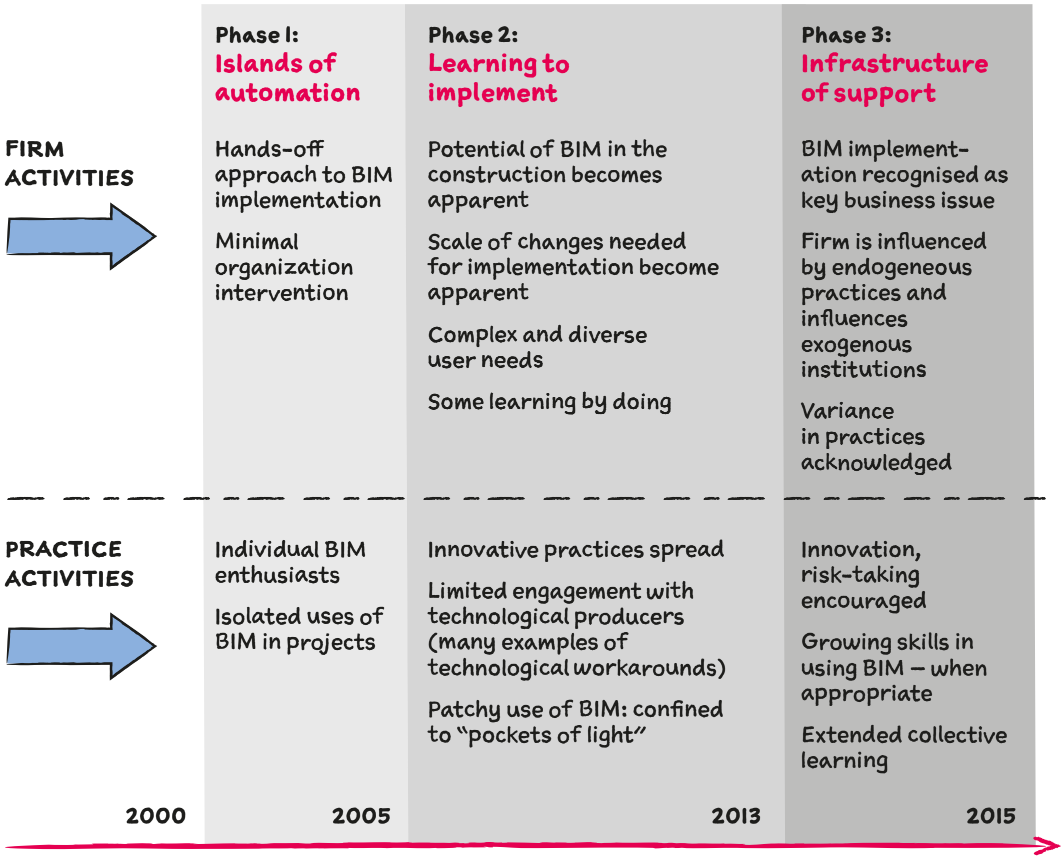

Figure 20: Growing alignment between firm and user in Design Partnership

During Phase 1, a few technological enthusiasts in Design Partnership use BIM. The firm invests limited resources in implementation, opting instead to take a hands-off approach and rely on evolutionary change to effect implementation. During this time use of BIM is isolated, confined to individual BIM enthusiasts.

Phase 2 is transitory, during which time Design Partnership learns about BIM. The firm's strategic attention understandably turns to surviving the recession during the early part of this phase. However it focuses once again on BIM towards the latter years of Phase 2, as its potential becomes apparent to the firm and wider industry. This focus brings a realization of the scale of the changes needed to adopt BIM, endogenous and exogenous to the organization.

A growing number of innovative uses of BIM become apparent during this phase. Through these practices, formative routines begin developing. However as projects like Project University demonstrate, a lack of institutional standard and frameworks restricts the use of BIM, as does a lack of engagement between users and the producers of software supporting BIM. Thus BIM implementation remains patchy in this phase; as a leader at Design Partnership commented during one interview, its use remained confined to “pockets of light” at Design Partnership.

The current phase, Phase 3, shows alignment between firm and users of BIM in Design Partnership. An *infrastructure of support* is created which affords technological implementation. In this phase, implementation of BIM is a key business issue for Design Partnership, as shown by strong senior leadership support, investment and strategic direction.

The firm acts as a filter between users of BIM and the wider ecology, influencing and responding to changes at both levels. It achieves this by offering targeted training that acknowledges the variety of users, by diffusing information and by increasing involvement with industry and institutional bodies. Attempts are made by Design Partnership to open discussions between producers of BIM software and its practitioners.

During Phase 3 users of BIM are becoming increasingly innovative and confident in using BIM. Their skills in using BIM are growing, both technically and with regards to the organizational routines needed to use it in everyday work. Learning is cyclical and often extended beyond organizational boundaries.

4. Affordance and constraint

The impact of firm and user alignment can be seen during implementation in different dimensions of work at Design Partnership. They demonstrate how the generative relationship between firm and users affords and constrains implementation. Three areas discussed here – collaborative working, skills and training and software development – which are all critical to using BIM.

4.1 Collaborative working

Using BIM both demands and creates opportunities for collaboration (Eastman *et al* 2011). Collaborative working is espoused as a key determinant in advancing uses of BIM, as shown in the BIM maturity index (Bew and Richards, 2010).

Yet BIM demands increased levels of collaboration across the supply chain, an area in which the industry has long struggled (Wolstenholme, 2009; Egan, 1998; Latham, 1994). As one business leader at Design Partnership observed:

> "The collaboration agenda didn't really happen – the industry is still a very litigious one that makes its money on claims. Many parts of the industry cannot get their heads around the idea that you do not make money on claims."

In Design Partnership, approaches to collaborative working have evolved over the implementation process. For example, during the first phase of the BIM implementation process in Design Partnership there is little alignment in its approach to collaborative working. As a result of this misalignment, Design Partnership does not develop an understanding of the collaboration demanded by BIM, both within the firm and across organizations. This situation begins to change during Phase 2 of the implementation process. For example, experiences gained in Project University and other projects undertaken during this phase show the importance of collaborative communication and coordination while enacting the project. This is illustrated strongly by evolving clash detection practices and routines. BIM is found to enable better coordination but demands high levels of ongoing communication within and between organizations.

Project University clearly shows the benefit of establishing collaborative working in early project stages (forming and preparing). Jointly agreed protocols reinforce a wider collaborative culture. However a lack of institutional standards and unsuitable software impedes collaborative working.

The firm responds to these lessons learnt. Design Partnership shows awareness of the potential and demands BIM holds for collaborative working. Thus Design Partnership offers users of BIM training that goes beyond the use BIM software, to encompass wider issues related to collaborative working. In partnership with a UK university, Design Partnership invests in a select group of experienced BIM users offering intensive training that covers areas relating to collaborative working, such as supply chain integration.

Firm strategy also contributes to a growing awareness of the challenges of collaborative working using BIM. One of the reports developed by the firm early in this phase, '3D Documentation Transition', draws together user accounts of using BIM on projects from its global offices. These accounts clearly show the significant variations in the implications of BIM for different disciplines and occupations.

For example, the report highlights the challenges facing MEP engineers using BIM. As a consequence of this, a task force was established in Design Partnership to address these challenges in more detail. It focused on the limitations of BIM software in enabling collaborative MEP working. The current software did not allow for connections to be made between physical building components, and across disciplines.

This acknowledgement of variation underlies Design Partnership's current approach to implementation. A number of initiatives aimed at enabling collaborative working are evident. For example, the strategy builds on lessons learnt that established the importance of establishing collaborative protocols and a clear BIM brief early in the project. At firm level, Design Partnership is trying to routinize the production of these key documents. It makes BIM execution plans a requirement for every project, and provides guidance on producing them, detailing how they should include collaborative protocols guiding issues such as data drops and levels of development.

Design Partnership is also addressing a number of issues shown to impede collaboration. For example, it has realized that project leaders have key roles to play in pushing through collaborative working, both in their team in Design Partnership and across the wider project team. However, project leaders are hampered at the moment by a number of issues relating to cost, liabilities and contracts, in addition to having a lack of practical experience in using BIM software (as described in Project Media). Design Partnership has developed a bespoke training package to address these gaps in knowledge for this critical group.

On firm level, it is addressing problems with the capabilities and functionality of BIM software. As one user at Design Partnership explained:

> "In the BIM world with federated models you are supposed to be able to export to any number of packages. If your software package can't export something that's readable, it's not usable. And because there are so many teams involved in projects, there's no one bit of software that will do absolutely everything on a project."

