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**A Sociotechnical Systems Analysis of Building Information Modelling
(STSaBIM) Implementation in Construction Organisations**

By

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Abstract

The concept of BIM is nascent but evolving rapidly, thus, its deployment has become the latest shibboleth amongst both academics and practitioners in the construction sector in the recent couple of years. Due to construction clients' 'buy-in' of the BIM concept, the entire industry is encouraged to pursue a vision of changing work practices in line with the BIM ideas. Also, existing research recognises that the implementation of BIM affects all areas of the construction process from design of the building, through the organisation of projects, to the way in which the construction process is executed and how the finished product is maintained. The problem however is that, existing research in technology utilisation in general, and BIM literature in particular, has offered limited help to practitioners trying to implement BIM, for focusing predominantly, on 'technology-centric' views. Not surprisingly therefore, the current BIM literature emphasises on topics such as capability maturity models and anticipated outcomes of BIM rollouts. Rarely does the extant literature offer practitioners a cohesive approach to BIM implementation. Such technology-centric views inevitably represent a serious barrier to utilising the inscribed capabilities of BIM.

This research therefore is predicated on the need to strengthen BIM implementation theory through monitoring and analysing its implementation in practice. Thus, the focus of this thesis is to carry out a sociotechnical systems (STS) analysis of BIM implementation in construction organisations. The concept of STS accommodates the dualism of the inscribed functions of BIM technologies and the contextual issues in the organisations and allows for the analysis of their interactive combination in producing the anticipated effect from BIM appropriation.

An interpretive research methodology is adopted to study practitioners through a change process, involving the implementation of BIM in their work contexts. The study is based on constructivist ontological interpretations of participants. The study adopts an abductive research approach which ensures a "back-and-forth movement" between research sites and the theoretical phenomenon, effectively comparing the empirical findings with the existing theories and to eventually generate a new theoretical understanding and knowledge regarding the phenomenon under investigation. A two-stage process is also formulated for the empirical data collection - comprising: 1) initial exploratory study to help establish the framework for analysing BIM implementation in the construction context; and 2) case studies approach to provide a context for formulating novel understanding and validation of theory regarding BIM implementation in

construction organisations. The analysis and interpretation of the empirical work follows the qualitative content analysis technique to observe and reflect on the results.

The findings have shown that BIM implementation demands a complete breakaway from the status quo. Contrary to the prevailing understanding of a top-down approach to BIM utilisation, the study revealed that different organisations with plethora of visions, expectations and skills combine with artefacts to form or transform BIM practices. The rollout and appropriation of BIM occurs when organisations shape sociotechnical systems of institutions, processes and technologies to support certain practices over others. The study also showed that BIM implementation endures in a causal chain of influences as different project organisations with their ‘localised’ BIM ambitions and expectations combine to develop holistic BIM-enabled project visions. Thus, distributed responsibilities on ‘holistic’ BIM protocols among the different levels of influences are instituted and enforced under ‘binding’ contractual obligations. The study has illuminated the centrality of both the technical challenges and sociological factors in shaping BIM deployment in construction. It is also one of the few studies that have produced accounts of BIM deployment that is strongly mediated by the institutional contexts of construction organisations. However, it is acknowledged that the focus of the research on qualitative interpretive enquiry does not have the hard and fast view of generalising from specific cases to broader population/contexts. Thus, it is suggested that further quantitative studies, using much larger data sample of BIM-enabled construction organisations could provide an interesting point of comparison to the conclusions derived from the research findings.

Keywords: Building Information Modelling (BIM); Construction Organisations; Sociotechnical Systems (STS); Sociotechnical Constituency (STC) Theory; BIM-enabled Case-Study Organisations; Digital Infrastructure in Construction; Organisational Studies; Technological Innovation.

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List of Abbreviations

2D	Two Dimensional
3D	Three Dimensional
ACA	Association of Consulting Architects
AEC	Architecture, Engineering and Construction
AGC	The Associated General Contractors of America
AHU	Air Handling Unit
AI	Architect Instruction
AIA	American Institute of Architects
ANT	Actor Network Theory
ATF	Activity theory Framework
BCMM	BIM Capability Maturity Model
BCO	BIM-enabled Construction Organisation
BEP	BIM Execution Plan
BIM	Building Information Modelling
BIMM	Building Information Modelling and Management
BIS	The Department for Business Innovation and Skills
BIW	Business Information Warehouse
BoQ	Bill of Quantity
BP	Business Process
BREEAM	Building Research Establishment Environmental Assessment Method
BS	British Standards
BSRIA	Building Services Research and Information Association
BTEC	Business and Technology Education Council
CAC	Common Access Card
CAD	Computer Aided Design
CADD	Computer Aided Drafting and Design
CDE	Common Data Environment
CHS	Circular Hollow Section
CIC	Construction Industry Council
CM	Change Management
CMM	Capability Maturity Model

CNC	Computer Numerically Controlled
Cobie	Construction, Operation and Building Information Exchange
COMIT	Construction Mobile Information Technology
COT	Commercial-off-the-shelf
CPIC	Construction Product Information Committee
CSE	Cognitive Systems Engineering
DB	Design and Build
DCF	Distributed Cognitive Framework
DOI	Diffusion of Innovation
EC	European Commission
ECITB	Engineering Construction Industry Training Board
ELSEwise	European Large Scale Engineering Wide Integration Support Effort
EPC	Energy Performance Certificate
EU	European Union
FM	Facilities Management
GA	General Arrangement
GDL	Geometric Description Language
GPS	Global Positioning System
HP	Hypotheses and Propositions
HQ	Headquarters
HRM	Human Resource Management
HVAC	Heating, Ventilation and Air Conditioning
IA	Information Assurance
iBIM	Integrated BIM
ICCI	Inter-Connecting Construction Industry
ICE	Institute of Civil Engineers
ICT	Information and Communication Technology
IES	Integrated Environmental Solutions
IFC	Industry Foundation Classes
IPD	Integrated Project Delivery
IPR	Intellectual Property Right
IS	Information System

ISD	Information Systems Design
ISDN	Integrated Service Digital Network
ISO	International Standard Organisation
IT	Information Technology
JCT	Joint Contracts Tribunal
LAN	Local Area Network
LOD	Level of Detail
LS	Lump Sum
LSM	Leavitt System Model
M&E	Mechanical and Electrical Engineering
MEP	Mechanical, Electrical and Plants
MLP	Multilevel Perspectives
NBIMS	National Building Information Modelling Standard
NBL	National BIM Library
NBS	National Building Specification
NCS	National CAD Standard
NEC	New Engineering Contract
NIBS	National Institute of Building Sciences
NWD	Navisworks Document File
NWF	Navisworks Cache File
O&M	Operation and Maintenance
ODBMS	Object-oriented Database Management System
OS	Operating System
PC	Personal Computer
PI	Professional Indemnity
PPC	Project Partnering Contracts
QTO	Quantity Take-off
R&D	Research and Development
RAM	Random Access Memory
RCA	Root Cause Analysis
RFID	Radio Frequency Identification
RIBA	Royal Institute of British Architects

ROI	Return on Investment
RTD	Research and Technology Development
SCOT	Social Construction of Technology
SME	Small to Medium-Size Enterprises
SOA	Service Oriented Architecture
SSM	Soft System Methodology
STC	Sociotechnical Constituency
STCA	Sociotechnical Constituents' Alignment
STS	Sociotechnical Systems
T&C	Terms and Condition
TAM	Technology Acceptance Model
TAP	Technology in Architecture Practice
UCL	University College, London
UTAUT	Unified Theory of Acceptance and Use of Technology
VDU	Visual Display Units
viDCO	virtual-integrated Design, Construction and Operation
WAN	Wide Area Network
WI FI	Wireless Fidelity
WSM	Work System Methodology
QTO	Quantity Take-off

CHAPTER ONE

1 INTRODUCTION TO THE RESEARCH

1.1 Introduction

This chapter discusses the background of the thesis and justifies the rationale for the research. Following this, the research aim and objectives are established and the research questions are presented. The chapter also introduces the research strategy and conclude with an outline of the overall structure of the thesis.