Users often solve such problems with ad hoc "workarounds" developed internally, often with high costs and resources. However the firm is currently establishing a strategic relationship with a major software producer. It hopes that this connection will enable improved internal and external interoperability.
In parallel, users are developing practices and routines that aid collaborative working. They are learning from past projects and drawing on firm routines to improve this. For example, the importance of establishing collaborative approaches and protocols early in the project are clearly shown in Project University. This is reinforced and routinized at firm level, where standard approaches are available for creating a BIM Execution Plan at the outset of the project. In turn, this routine to aid collaborative working is currently being developed: at a new project in Qatar, Design Partnership has convened a workshop with the wider project team to define a detailed BIM brief and collaboration protocols.

Collaborative working is also important through the "enacting" stage of projects. The digital model is being used in increasingly sophisticated ways to aid collaborative working in this stage. The flexibility and versatility of the model to enable collaboration within and between organizations are evident. The limitations of the digital model are also apparent.

For example, in Project Media the model is used to aid the internal design process and decision-making amongst the project team in Design Partnership. Because

Design Partnership is providing integrated design services it is effectively developing a shared model within one organization. This shared model has also been used by other organizations in the project team, for product manufacturing and logistical purposes.

Practitioners working on Project Media also learnt about the limitations of the model. When working at speed and dealing with complex problems, traditional forms of communication and coordination (such as face-to-face discussions) are vital. Members of the team working on Project Experiment stressed this point. Despite the innovative nature of this project, and potential to take risks, the project was managed using traditional methods and co-location building on existing relationships that were vital in enabling collaboration.

During the final reflecting stages, collaborative working is evident in collective learning. At firm level, routines are put forward for virtual design reviews. Through these reviews, collaboration occurs internally as lessons learnt about technologies and BIM are discussed and shared across Design Partnership. Where possible, Design Partnership gets practitioners from the wider project team involved. Through this mechanism, Design Partnership develops innovative uses of BIM with collaborators. For example, through its work with the external MEP engineer on Project University, Design Partnership has been able to provide innovative and advanced uses of BIM on its current work with a major automotive manufacturer.

4.2 Skills and training

The approach that Design Partnership has taken to skills and training has also evolved during the implementation process.

At firm level, the first official training offered by Design Partnership in Phase 2 was targeted at the mechanics of BIM, users were trained to use BIM software. As the implementation process went on, the wider and diverse requirements of using BIM became apparent, that is the human and knowledge implications of using BIM in collaboration with other disciplines. This trend has continued during Phase 3 of the implementation process. Users continue to be offered extensive technical training, alongside training in wider project team and industry issues.

The training Design Partnership provides is increasingly tailored to the needs of different individuals and groups. This is evident in the intensive program of training that specifically meets the needs of project leaders, covering contractual, liability and cost aspects of using BIM. Similarly, structural and MEP engineers are offered different training, tailored to their specific needs. Advanced users of BIM at Design Partnership are offered intensive training in partnership with a leading university.

In skills development, Design Partnership's approach to skills and training reflects changes in the overall process from minimal organizational involvement to greater intervention. It encourages learning by using approach, encouraging practitioners to use BIM innovatively in projects. This is evident in both the types of investments it makes and the focus it brings to capturing learning from projects.

In the former of these, Design Partnership invests in projects that are innovative and have an explicit aim of pushing forward learning and skills. This is most apparent in Project Experiment, which was funded specifically in order to advance skills and provide an example of what can be achieved using BIM internally and externally.

The business is making efforts to ensure learning is captured during and after projects. Post project briefings ensure this happens in the project team involved, an array of internal seminars, conferences and reports help disseminate these lessons across Design Partnership. Skills are built in this way, for example in Project Media interviewees explicitly took learning points such as problems created by the lack of a collaborative protocol on Project Media and addressed this in future projects. Similarly in Project Experiment, learning that was developed during the project on the interdependencies between work processes is being applied to a current project Design Partnership is involved with a major rail terminal project in London.

Design Partnership's research and development leader says he has seen a huge increase in the number of applications for research related to BIM in the last two years. Through this fund, Design Partnership is putting considerable investment into developing innovative applications for BIM. Attention is already being paid to research and development of the next generation of technological applications, such as Big Data and analytics. The intention is to undertake projects using these skills, applying the findings of these research projects.

4.3 Software

Implementation of BIM in the construction industry and Design Partnership has been and continues to be constrained by the functionality of software. In Design Partnership, this constraining effect was exacerbated by a lack of engagement between users and software developers during early phases of implementation.

User accounts indicate a number of ways in which BIM software constrains adoption. Practitioners regularly experience a lack of reliability in the software:

> "Often things just break, the software can't cope. So you end up scrabbling around at the end of the project trying to sort out the mess and issue drawings."

Users frequently express concern at the lack of fit between design skills and outputs and 3D modeling software. The impression created by modeling gives a misleading sense of finality to the design when in early concept design stages. A number of architects said they do not use BIM software to design for these reasons. They felt that the standard library of objects contained in BIM software restricts designers' options to create elements specifically for the project. Similarly, users expressed discontent with the nature of the drawings generated by the model, which are still often the contracted deliverable.

Reflecting a wider issues, users of BIM at Design Partnership are experiencing major problems with interoperability of the software. In projects that rely on interdisciplinary working, and on improving collaboration, this places a substantial constraint on the use of BIM and therefore its widespread adoption.

The data show many ways in which BIM software constrains implementation of BIM at Design Partnership. For example, early attempts to use BIM reveal the inadequacy of the software to support engineering design across the disciplines. Users of BIM on Project University struggled with the lack of software capabilities to address coordination. On Project Media, practitioners were unable to produce 2D drawings from the digital model that were of high enough quality to be delivered to the client. Conversely, as the software developed in line with user needs, implementation was afforded. For example specialist software such as NavisWorks improves the efficiency and effectiveness of clash detection, and is widely used.

Design Partnership has now established a strategic relationship with a major software developer. In doing so, it has created a direct channel between its practitioners and the developers of software. This issue is discussed in more detail in Chapter 8 of this study.

5. Enabling firm and user alignment

If firm and user alignment are necessary for technological implementation in complex operations, how can firms achieve this alignment? How can they organize for technological implementation?

Data collected in this study indicate that firms use both formal and informal mechanisms to achieve alignment with users. Formal mechanisms include policies, contracts and standards. Informal mechanisms include extended collective learning and leadership. These mechanisms are presented here and discussed in detail in the subsequent chapter.

5.1 Policies, standards and guidance

A number of policies, standards and guidance have been created that support the use of BIM at Design Partnership. These mechanisms provide information to users of BIM and help establish organizational routines.

Turning first to Design Partnership's internal policies, standards and guidance. The majority of these have been produced recently during Phase 3 of the implementation process. Guidance for users is plentiful. It explains the potentially confusing array of terms and concepts relating to BIM such as COBIE, Omniclass, Levels of Development and so on. Guidance is provided on the application of these standards. For example, users are advised to use industry standards laid out in PAS 1192 as a minimum in implementing a Common Data Environment.
Other internal guidance is available that advises users on the plethora of BIM software available. Collaborative software such as *Navisworks* or S*olibri* can be used for clash detection and to regularly review the project by the team, and software such as *BIM360*, *Tekla BIMSight* or *Bentley Navigator* as a means to communicate and track comments.

Design Partnership has adapted existing organizational routines to develop its own standards. For example, routine post project reviews are now required to include virtual design reviews. This ensures that learning points one the use of BIM, and other related technologies in projects are formally captured. Similarly, Design Partnership's traditional briefing process has been updated to include BIM requirements. The firm requires every project to produce a BIM Execution Plan (BEP). It provides a standard form for this document and guidance for producing one, detailing its purpose and content.

Policies are being updated across the firm. For example, the BIM strategy team is working with the Human Resources department in Design Partnership to ensure that its recruitment and review policies are aligned with BIM implementation. They are thus ensuring that Design Partnership is recruiting staff with appropriate skills in BIM and appropriately rewarding existing staff for using BIM.

Design Partnership is adapting external standards. For example, the building engineering division of the firm has recently taken guidance developed by Penn State University and adapted it to develop a survey. The results from this survey are informing the firm about the level and ways BIM is being used..

Design Partnership filters and translates BIM standards for its practitioners, and further it seeks to influence them. Senior business leaders and advanced users of BIM are encouraged and supported to become involved with institutional and industry bodies. Evidence of the success of this approach is apparent in the firm's involvement with organizations such as BuildingSmart, the Construction Industry Council, and the UK BIM Task Force to name a few.

5.2 Collective learning and leadership

Collective learning and leadership are key mechanisms for aligning users and firm during implementation. The role they have in facilitating the implementation of technology has been discussed in Chapter 6. This discussion focuses on the value of collective learning and business leadership in organizing for implementation.