1.2 Research Background

The architecture, engineering and construction (AEC) sector is made up of highly fragmented, data intensive project-based organisations that are governed by a multifarious knowledge workforce with increasing information sharing requirements. The underlying problems inherent in this setup have been widely articulated in literature (c.f. Senescu et al., 2011; Ibrahim el al., 2013; Dainty et al., 2007, Anumba et al., 2002). The challenges associated with the configuration of the AEC sector organisations have compelled the sector to be stigmatised as ‘adversarial’ in nature (Anumba et al., 2002).

In more recent years, it is the capabilities inscribed in the BIM technological solutions which are implicated to contribute to addressing the challenges that have perpetuated the AEC sector organisations (e.g., Teicholz, 2013; Bryde et al., 2013; Khosrowshahi & Arayici, 2012; Eastman et al., 2011; Richards, 2010; Young et al., 2009; Smith & Tardif, 2012). Indeed, the development of academic writings dedicated to the study of existing and emerging list of construction technologies (e.g., BIM, virtual construction, integrated databases, laser scanning, electronic data interchange (EDI), artificial intelligence etc.) are widely seen as reflecting the pervasiveness of ICT and its relevance in the AEC sector organisations. For instance, Singh et al. (2011) assert that BIM has the potential to profoundly change how construction is documented and performed by stimulating the effectiveness of information sharing among project stakeholders.

However, even with the plethora of research and investment in the development and deployment of BIM, its use is not in mainstream construction practice and the practicality of the implementation process is not well understood. Hence, it remains a rare approach in a typical project; therefore the purported benefits and efficiency gains are not clearly well articulated and/or widespread. According to a recent report by the NBS National BIM Report (2013)

significant change is necessary for BIM-enabled work practices to become mainstream. This is particularly relevant as it impacts on BIM capability protocols (e.g., Succar, 2009; Richards, 2010) and government-driven BIM strategy mandates on public procurement projects (e.g., Plesner and Horst, 2013; BIM Task Group Report, 2011). The NBS (2013) report also identified that, managers of construction firms are lacking in knowledge of relevant organisational theory, structure and behaviour in the rollout of BIM. The key reason for this may be attributed to the fact that the uptake of construction related technologies is shaped by many factors, which have roots in the idiosyncrasies of the construction industry, intertwined with the concomitant process changes as demanded by the associated technologies. In effect, the process change intrinsic to BIM implementation is substantial and it impacts nearly all activities related to the planning, delivery and operation of buildings on social, as well as technical levels (Suerman, 2009).

Currently, there is no clear roadmap to overcoming some of the concerns associated with skills, knowledge gaps and processes which are critical to answering the ‘how’ question associated with effective BIM deployment. According to Whyte and Sexton (2011) policy-makers have particularly struggled to understand innovation in building and infrastructure design, where work is distributed across global networks of design, manufacturing, installation and use. Thus, the complexities of the concomitant change processes associated with the BIM technological artefacts have largely been ignored in this regard. In engaging with the relationships between technology and organisation, one “requires a scheme which acknowledges all those institutions, artefacts and arrangement within which the adaptation and appropriation of those technologies take place” (Williams & Edge, 1996; pp 875). Thus, with the expanding capabilities of BIM and its integration in construction, the field of study has to emerge to focus on the question of how can computer-based ICT be integrated into the organisation processes to make the organisation, and the processes more efficient and effective, or otherwise to fulfil unmet construction organisational challenges.

The implementation of BIM induces an important change in the way construction services are delivered. BIM solutions compose of multiple systems that are created by specific parties, shared or distributed across multiple organisational boundaries, and are stored or kept using cloud based solutions. In effect, it affects the way construction organisations are managed; the way construction professionals integrate their works and interact among themselves and how the construction projects are accomplished. Accordingly, this thesis argues that the intrinsic characteristics of the AEC industry means that, the efforts towards establishing BIM-enabled

organisations requires an appropriate theoretical and practical framework for its successful implementation.

The challenge is to recognise and identify the interconnected social and technical issues associated with the implementation of a BIM solution whose parts are distributed across organisational boundaries. On this basis, this thesis suggests that both BIM developers and users should approach the development and ultimate use from a sociotechnical perspective that considers technology and practice as interrelated (Baxter & Summerville, 2011; Kling & Lamb, 1999). Indeed, STS theorists do not accept an organisation and its contextual issues as a stable domain through which the innovation is brought to the attention of the users to achieve a predefined agenda. Rather, the implementing organisation is considered a part and parcel of the innovation implementation process, which comprises development, adaption and appropriation.

This thesis therefore seeks to improve understanding of the nature of BIM and of the processes involved in BIM uptake, and to identify the obstacles that affect the implementation of BIM by analysing practices of BIM-enabled construction organisations. The ultimate goal of this thesis is to contribute to the theory and practice of BIM implementation strategy and will concentrate, in particular, on the processes involved in BIM. It is expected that the insights from this thesis will make a contribution to construction stakeholders' BIM strategy design and can thus enhance competitive advantage of BIM-enabled organisations.

1.3 A Sociotechnical View of BIM Implementation

It is inherent in the process of BIM implementation that the end result is to introduce appropriate, effective and efficient construction technologies and processes that improve the organisations' ability to perform its tasks and interact in a relevant manner with other project organisations to enhance the project delivery processes. This necessitates a more encompassing view of the process that would include both the social and technical aspects - i.e. a sociotechnical perspective. For as Mina et al. (1999) say, if there is only business specialist input then the plan is likely to be technically unworkable, and if there is only IS/IT involvement then the plan will be overly technical. Mina et al.'s (1999) work implies that there needs to be a balance from all parts, and from all levels, of the organisation in terms of involvement. Nevertheless, many researchers have shown that what is not always apparent in the performance of technological initiatives is the concept of optimisation of both people and technology. In many cases the optimisation of the technology has been at the expense of the people concerned, and has thus, in many cases, resulted in the failure of the initiative (Mumford & Hendricks, 1996; Peltu, 1996;

Clegg, Gray & Waterson, 1999; Performix, 2001; Coakes & Elliman, 2002). The process of BIM implementation should therefore be a process of balancing these social and technical subsystems within an organisation in order to ensure joint optimisation of both subsystems.

A sociotechnical view of the process of BIM implementation combines the two paradigms of the social and technical worlds. Socio is derived from the Latin *sodus* and had the original meaning of associate or companion, and it now relates to the social world or society (Random House, 1967). The ideas of society and companion relate strongly to the word stakeholder or actors in an organisation, as all actors in an artefact such as Information System (IS) or in the planning of the process for such a system, must be companions in the same society (organisation). The word sociotechnical is thus made up of these two root paradigms and is intended to imply a broad viewpoint of the way technology is implemented in the social environment. It is argued that consideration of only one paradigm, whether the social or the technological, is insufficient to fully consider the technology and the social environment in which it is acted upon (Coakes & Elliman 2002).

Over the years, socio-technology has developed a number of principles or moral imperatives that enlighten its practice in the process of organisational change (Cherns, 1987), notably that the implementation of technology is, by implication, a process of undertaking organisational changes, as existing processes and relationships will be impacted by this implementation. These sociotechnical principles focus largely on the achievement of a participatory democracy with the optimisation of people and technology being a prime aim (Eijnatten, 1993). It has become apparent that many strategic plans have not taken these principles into account during their process of development (Coakes & Elliman 2002).

The sociotechnical viewpoint advocated here would accentuate the involvement of actors in the BIM implementation process, including the learning curve that would take place from the knowledge-sharing of other stakeholder organisations in the process of BIM deployment and appropriation within the construction context.

1.4 Justification of the Research

There are three key drivers for this research: 1) the significant roles of BIM in construction organisations; 2) prior research into ICT implementation in general and in particular, construction related technologies; and 3) the underdeveloped research area of BIM implementation within the AEC sector.

1.4.1 The Significant Role of BIM in Construction Organisations

The first driver for this research is related to the important role of BIM in the AEC industry. BIM and emerging construction technologies have been advocated to be key enablers and instrument to support leading edge, innovative solutions targeting the main issues that confront the AEC sector. The introduction of BIM in construction is purported to address a range of industry issues such as inter alia: producing predictable project outcomes from design phase through to construction with the use of BIM tools and concomitant processes; advocating a collaborative working culture model; overcoming team coordination deficiencies; promoting interdisciplinary collaboration among various project participants to optimise the project delivery process; and improving the effectiveness of information sharing among project stakeholders (e.g., Korkmaz et al., 2012).