Turning first to leadership. The approach of leadership at Design Partnership changes during the implementation process, as BIM shifted from being a bottom-up to a top-down business issue. During Phase 1, business leadership takes a "hands-off" approach to BIM implementation. They view BIM as a plug-in technology, as peripheral to the business. Accordingly Design Partnership's business leaders consider outsourcing the use of BIM,

During Phase 2, the approach and style of the leadership of the firm begins to change. Some business leaders adopt a command and control leadership style in their interventions. They attempt to mandate 3D modeling, making it compulsory on all projects but have very limited success. Recognizing that command and control management intervention is unlikely to encourage BIM implementation amongst users in Design Partnership, they begin to change their approach. By focusing on the needs of users and the diverse requirements of different disciplines, they recognize the variety and complexity inherent in implementing BIM.

During Phase 3, leadership engages fully with BIM implementation and signals this shift to the firm. The launch of the current BIM strategy by the Chairman at the organization's Annual General Meeting in 2014 reflects the ongoing support of national and business leaders in the firm. This marks a shift in the perception of BIM from being a plug-in technology to something that is integral to Design Partnership's business.

The approach of leadership implementing the strategy reflects this shift. Command and control styles of leadership have been abandoned in favor of providing users of BIM with an infrastructure of support. This is evident in a number of areas and dimensions. For example, leadership support for Project Experiment was instrumental in realizing the project, by gaining funding and ensuring ongoing investment in the project. Supporting this exemplar project was unusual for Design Partnership, yet brought great benefits in terms of advancing BIM implementation.

The level and nature of collective learning undertaken in Design Partnership has increased through the implementation process, partly as a result of increased leadership support. During Phase 1, collective learning was facilitated by a skills network and mainly took place amongst technological enthusiasts. Collective learning grew during Phase 2, embracing a wider community in Design Partnership for example through producing and disseminating BIM guidance through reports.

During Phase 3, collective learning in Design Partnership regarding BIM use has increased exponentially. It is evident in the quantity of formal mechanisms given over to disseminating collective learning: from firm-wide seminars to discipline specific reviews, to guidance sheets and intranet-based information. It is evident in processes such as post project reviews, and firm training events. The impact of this shift is evident: during interviews, users constantly made connections between learning made in past projects, to current ones and explained how this learning had been taken forward into subsequent projects.

There are indications that collective learning is being extended across organizational boundaries at Design Partnership. At firm level, channels of communication are being established with technology developers offering the potential for users and developers of BIM software to engage in collective learning.

Users are working with collaborating organizations to develop inter organizational routines and capabilities in using BIM.

6. Summary

This chapter has drawn on the process model of implementation described previously in order to show how implementation can be organized in complex operations. The process of organizing involves multiple levels in the wider ecology. It is achieved through alignment between these levels, at individual, firm and industry level. Attention is drawn to the reciprocal relationship between them.

By viewing organizing for implementation in complex operations the significance of this relationship is emphasized. In such settings, users draw skillfully and seamlessly on firm and institutional frameworks to provide a stable structure within which they innovate and adapt practices and routines. The firm plays a central in achieving this alignment: it responds to and influences exogenous change and endogenous change.

Chapter 8: Discussion

1. Introduction

This chapter details the contributions and limitations of this thesis. It presents recommendations for managers and policy makers working in the construction industry and discusses opportunities for future research.

It begins by reviewing the central theoretical contributions made by this thesis. As summarized in Table 11, these relate to the nature and form of the generative process of technological implementation in contemporary firms, to the organizational routines and practices that drive this process and to organizing for implementation in complex operations.

This study also makes wider findings that have implications beyond the core theories used. These areas include the lack of engagement of technology developers in the implementation process, studies of project based and professional service firms. The methodological contributions made by this study relate to recommendations for improving visual representations in process research and observations drawn from the experience of undertaking collaborative research with business.

A number of practical recommendations to managers and policy makers in the construction industry are drawn from the findings of this thesis. This normative advice is grounded in the growing importance and potential for the construction industry and its firms to develop capabilities in technological implementation.

The limitations of this study are discussed. The steps taken to address methodology of the case study design are detailed with relation to the thick descriptions developed, the strong theoretical grounding maintained throughout the study and the rigorous analysis of data. This thesis indicates a number of opportunities for future research. Questions are raised by its findings such as: How do material properties of technologies change the implementation process?

How can practice research enhance our understanding of other organizational processes? And how does the firm, industrial and operational setting of implementation affect the process?

2. Theoretical contributions

This study offers an analysis of organizing for technological implementation in complex operations. It makes a number of theoretical contributions by challenging and extending existing literature. These contributions are summarized in Table 11.

	Findings	**Implications and contributions**
RQ1: How do organizational routines and practices influence processes of technological implementation in firms?	Practices and organizational routines are central to the generative process of technological implementation experience.	Extant theory depicts technological implementation in firms as linear and finite. In contrast, this study finds that implementation in firms is an iterative and continuous process driven by changing organizational routines and practices.
		While organization routines have been viewed as malleable during implementation, and fixed on completion, this study views organizational routines as sources of generative change in processes of technological implementation. This generative process is illustrated in a model of technological implementation, which shows how organizational routines and practices develop across four stages of implementation.
RQ2: How can you organize for technological implementation in complex operations?	In organizing for technological implementation in firms, the relationship between firm and practice is mutually constitutive.	Alignment between firm and practice catalyzes technological implementation.
		Existing theory suggests that organizing in complex operations should be done using an “organizing to learn” approach (Edmonson, 2012). This thesis extends this model by finding that during technological implementation, organizing is achieved through informal (collective learning and leadership) and formal mechanisms (policies, standards and guidance).

Table 11: Summary of theoretical contributions

2.1 The process of implementing technologies

This study's central theoretical contribution is derived from its findings that the organizational routines and practices of users are central to processes of technological implementation in firms. This finding has implications for our understanding of the nature and form of implementation.

2.1.2 A generative process model of implementing technologies

In adopting the practice perspective of organizational routines (Pentland and Feldman, 2005, Feldman and Pentland, 2003; Feldman, 2000), this study finds that technological implementation is a generative process in contemporary firms. This finding is developed in a process model that illustrates four practices stages of implementation: forming, preparing, enacting and reflecting (illustrated in figure 17).

When applied to building projects implementing BIM (illustrated in Figure 18), this process model shows the elements of the organizational routine – the performative element (or 'routine in practice'); the artifacts (or 'routine in principle') and the enablers of each process stage. For example, the BIM brief is a key artifact in the forming stage, collaborative protocols are central in the preparing stage, the digital model in used during the enacting stage, and project sheets and presentations are used during reflecting stages. In building projects, performative elements of the routine that are evident during forming stages to help establish collaboration, this is built on during the subsequent preparing stage when joint ownership for the project is established. During enacting stages communication and coordination performances are critical, and during the final reflecting stage, performances are taken to capture and transfer project learning.

Further detail of elements of the routines is apparent from this model when applying it to the core project case studies as shown in Table 10, For example, during the first *forming* stage which includes putting together the team, a BIM brief specifying requirements and delivery methods is a key artifact enabling movement through the implementation process. This is developed during a subsequent *preparing* stage, when the team develops the BIM brief into a set of collaborative protocols. During the *enacting* stage, when the project is built the collaboration protocols are adapted to suit the needs of actors on the project; during the *reflecting* stage, which occurs post project stage, the team learns from their experiences, taking these learning forward into new projects. In this study, Design Partnership decided to improve upon the quality of the BIM brief produced during forming stages by holding an early workshop with all members of the construction team. Thus, by focusing on the lifecycle of one artifact – in this example the BIM brief and detailed collaboration protocol - a generative process of implementation is described, driven by constantly adapting organization routines and practices.

Thus the process model put forward in this study has a number of possible applications. Overall it suggests an alternative role for organizational routines during implementation. This view diverges from a number of past influential studies of the implementation process that identify organization routines as being adaptable during implementation but rigid and fixed when it is complete (Leonard-Barton, 1988; Tyre and Orlikowski, 1992; Edmondson et al, 2001). Routines are changed during finite implementation processes in order to mutually adapt technology and organization but become core organizational rigidities upon completion of the process (Leonard-Barton, 1992). Implementation is depicted as linear, finite and episodic, constrained by rigid and fixed routines and enabled by flexible ones (Leonard-Barton, 1998; Tyre and Orlikowski, 1992; Edmondson et al, 2001). In contrast, my data shows users adapting and creating routines as they move through stages of the implementation process. Users draw seamlessly on organizational routines and institutional standards to create a framework for problem solving in complex situations. Thus changing organization routines creates a generative process of technological implementation.