Recognition of the significance of integrated computer-based solutions has come slowly to the AEC sector as compared to other industries. During the late 1980s and early 1990s, some construction experts recognised the tremendous benefits that might be provided by more efficient information sharing in the AEC sector in their efforts to understand the concept of BIM and related technologies (see Linderoth, 2010). These early advocates had a vision of promoting the power of computerisation to prototype building as assemblies of building elements with parametric intelligence that integrate graphical and textual design information rather than using the computer to create the same design drawings that had been used to describe buildings for centuries.

Early CAD implementation ideas have been very “geometry centric”, with 3D representation of geometric models (Choi et al., 1984; Perng et al., 1990). Nevertheless, the concept has been expanding. Now, models are embedded with features and their attributes such as dimensions, material characteristics, and parametric integrity. Accordingly, the model allows for analysis applications such as, energy use simulation, quantity take-off, cost estimating, components prefabrication and installation analysis, construction planning and various types of engineering analysis (Richards, 2010). As construction stakeholders continue to discover that the BIM concept and practices can restore construction competitive edge, they are paying attention to BIM, promoting BIM studies and implementing BIM in construction project delivery.

Recently in the United Kingdom, a government-industry-academia BIM task group¹ report was launched by the department of business, innovation and skills (BIS) in 2011 to encourage the practice of BIM as a requirement on all UK public procurement projects by 2016. The overall aim of the government's BIM strategy implementation is to *“change the dynamics and behaviours of the construction supply chain, unlocking a new, more efficient and collaborative way of working. To put the industry at the vanguard of a new digital construction era and position, the UK is to become the world leaders in BIM”* (Francis Maude, Minister for the cabinet office).

Also, many UK construction firms and private sector clients, such as Asda, Tesco, Mott Macdonald, Gatwick Airport, BAM, Costain, Mace, Laing O'Rourke, HOK, Skanska and many others have been honing their BIM capabilities; many of them with demonstrable BIM projects, fortifying their products/services with the discovered concept of BIM. Apart from the UK, BIM has also taken hold in many developed regions across the world, including North America, Western Europe and Asia Pacific. Pike Research (2012), a consulting team that provide in-depth analysis of global clean technology markets has characterised the global BIM market as “nascent” but “evolving rapidly.” They have predicted that annual worldwide revenue for BIM products and services solutions will grow from \$1.8billion in 2012 to almost \$6.5 billion by 2020. The BIM products in this context represent the different BIM software tools which are developed and marketed by some well-known vendors such as Tekla, Autodesk and Bentley.

Paul Morrell, the government's chief construction advisor, has argued that, BIM introduction could lead to integration of the industry's players which is the biggest challenge facing the industry. It also has the potential to eliminate waste, and thereby reduce cost and increase profit, and it also opens the door to greater use of offsite prefabrication (Morrell, 2010).

Several researchers have also elaborated on how construction business system will be reshaped by BIM implementation. For example, from fragmented processes to integrated and collaborative procedures (Mao et al., 2007); from limited relativity of subsystem to interoperable digital forms (Mihindu & Arayici, 2008); and from manual to intelligent systems (Lin et al., 2003). London et al (2008) also outlined how certain skill areas in BIM may elicit considerable gains in terms of

¹ The BIM task group (draws in expertise from the construction sector, its client base, software suppliers, government and academia) was set up by the Department for Business, Innovation and Skills (BIS) and the Efficiency Reformed Group from the UK Cabinet Office to look at the construction and post-occupancy benefits of BIM (including building, asset information modelling and management) for use in the UK building and infrastructure market

accuracy, interactivity, productivity, cost savings and improvement in process quality, which the construction industry appears to be bedevilled with (Rezgui et al., 2011).