This generative process of implementation fits with Weick's view that use of technologies requires a balance between maintaining the equivocality of technology and developing rules and routines (1979). It concurs with recent research that finds that a generative relationship exists between practices and routines, wherein practices are constrained and afforded by organizational rules and routines (Scott and Orlikowski, 2014; Orlikowski and Scott, 2015).

This study also follows other practice studies in wider management and organizational research. Such studies show how practices enacted at micro levels drive change at meta-levels. Smets, Morris and Greenwood find that the innovative work of individuals in the financial sector drives wider firm and institutional level change (2014). The micro-level activities that make up strategizing are influential in organizational strategies and the focus of extensive research (for example Whittington, 2007, 1996; Jarzabkowski, 2004).

In viewing the process of implementation in its wider ecology, this thesis explores how the actions of users are influenced by their situation of action. It finds that practices enacted and routines developed in this process are afforded and constrained by the firm and institutional context. For instance, Design Partnership's hands-off approach to BIM implementation during Phase 1 relied on the innovative work of a few advanced users. However, without firm support and appropriate standards and frameworks, practices alone did not advance implementation.

In suggesting that implementation should be viewed as a generative process driving by changing user practices and organizational routines, this study concurs with existing studies of technology that describe users adapting technology and routines flexibly during implementation (Leonardi, 2011). It extends these findings by embedding studies of implementation in a wider context, thus viewing how multiple embedded levels enable implementation. By doing so, this study suggests that the effect of the organizational and institutional setting is significant in the extent and nature of routine adaptation and creation.

2.1. The nature and form of technological implementation in firms

In suggesting that technological implementation is a generative process, this study finds that technological implementation in contemporary firms is a continuous, perhaps accelerating process. It implies that technological implementation in firms today may be a constant process, thus increasing its importance as a competitive capability for firms. This presents an alternative view of the nature and form of technological implementation in firms that contrasts with a number of past influential studies of technological implementation that illustrate this process as a finite and linear one (Leonard-Barton, 1998; Tyre and Orlikowski, 1992; Edmondson et al, 2001).

My data shows that the end of one technology and start of another is indistinct, and that boundaries between technologies are blurred. This difference in the nature and form of the process of implementation observed in this study supports this view. Analysis of my data suggests that rather than viewing a discrete process, I observed a snapshot in an ongoing process of organizational change. This view challenges and problematizes the assumptions of existing theories (Alvessson and Sandberg, 2011).

In Design Partnership, I observed BIM being used in multiple ways, simultaneously and with varying degrees of sophistication. In some settings, users employ basic BIM technologies, relying heavily on existing CAD modeling skills. In parallel, innovate and sophisticated applications of BIM technology are evident, focusing for instance on 'Big Data' and sophisticated modeling applications of BIM. Evidence of hybrid practices (Harty and Whyte, 2010) was evident in both novice and advanced users of BIM alike.

Although the dynamics of the process alter – that is the pace of the process may accelerate or decelerate – its cumulative, iterative nature remains. Thus putting temporal boundaries around a longitudinal study of BIM implementation was challenging but methodologically necessary (Pettigrew, 1990).

The difference in the nature and form of the process of implementation found in previous studies (Leonard-Barton, 1998; Tyre and Orlikowski, 1992; Edmondson et al 2001) and this one may be a consequence of the rapid acceleration of the technological change. The pervasive nature of technology and accelerating rate of change increases the urgency to address the marked absence of technology in management and organizational literature (Orlikowski and Scott, 2008).

2.2 Organizing for technological implementation

In response to this study's second research question relating to organizing for technological implementation in complex operations, this thesis finds that the generative relationship between firm and users is critical.

Organizing for technological implementation is a process involving both firm and users. As shown in Figure 19, alignment between firm and users supports technological implementation. Conversely a lack of alignment between firm and users impedes the rate of technological implementation

In accordance with this study's focus on studying actions, organizing is explored, as opposed to organizations. This study therefore observes the process of implementation through multiple, embedded levels, thus drawing attention to the relationship between levels of analysis. Such a nested view of the process of technological implementation shows that in organizing for implementation, alignment between the firm and users affords the process of implementation and vice versa.

In this process model, the firm is shown to play a central role. Far from advocating a neutral or 'hands-off' role for the firm in implementation, the firm is key in this process. The firm is changed by and changes practices and routines; it reflects and influences the external environment.

In viewing organizing for technological implementation, the role of the firm fits well with Weick's view that organizations need to balance stability and flexibility (1979). Firms need to create routines and rules, while maintaining the equivocality intrinsic in technology (Weick, 1979). The process of organizing needs to fit with the view that firms operate in 'relentlessly shifting organizations' (Brown and Eisenhardt, 1997).

2.2.1 Technological implementation in complex operations

While previous studies focus on technological implementation in routine operations (Leonard-Barton, 1988; Tyre and Orlikowski, 1994) or view implementation from a user perspective in complex operations (Edmondson et al, 2001), this thesis studies technological implementation in complex operations.

Implementation of technology in such settings is interesting and important. When implementing new technologies, users in complex operations play a key role in the success of implementation. Working together, they develop routines that align new technologies and existing practices (Edmondson et al, 2001). In complex operations, users deal with new and old tasks, they balance the routine and innovative in their everyday work (Edmondson, 2012).

Unlike in routine operations, attention is therefore drawn to users of technology work in complex operations. These users need and require autonomy in implementing new technologies, however they also draw heavily on organizational routines and standards.

In organizing for implementation, the critical role of learning and leadership in the implementation process becomes clear. This concurs with Edmonson's organizing to learn model, described as a suitable approach for organizing in complex operations (2012). It results in "constant, unremarkable and small-scale learning being integrated into day-to-day work" (Edmondson, 2012: 131).

This study extends Edmondson's normative advice by finding that formal mechanisms such as policies, standards and guidance also enable organizing for technological implementation in complex operations. Such formal mechanisms are internal to the firm and externally generated.

2. Other findings

2.1 A developer-shaped hole

This study implies that the absence of technology developers in the BIM implementation process is constraining the construction industry and its firms' uptake of BIM.

Diverse streams of research show that such engagement is critical. Through the life cycle of a technology, a collective technological frame emerges, held and changed by producers and users of technologies and institutions (Kaplan and Tripsas, 2008). Studies into technology and organizations have found a significant relationship between technological frames and the implementation process at multiple levels - user, organizational and institutional (Orlikowski, 1993; Orlikowski and Gash, 1994). Technologies and user environments are mutually adapted during implementation to create alignment (Leonard-Barton 1988).

In turn, this raises interesting questions about the role and relationship of power and technology. It echoes calls for research that generates insights into power relations and technological implementation (Leonardi, 2011). Viewing implementation as a process of adaptation, scholars argue that firms' position in the technological field effects implementation: peripheral firms in the field have low power and consequently suffer episodes of maladaptation (Whyte, 2010). Studies show that BIM is used as a significant object of power and conflict (Davies and Harty, 2012).

Innovation literature also points to the many benefits of engagement between users and developers when technologies are being used. When producers of technologies are engaged they access valuable information generated by users which informs how technologies are adapted to fit complex user requirements (Baldwin and von Hippel, 2011; von Hippel, 2005, 1976; Rosenberg 1963). In learning by using, developers and users of technology engage in a mutual process of learning. Such collective learning in projects can create wakes of innovation that spread across networks of firms (Boland, Lyytinen, and Yoo, 2007).

However, data collected at Design Partnership showed a pronounced lack of engagement between users of BIM technology and developers of the software, particularly at user level. This observation concurs with existing research in the construction industry and its firms where insufficient user-developer interaction contributes to poor rates of adoption of technology (Salter and Gann 2003; Whyte 2002; Gann, 2000). Construction industry professionals have little impact on the development of technology, as was found in studies of the development of virtual reality and CAD technologies (Whyte, 2003; Whyte et al, 2002;). Given that the construction industry uses generic technologies adapted to highly complex and heterogeneous settings (Whyte, 2013, 2003; Whyte and Sexton, 2011) the absence of technology developers in implementation is perplexing and problematic for users and developers of technology alike (Whyte, 2010).

During the course of this study , I observed the consequences and impact of this lack of engagement. There was a pronounced lack of fit between BIM software and user requirements. Users were often frustrated by the software, which was seen as “clunky” and “unreliable”. Problems were often solved with last-minute workarounds, plugging and patching. These inefficient solutions were often developed in-house as one-offs: there was no formal system for feeding problems encountered in daily work to technology developers. (Although Design Partnership was in the process of building a relationship with a major technology developer, this happened late in the implementation process.)

Intrigued by this, I collected some additional, exploratory data through interviews with users working in a similar organization, “Construction Ltd”, currently implementing BIM (the source of this data is described in more detail in Chapter 3 of this study). In contrast with Design Partnership, Construction Ltd had a strategic relationship with a major BIM software developer. This relationship had been in place for a number of years and was developed by virtue of market share. This created a channel through which users in Construction Ltd. could directly feed their day-to-day experiences in using BIM back to the developer, who then attempted to accommodate any issues in the software.

Because this additional data was exploratory in nature it is insufficient for robust analysis and no firm conclusions could be drawn as to the prevalence of the problem, or the effect of this relationship on the implementation process. However, drawing on existing theory, the absence of technology developers seems to substantially limit the flexibility of technology, thus restricting processes of adaptation that are necessary through implementation. .

2.2 Implementing technologies in project based firms

Although this study did not directly adopt frameworks from project-based firms (PBFs), focusing instead on implementation in complex operations, its findings have implications for this body of research. It provides insights and opportunities for future research in considering practices and processes in PBFs.

In considering practices, this study follows recent calls for researchers to consider the context, both historical and temporal, and practices involved in project work (Lundin et al, 2015; Engwall, 2003). By viewing projects nested in a wider ecology, a generative relationship is found between elements in this ecology, concurring with recently published research (Grabher and Thiel, 2015). The data collected in this study show that change at user level is happening simultaneously and continuously in project based firms, as multiple practices are enacted in numerous project contexts. The process implementation process shown in my data is occurring some 10,000 times simultaneously in one PBF. Therefore the challenge of organizing in such complex and pluralistic settings is considerable.

This study reflects an increased interest in studying processes in projects or temporary organizations, which is apparent in mainstream management literature. For example, studies explore evolving processes of role-based coordination in projects or temporary organizations (Bechky, 2006). Projects are used to start processes of wider organizational change (Obstfeld, 2012). The findings of this study also have implications for our understanding of how practices in projects evolve, an area attracting increasing scholarly interest in the construction industry (Bresnen and Harty, 2010) and beyond (Lundin et al, 2015).

2.3 Implementing technologies in professional service firms

As Design Partnership is a professional service firm (PSF), the findings of this study have implications for the study of PSFs, particularly in the construction industry. As discussed in Chapter 4, the management of PSFs creates a number of challenges. Perhaps the most prominent among these is "the cat-herding" problem of managing PSFs (von Nordenflycht, 2010; Maister, 2007). This refers to attempts to collectively manage a number of autonomous and highly skilled professionals, who provide complex and customized services for clients.

This study shows how professionals skillfully adapt their complex work to changing circumstances (in this instance, the need to use a new technology). It shows how, in one firm, some professionals adopt technological changes enthusiastically, while others are resistant to adopting new technologies, using "hybrid practices" in their work in using both digital and traditional tools (Harty and Whyte, 2010). Variance is also pronounced in the relationships that different professional disciplines in one firm develop with digital artifacts (Whyte, 2011).

While the emerging nature and changing roles of professions in digitally mediated work is the subject of recent research (Jaradat et al, 2012), this study contributes to how such variance is managed in firms. In studying organizing in PSF settings, it suggests that the firm should try to provide an infrastructure of support for practitioners. By organizing PSFs in this way, individual professionals are able to create and adapt routines, rather than having them created for them and imposed on them. This view concurs with literature that shows professionals resisting attempts to impose organizational routines on them as seen, for example, in solicitors attempts to undermine a new billing system (Brown and Lewis, 2011).

PSFs also capture and transfer routines developed by users in order to influence the external environment (industry and institutions) on professionals' behalf. The view put forward in this study concurs with Maister's description of managers of PSFs needing to perform a delicate balancing act between controlling and enabling professionals (Maister, 2007).

Within the study of PSFs, the multi-professional firm has attracted particular interest. Such firms contain a number of professional groups, which link into wider professional communities of practice (Wenger, 1999). Research indicates that the spread of innovations in such multi professional organizations can be impeded by social and cognitive boundaries between professions (Ferlie et al, 2005). This research contributes to this body of work, and raises questions for future research specific to studies of multi professional firms adopting innovations.

3. Methods and Methodological findings

The methodologies used in this study generate two findings relating to process and collaborative research.

3.1 Visual representations in process research

Process research is concerned with how sequences of events lead to an outcome (Van de Ven, 2007). They draw attention to the importance of time and change in organizational life (Langley et al, 2013).

However, the dominant form of studies in management and organizational research are variance studies. These studies are primarily concerned with relating, sometimes quantifying, variables and outputs. Variance studies are mainly communicated through text, sometimes numerical analysis. While great care is taken in the selection and form of language and numerical analysis, in contrast, visual representations are used sparingly, often appearing as rather crude boxes and arrows (Langley et al, 2013). These conventional diagrams of variance studies do not adequately describe the complex, living processes captured in process research. Visual representations are central to communicating the findings of the process research (Langley et al, 2013).

Given the importance of visual representations in process research, there is an absence of published work offering guidance on their use. I therefore drew on my initial training as an architect and subsequent work in the construction industry.

In these occupations, communication is commonly achieved through visual representations, be they digital or non digital. Thus they are the focus of considerable pedagogical and practitioner efforts. Substantial academic research explores the role of visual representations in the construction industry (for example Hales and Tidd, 2009; Whyte et al., 2008; Whyte and Ewenstein, 2007).

Not only do visual representations play a key role in communicating the final design output of projects but also in its development. Visual representations are the dominant form for developing and communicating ideas. They range from the sketches of designers during concept design stages, to the detailed working drawings or models used during construction.

Informed by this, I paid attention to the nature of visual representations, both in presenting the study's findings and as a tool for its development. On the former aim, a degree of success was achieved. The conceptual models developed in this study are core tools for communicating its findings. They are purposefully presented in sketch form to signify their conceptual nature. On the latter aim of using visual representations in developing this study, I was less successful, in part owing to a notable lack of methodological guidance and tools available for using visual representations in analyzing data.

My experience of the current knowledge of visual representations in management research and organization studies implies that they are inadequate in undertaking process research. It invites reflection on potential avenues for future research in this area.

3.2 Collaborative research

Because this thesis studies users in firms, deep engagement with business was necessary, enabling emerging practices and routines to be observed *in situ* (Feldman and Orlikowski, 2011). In keeping with the principles of Engaged Scholarship, research was undertaken as a joint endeavor with this business (Van de Ven, 2007). This collaboration was established from the start of this study and considerable efforts were made to preserve this collaboration throughout the project.

A number of observations arise from this experience. The first stems from Design Partnership's requirement for a Non Disclosure Agreement (NDA) to be drawn up between UCL and Design Partnership at the start of data collection. As described in Chapter 3, this document ensures anonymity for Design Partnership. As data collection progressed, the NDA proved very valuable in gaining the deep access required for this research. It provided managers at Design Partnership with the reassurance needed to provide access to potentially commercially sensitive information. Protected by the NDA, I was able to attend internal meetings and to have ongoing, unrestricted physical and virtual access to the firm's resources. It formed a safety net for interviewees, meaning the vast majority of participants felt able to talk freely and openly about their experiences using BIM.

Other observations arise from the experience of conducting process research in a firm. The method of Engaged Scholarship provided a framework to do this (Van de Ven 2007). As described in Chapter 3, the original form of Engaged Scholarship followed was to conduct a collaborative research project to coproduce knowledge on a question of mutual interest. However, the intensity and nature of this collaboration fluctuated over the course of the study: at times I observed events at Design Partnership, at other times I was called on to input or comment on events and initiatives. This was influenced by perceptions of my skills and experience. For instance, often when I was interviewing designers about their work in projects, I took the position of observer. I (rightly) had no perceived expertise in this area and was not asked to comment on the quality of this work. However, sometimes when I was attending a meeting, conference or seminar I was called on to comment on the efficacy of proposed initiatives. My skills and experience in management were perceived as valuable in these situations. I suggest that this movement between forms of Engaged Scholarship is to be expected particularly in longitudinal studies such as this one. However, researchers using this method need awareness of this likely fluctuation, and to be prepared to deal with it without compromising the collaborative spirit of the study.

Process research methods require longitudinal data to be collected over varying time periods (Pettigrew, 1990). When collecting longitudinal data in businesses, significant change is extremely common. On occasions this business change directly impacts data collection. For example, during data collection in this study, the senior internal sponsor left Design Partnership. An alternative sponsor was found with some difficulty, but data collection was delayed and disrupted, as was the collaborative nature of the study, as laid out in Engaged Scholarship.

These observations have a number of implications. They illustrate a dilemma that underpins research carried out with commercial organizations, particularly longitudinal research. On one hand, researchers are being encouraged to undertake research in the field in order to develop insights based on processes, and data that reflect the reality of organizational life (Feldman and Orlikowski, 2011; Bechky, 2011, 2006; Barley and Kunda, 2001). Models such as Engaged Scholarship encourage researchers to undertake collaborative research with business (Van de Ven, 2007). On the other hand, commercial organizations are sensitive about disclosing information, or sometimes reluctant to provide the necessary access to researchers. They have different and changing expectations of collaborative research - the goals of business and academia invariably diverge. Unexpected change is the norm when working with businesses over significant periods of time.

Both academic institutions and researchers need to develop better capabilities in conducting collaborative research with commercial organizations. Drawing on the experience of this study, such capabilities may include the standard use of tools such as NDAs and support for researchers in managing them. A greater understanding of the practical challenges inherent in conducting research with changing commercial organizations is needed. Researchers entering the field should be prepared for change and supported during it. Similarly, in conducting research collaboratively with academia, businesses need to provide better access to data and research sights and be prepared to work collaboratively with academia. The goals and modus operandi of business have to be reconciled with those of academia.

4. Practical recommendations

The central findings of this thesis have implications for managers and policy makers in the UK construction industry.

Technological implementation is a key process in the construction industry as it generally imports rather than invents technologies (Whyte, 2013, 2003; Pavitt, 1984). However, there is strong academic and practitioner evidence showing that it is a slow and inefficient process (for example Bew and Underwood, 2010; Gann and Salter, 2003; Whyte 2002). The need to improve firm capabilities and industry policies in technological implementation is evident. This need is more pronounced as the rate of technological change accelerates.

As with many other industrial sectors, firms in the construction industry operate in a continually changing environment. Managers and policy makers need to develop strategies and policies that accommodate these 'relentlessly shifting organizations' (Brown and Eisenhardt, 1997). The findings of this study generate a number of recommendations for managers and policy makers working in the construction industry for improving the efficiency and effectiveness of technological implementation.

4.1 Recommendations for managers

Currently, the poor rate of IT implementation impedes firms' competitive advantage. Therefore for managers of firms in the construction industry, developing capabilities and routines that catalyze technological implementation is important.

As shown in this thesis, the process of technological implementation in firms is continuous and iterative. As the boundaries between technologies become blurred with increasing rates of technological change, technological implementation in firms is constant. The speed and intensity of the process may vary with endogenous and exogenous factors. A number of recommendations are therefore derived from this study that enable managers to accelerate and improve processes of technological implementation.

This study finds that practices and routines are central to processes of implementation. It follows then that managers of construction firms should pay greater attention to users: to how technologies are being used at “the coal-face”. Managers often view technological artifacts in isolation, with insufficient attention being paid to how technologies are being used. Managerial attention should instead shift to actors’ use of new technologies – to their evolving practices and routines - as indicated in recent research (Harty and Whyte, 2010).

Despite the process model presented here, the firm plays a key role in enabling processes of technological implementation. The firm is changed by and changes users practices and routines; it reflects and influences the external environment. In order to afford technological implementation, firms and user should be aligned. Thus when firms create an infrastructure of support that attends to evolving uses of technology they accelerate implementation. In attending to users, managers will gain more accurate views of how an infrastructure of support can be created. As shown in Figure 18, by applying the model developed in this study to building projects, managers can tailor the support they give at project level through the artifacts they develop and the approach they take to leadership and learning.

For example, during forming stages of projects, trust and collaboration is established. Managers of projects should pay attention to creating artifacts such as BIM briefs, which detail expectations around the use of BIM. Project and business leadership needs to demonstrate support for individuals taking risks in their use of BIM. During preparing stages, collective learning plays a key role in establishing joint ownership for the project. Collaboration amongst the team is developed and individual skills are identified. During the enacting stage in the implementation process, collective learning is important in joint problem solving; project leadership needs to be practical and hands-on. The digital, shared model is the key artifact. Practices and routines that enable communication and coordination are central. In the final reflecting stage, learning is vital in capturing and transferring lessons learnt and routines developed. In this stage, project and business leaders need to ensure that these learning points and routines are captured, transferred to the business and built on in the next project.

Managers should expect considerable variation in BIM use across users, occupations, project stages and wider settings. Such variation is inevitable in large firms such as Design Partnership, which estimates that it works on some 10,000 projects as any one time. Variation is not only inevitable: it is potentially valuable. Advanced users of technologies are sources of innovation in developing new applications and uses of BIM. Managers should ensure that advanced users of BIM work on challenging projects and are able to take active roles in implementation.

Firms should therefore encourage variation , not focus purely on achieving standardization. As with March 's influential concept of exploitation and exploration in organizational learning (1991), technological implementation involves managers balancing variation and standardization in firms. By attending to variation in users, managers can tailor the support needed by specific groups. For example, by attending to user needs, Design Partnership offered bespoke training packages that met the needs of diverse user groups.

A number of formal and informal mechanisms are available to managers looking to creating an infrastructure of support. As discussed in detail in Chapter 7, formal standards, policies and guidance can be used, as can informal approaches to collective learning and leadership. Managers can use these tools internally to support users and externally to influence the environment. Exemplar and innovative projects, such as Project Experiment, are effective managerial tools for encouraging such variation. Online internal communities, such as Design Partnership's Skills Networks, are valuable tools for connecting advanced users globally

These recommendations emphasize that in organizing for technological implementation, managers are presented with another "balancing act". They need to look inside the organization, and support users evolving practices, while being engaged externally, seeking to influence institutional and industry developments.

4.2 Recommendations for policy makers

The process model of technological implementation in firms proposed in this thesis has implications for policy makers working in the construction industry. Uptake of BIM in the construction industry in the UK is an ongoing process that has been slow and lengthy to date. It is likely that the industry will face similar challenges in the future. Policy makers should therefore learn from the experience to date: on policies that have proved effective and those that have not.

This study shows that polices, standards and guidance that have afforded implementation are process. My data therefore shows support for recent calls for policy makers to pay greater attention to the heterogeneous work of the construction industry (Whyte and Sexton, 2011). The resistance to change demonstrated in the industry to policy interventions from the Latham and Egan reports in the 1990s stems, in part, from homogeneous policies that fail to reflect heterogeneous practices (Whyte and Sexton, 2011). In attending to users, policy makers should anticipate variable industry demands. These need to be put at the heart of policies aimed at increasing rates of technological adoption.

This study describes a positive role for policy makers, apparent in viewing the BIM implementation process described here. The leadership displayed by Government in mandating use of BIM on its projects by had a significant impact. It has catalyzed change in the professional institutions, amongst technology developers and generally raised the profile of BIM in the industry. The policies, standards and guidance that have been issued in the UK since 2010 have supported BIM adoption.

5. Limitations and future research

The limitations of this study are methodological and theoretical. These limitations help identify possible avenues for future research, as discussed here.

5.1 Methodological

The methods used in this study have been guided by Lincoln and Guba's (1985) criteria for evaluating the trustworthiness of qualitative research, namely dependability, conformability, transferability and credibility. The application of these criteria is discussed in detail in Chapter 3.

This study's research design comprises a single embedded case study design. This is a suitable research design for the questions posed in this thesis. Single case studies are suitable designs for longitudinal, process research and are especially useful in studying longitudinal change processes (Van de Ven and Poole, 2002; Yin 2009). However, a weakness of case study designs relates to generalizability, that is the ability to generalize the findings of the case to other settings (Yin, 2009; Ferlie et al, 2005). The aim of this study is to achieve theoretical generalizability. This is in contrast with deductive, usually quantitative research, which aims for statistically generalizability (Yin, 2009).

Design Partnership was selected to "shed empirical light about some theoretical concepts or principles." (Yin, 2009: 40). As a large, well-established multidisciplinary design consultancy, Design Partnership is a leading firm in the construction industry. It is renowned for being creative and explorative and has a strong reputation for innovation. It is more likely to adopt technologies quicker than many peers, thus making Design Partnership a good case from which others can learn.

Other steps taken to increase the generalizability of the case draw on Lincoln and Guba's advice to improve the transferability of qualitative research by developing "thick descriptions" of settings (1985). By gathering data over 15 months, covering a 15-year period of technological implementation in one firm, thick descriptions of the process of technological implementation were generated. As data gathered was both retrospective and contemporary, the internal validity of the case was increased (Leonard-Barton, 1990).

Existing literature also provides a strong theoretical grounding for this study. Comparison with conflicting literature increases the study's internal validity, comparison with similar literature increases its generalizability (Eisenhardt, 1989). During data collection a close relationship was maintained with existing theory through constant iterations between emerging data and existing literature. In this way, intriguing and unexpected results that arose, such as the lack of engagement of technology developers in the implementation process, were explored further (as discussed in section 4.1 of this chapter).

During data analysis, the Gioia Methodology was used, as laid out in chapter 3; ensuring data were interpreted rigorously (Gioia et al, 2013). This approach increases the generalizability of the study by enhancing its trustworthiness. It maps the transition from abundant raw data to final conclusions (Miles and Huberman, 1994).

5.2 Limitations of theoretical findings and future research

The theoretical findings of this study also present limitations and opportunities for future research. Possible avenues for this research are detailed below.

5.2.1 Processes of technological implementation in firms

This study's finding that technological implementation in firms is an iterative and continuous process is based on data collected over time in one firm. This data relates to the process of BIM implementation in general building projects located in the United Kingdom.

As explained in detail in Chapter 3, section 4 of this thesis, the selection of Design Partnership for a case was driven by its ability to "shed empirical light about some theoretical concepts" (Yin, 2009: 40). In order to do so, temporal, sectorial and geographic boundaries were imposed. These boundaries serve to control a number of potential confounding variables, identified through empirical and theoretical literature. These variables include the technological artifact, and the industries, market, firms and national contexts. While these boundaries increase the robustness of the findings presented here, they also present opportunities for future research.

5.2.1.1 Technological artifacts and implementation

Future research could consider how material properties of technologies influence implementation processes. Such research would address a division that exists amongst technology and organization scholars, particularly those employing sociomaterial perspectives in their work (as discussed in Chapter 2).

In general, studies of technology and organizations suggest that the material properties of technology are significant in how they are used. This view is evident in the work of early contingency scholars such as Woodward, who identified the complexity of technology as a key variable in the relationship between technologies and organizations (1958). The absence of technology in ensuing socio-technical studies has been widely criticized (Leonardi and Barley, 2010). Under sociomaterial perspectives, attention is drawn to how the material influences social interactions and practices (Whyte and Harty, 2012). Such research shows that materiality of technology influences processes including implementation (Volkoff et al, 2007).

Because of the evidence emerging from exploratory data and strong theoretical evidence from past studies, in this thesis the material properties of technology are assumed to affect processes of implementation. Technology is therefore treated as a potential confounding variable and data collection is purposely confined to studying the implementation of one technology in one of Design Partnership's market, the general building market.

This presents an opportunity for future research. The findings of this study could be extended through research that seeks to identify and quantify the type and effect of different material properties of technology on implementation. These material properties may include the complexity of technology and the hardware used to access it. It may include wider social factors such as any interdependencies created or demanded by the technology and the degree to which it disrupts existing technologies and work.

Such research may take a comparative design. It could employ quantitative methodologies, treating material and social properties as variables that moderate implementation in quantifiable ways. Alternatively further qualitative research may study implementation processes of different technologies in detail. In doing so, it could adopt a practice perspective thus directly building on the findings of this study.

This study also offers observations on a division that exists amongst sociomaterial scholars regarding the separation of the social and material (Whyte and Harty, 2012). One group of sociomaterial scholars regard human and material agency as inseparable, as constitutively entangled (Orlikowski, 2007; Orlikowski and Scott, 2008). Studies using this perspective have generated insights into technologies from mobile devices, to robotics, to internet-based communities (Mazmanian et al, 2012; Barrett et al, 2012; Orlikowski and Scott, 2008). Other sociomaterial scholars claim that the social and material can be observed separately. They argue that during certain processes, including technological implementation, the social and material become disentangled, offering opportunities to address the relationship between the two (Leonardi and Barley, 2010). Empirical studies adopting this view show that flexible technologies are changed during implementation, based on users past experiences (Leonardi, 2011).

Exploratory data collected at Design Partnership shows some support for Leonardi's and Barleys view that the social and the material can be viewed separately during processes of implementation (2010). While inconclusive, this indicative finding does highlight a fruitful angle for future research. These indications can be found in data describing initial attempts to implement BIM by evolution, as had been done for previous ICTs in Design Partnership. The reasons for this lack of success were attributed, in the main, to the material properties of

BIM (as detailed in Chapter 5). For example, the complexity and variability of BIM software created demands for new technical and process skills. In turn, these created unprecedented levels of disruption across all functions in the company.

5.2.1.2 Setting of implementation

Turning to the second group of variables – the industry, market, firms and geographic setting of implementation. Future research could focus on the effect of the setting of the implementation process, comparing implementation in a range of industries, markets, types of firms and national contexts. In doing so, such research would emphasize the importance of the context of implementation. In this study, implementation is viewed as a process nested in a wider context: at firm, institutional and industry level. All of these contextual levels create opportunities for future research. Each level could be flexed to explore its impact on implementation processes.

For example, in studying implementation of BIM in a firm working in the construction industry, this study offers a basis to undertake studies of firms in other industries, who have implemented or are implementing similar generic technologies. Therefore comparative research could be used to explore commonalities and differences in the nature and form of the implementation process in firms across numerous industries adopting similar technologies. The type of firm implementing technologies is a variable that offers a number of possible future studies. The management and organization literature is divided on whether firm characteristics influence technological capabilities. One set of literature argues that the firm is an important contingency in developing technological capabilities. For example incumbent firms are shown to struggle to implement new technologies, displaying inertia and an unwillingness to change (Tripsas and Gavetti, 2000; Henderson and Clark, 1990). Other literature suggests that organizational characteristics are not important in technological implementation (Edmondson et al, 2001).

Research arising from this study may compare the process found here with technological implementation processes in SMEs and start-ups. These firms may operate in the construction industry and also be implementing BIM. The role of institutions and the ability of the firm to influence industry and institutions would be an interesting perspective in any such studies. Such research would address the power of different firms and their influence over the implementation process. It would build on arguments found in existing literature that firms operating on the periphery of technological fields, such as SMEs, are vulnerable to maladaptations of technology and firm (Whyte, 2010).

Comparative studies could also be made with contracting firms operating in the construction industry implementing BIM. Such studies could identify any substantive differences between implementation processes in design and construction firm. Existing research suggests that this occupational difference may be significant. The historical separation between the design and construction persists, creating ghosts in the machine that may account for difficulties encountered in using technology (Henderson, 1999).

Future research could address whether the nature and form of other organizational processes are similar to the process of technological implementation studied here. Examples of such processes may be strategic or operational; they may relate to decision-making in organizations, changes in organizational structure or premises. If the continuous, iterative process found here is replicated across firms, it could have implications for basic approaches to strategic management. This reinforces Mintzberg and Water's view that leaders of "unpredictable and uncontrollable environments" should adopt process strategies (p264, Mintzberg and Waters, 1985).

5.1.3 Routine, complex and innovative operations

This thesis looks at organizing for implementation in complex operations. It does so as complex operations present an important but little understood setting for implementation. By focusing on this setting, this thesis finds that organizing for implementation in complex operations involves alignment between firm and users of technologies with each having a specific role.

Organizing for technological implementation in complex operations is achieved through a number of informal (collective learning and leadership) and formal mechanisms (policies, standards and guidance). These factors are found to influence the speed of implementation by enabling alignment between firm and user in complex operations, namely collective learning, leadership, policies, standard and guidance.

The magnitude and nature of influence of these factors on technological implementation forms an interesting and useful topic for future research. Such research could adopt the process model of implementation developed in this thesis and study the impact of each factor through the process.

Future research could also address whether technological implementation follows a similar process in routine operations. Existing studies of implementation set in routine operations imply the form of the process is different, with implementation depicted as linear and finite (Leonard-Barton, 1988; Tyre and Orlikowski, 1992). Research could address whether this difference in form is because of operational settings or other factors (such as the accelerating pace of technological change, as speculated earlier in this chapter).

As the nature of knowledge is the defining attribute of routine operations (Edmondson, 2012), theory would imply that implementation in routine and complex operations differ: that it does not rely to the same extent on alignment between firm and individuals. Future research could explore this further in adopting a similar research design as used in this study, but gather data from routine operations.

A similar question is raised regarding processes of technological implementation in innovative operations. Existing models suggest that technological implementation does not happen in innovative operation, rather that technologies are invented in these settings (Edmondson 2012). Future research relating to innovative operations may then address how the inventors or developers of technology are involved with implementation.

5.1.4 Routines and technological implementation

This thesis finds that organizational routines are sources of generative change in processes of technological implementation in firms. Adopting the theoretical practice perspective of organizational routines helped generate this finding. Routines are the building blocks of organizational capabilities and therefore key in developing technological capabilities (Winter, 2012, 2003).

A number of opportunities exist for future research to draw on this insight and contribute directly to the substantial body of literature on organizational routines. For example, a central concern of scholars working in organizational routines is establishing how routines change and how are they are created and adapted. This concern stems from views of existing theory of organization routines as "inadequate" in explaining how organizations pursue "the markedly new" (Obstfeld, 2012). A recent special edition of *Organization Science* presents a number of studies of routines dynamics, and associated sources of stability and change (D'Adderio, Feldman, Lazaric, Pentland, 2016). The ecology of routine dynamics is explored, and the mediators and their generative effects studied (Sele and Grand, 2016). The influence of factors including reflective talk in organizations on routine dynamics is studied (Dittrich, Guérard, Seidl, 2016). Process research finds that internal and external learning is widely used to identify and adopt routines (Bresman and Zellmer-Bruhn, 2013).
Building on the findings of this study, a promising approach for future research would be to focus on the routine or selective elements of it, the ostensive, performative and the artifacts as the primary unit of analysis. Research could then view the evolution of the routine or elements of it through the process of implementation. The four-stage model presented in this study could be used to analyze the creation and adaptation of routines over the process of implementation.

Studies of artifacts created during BIM implementation could generate a number of findings and contribute to the growing literature on the nature of artifacts in organizational dynamics (D'Adderio, 2014, 2011, 2008; Cacciatori, 2012, 2008). Of particular interest is how technological artifacts influence routine dynamics (D'Adderio, 2008). Mutual adaptation occurs between the formal rules and routines embedded in software and the actual performances of routines. This mutually adaptive process is cyclical, going through stages of framing, overflowing and reframing (D'Adderio, 2008).

The model presented here shows a similarly cyclical process. The role of digital (such as the shared model) and non-digital (such as collaboration protocols) artifacts in the process of implementation is illustrated. By making these systems of artifacts the unit of analysis and exploring their role in evolving practices, their role in affording or constraining collaboration and multiple organizational goals across different stages of technology use could be unpacked. This research would contribute to studies exploring the role of digital objects in coordinating design work between projects (Whyte and Lobo, 2010).

Such research offers opportunities to study occupational and organizational boundaries. Drawing on Star and Greisemer's foundational work on boundary objects (1989), research explores how simulation technologies ease work across boundaries in inter- organizational teams (Dodgson, Gann and Salter, 2007). In viewing information technologies as plastic, changing over time with use, studies of the digital infrastructure at mega-project Heathrow T5, finds that boundary-spanning objects enable coordination across teams when they have a "dual epistemic and boundary-spanning role" (Whyte and Harty, 2012). Studies of such epistemic objects show how different communities of practice translate objects and artifacts (Nicolini, Mengis and Swan, 2012; Gherardi and Nicolini, 2000). Such research could generate insights into the important but little understood process of the creation and evolution of inter organizational routines (Zollo, Reur and Singh, 2002).

Chapter 9: Conclusion

This chapter concludes this thesis. The origins of this study lie in practical experience. These experiences were gained while working in the construction industry, where resistance to change was manifest in a number of levels and ways. They showed the need to understand work at the coalface of the industry. This view was reinforced by a number of academic studies exploring work in the industry (references previously cites on this count). The introduction of BIM into the construction industry offered the prospect of developing a similar study, using it to explore the crucial but problematic process of technological implementation.

In order to studying processes of technological implementation in firms, an embedded case study of a large, multidisciplinary design firm's efforts to implement BIM from 2000-2015 is presented. By collecting data on multiple levels – individual, firm and industry – during this time period, an embedded view of the process is generated. Analysis of this data shows a phased process of BIM implementation. It evolves from an initial phase when minimal management intervention was made, to a phase where managers and users alike learn about implementation, to the current phase where an infrastructure of support is created.

Drawing on this data, I propose a conceptual model to describe a process of implementation in firms. This model uses four stages – forming, preparing, enacting and reflecting – which are linked in a circular process. In order to create and adapt routines that enable implementation, users cycle iteratively through this process. A number of theoretical contributions are derived from this model. It presents an alternative concept of the nature and form of technological implementation in firms. While a number of previous studies depict technological implementation in firms as linear and finite process (Leonard-Barton, 1988; Tyre and Orlikowski 1994; Edmondson et al, 2001), this study finds that implementation in firms is iterative and continuous, driven by the creation and adaptation of routines are found to be sources of generative change in processes of technological implementation in firms.

Despite the process model of implementation presented in this study, firms are shown to play a key role in organizing for implementation. It does so by supporting users' and routines seeking to influence exogenous institutional change on their behalf. It achieves this dual role through informal (collective learning and leadership) and formal mechanisms (policies, standards and guidance).

Given that technological change is constant and accelerating in the construction industry, as with many other industries. Firms in the industry operate in a continuously changing environment and need to develop capabilities in implementing technologies. In order to develop these capabilities, managers and policy makers need to organize to learn*,* abandoning the command-and-control management styles in favor of an approach that enables and coordinates individual and collective learning. They need to pay more attention to users of technology, and ensure their approaches reflect what is happing in everyday work, rather than focusing on the senior echelons of organizations and industry.

As with much research, the findings of this study raise a number of questions that could be explored through future research. These include how does the type of technology influence the nature and form of the implementation process? How does the firm and industrial setting of implementation affect the process?

However it does bring much-needed insights into the critical process of technological implementation in the construction industry. It invites reflection on our understanding of this process in other settings.

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Appendices

Appendix 1: Example note sent to Design Partnership personnel before practice interviews

This case study is being developed as part of a research study into how BIM is used in practice. An initial stage of interviews identified a number of themes relating to the use of BIM in Design Partnership projects.

The cases will be used in two ways. Firstly they will form the basis of a report being delivered to Design Partnership later in 2014. Secondly, the case studies will be used in my doctoral studies at UCL.

Please be assured that the information provided in these interviews is covered by a Non Disclosure Agreement signed by Design Partnership and UCL (a copy of this is available on request).

I've outlined the issues I'm interested in discussing during our interviews. These relate to the project, the team (in Design Partnership and wider) and the individual. These questions are for guidance only.

Individual

What is your background?

What do you understand by BIM?

Have you used BIM before in project work? If so, what was your experience?

How and why did you get involved with the project?

What was your role on the project?

Did you have specific BIM-related responsibilities on the project? What were they?

How has your everyday work changed using BIM?

Based on your experience, what are the main benefits of using BIM? Similarly what are the main challenges in using BIM?

Did the experience of working on the project change how you view BIM?

Have you gone on to use BIM in other projects?

Have you received any training or similar from Design Partnership?

Are you involved with many external BIM networks? How do you think they affect your work and vice versa?

Team

Were your collaborators experienced and skilled in using BIM?
Did working with BIM change the way you communicated and collaborated between the construction team and client? Did you have to do more or less communication? Was it mainly formal or informal communication? Did you establish new communication mechanisms?
Do you feel you had the skills in the team to deliver the project? If not, what was missing?
Did you feel you could discuss issues related to BIM with your colleagues?
Did the roles in the team shift? If so, how?
How was the team lead? Can you give specific instances?
How did you experience and manage risk in the project?"

Appendix 2: Example note sent to senior personnel before interviews

Thank you very much for your time and input to this research. During these early stages, I'm working closely with Design Partnership to develop a study that is relevant to your business.

Over the last few months, I've had a few meetings with individuals at Design Partnership and BIM has emerged as a key business issue. I'm interested in learning about Design Partnership's approach to BIM and how Design Partnership is implementing this strategy. For guidance, some examples of the areas that we might cover during our meeting are:

- What is your wider role at Design Partnership? What is your specific role with relation to BIM at Design Partnership?
- What is Design Partnership's approach to BIM? How and why did this strategy develop?
- How have external factors, for example government policies or client demands, influenced Design Partnership's BIM strategy?
- What initiatives or projects has Design Partnership p taken or is it taking to deliver their BIM strategy?

- How is BIM changing day-to-day work at Design Partnership? What are the major challenges in using BIM at work? What opportunities do you see emerging?

These areas are guidelines only. If there are other issues that you feel are important, I hope we can discuss them during our meeting.

List of abbreviations

Abbreviation	**Meaning**
BEM	Built Environment Modeling
BEP	BIM Execution Plan
BIM	Building Information Modeling
CAD	Computer Aided Design (+/ Drafting)
COBie	Construction Operations Building Information Exchange
CPIC	Construction Project Information Committee
CT	Computerized Tomography (scan)
I(C)T	Information (Communication) Technology
IFC	Industry Foundation Classes
KIF	Knowledge Intensive Firms
MEP	Mechanical, electrical and plumbing (engineers)
MICS	Minimally Invasive Cardiac Surgery
MIT	Massachusetts Institute of Technology
NBIMS	National Building Information Modeling Standard
NBS	National Building Specification
NDA	Non Disclosure Agreement
PBF	Project Based Firm
PSF	Professional Services Firm
RIBA	Royal Institute of British Architects
SME	Small and Medium Enterprises
UKMEA	United Kingdom, Middle East and Africa