Nevertheless, the question that has often been posed is that, why has not every construction stakeholder organisation jumped on the BIM bandwagon to realise all the identified benefits? Part of the answer may lie in the fact that not all empirical studies about BIM are positive and some of the identified benefits in literature are not yet clearly demonstrated (e.g., Barlish & Sullivan, 2012). There may be bountiful rewards for organisations that are successful with the implementation, but there are miles to travel before the rewards are attained. Succar (2005) cautioned that “not all approaches to BIM implementation have been fully successful, hence a company actively seeking to deploy BIM needs to heed many warnings and best prepare itself for this technological and procedural migration.” The successful implementation of BIM faces many barriers within an organisation. Some of these are due to the nature of the industry or the implementing organisation (Dainty et al., 2006), others are idiosyncrasies of the construction sector (Linderoth & Jacobsson, 2008), and yet, others are inherent in the nature of BIM and related technologies.

Moreover, it is acknowledged that the outcome of the implementation depends on the interventions and the interdependencies of the technology and the organisations’ contextual influences (e.g., Likert, 1966). It then becomes essential to understand what the organisations and the actors do and how they work best with BIM technology in the pursuit of organisational success and higher efficiency.

Accordingly, for the purpose of this research, the focus is on a sociotechnical analysis of BIM implementation in construction organisations. With the sociotechnical approach the requirements of the BIM technology and the requirements of the construction organisation are taken into account simultaneously (Trist, 1981; Chersn, 1987; Bijker, 2000; Baxter & Summerfield, 2011).

1.4.2 Prior Research into Implementation Issues

The second driver for this research is related to prior research into ICT implementation in general and in particular, construction related technologies. The BIM concept and practices have been recognised to be nascent but evolving rapidly within the construction context (Pike Research, 2012). The concept of BIM is however, not entirely novel, as similar concepts have been implemented in other sectors. Aerospace, automobile, service corporations and the manufacturing sector for example, have been fundamentally transformed by the reliant on computer-mediated technologies which have the potential for achieving better collaboration,

content development and overall performance. Recent IT-mediated concepts such as, computer integrated manufacturing (CIM), manufacturing resource planning (MRP), and enterprise resource planning (ERP) generally known as enterprise systems include the provision of connectivity and coordination between functional departmental units located along a company's supply chain (Shields, 2001). These computer-mediated systems have something in common with the concept of BIM. Similar to BIM, these systems are designed to offer digital environments or platforms allowing cross-functional contributions and interactions by the users. They rely on integrated software applications and run on a variety of computer hardware and network configurations, typically employing a database as a repository for real-time information management.

Again, within information system research, there has been a long tradition of implementation research. This has mainly sought to conceptualize the implementation process, identify the factors which lead to implementation success or failure and then provide normative, prescriptive or descriptive strategies which practitioners can use to solve implementation problems (Stewart, 2000).

The implementation strategies for these IS oriented phenomena are captured in the mainstream IS theoretical models such as technology acceptance model (TAM) (Davis, 1989), unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al., 2003), and Roger's diffusion of innovation theory (DOI) (Rogers, 1983). These rather suggest the importance of intentional factors e.g., beliefs and intentions with respect to a system. TAM focuses on perceived ease of use and perceived usefulness of technology, whilst UTAUT considers factors that influence users' intention and subsequent use (e.g., performance, functions etc.) and DOI posits how communicating innovation via certain channels over time leads to rejection or acceptance. These theoretical foundations have been extensively discussed in prior literature (e.g., Sabherwal et al., 2006; Venkatesh et al., 2003).

These models have not however translated into successful implementation. Even after decades of usage, ICT systems still encounter an unacceptable rate of disappointment and failures (Mark & Poltrock, 2003; Fichman & Kemerer, 1999). Poor implementation of intended changes, systems poorly aligning with business and user requirement, and the persistent problem of the cost and schedule required to realise the tactical or strategic advantage of the systems, all continue to top the list of managerial concerns about new technological innovations in organisations (Norman, 2002; Dhillon, 2004; Bergman et al., 2000). ERP, for example, has been recognised to cause

detrimental effects to some organisations, mainly spawned by the lack of understanding of the intensity of process changes (Brown & Vessey, 2003; Turban et al., 2008).

Bergman et al. (2002) observe that some see the challenges as political while others tend to see the same problems as technical. Those on the political side cannot see the technical implications of unresolved political issues, and those on the technical side are unaware that the political ecology is creating serious problems that will show up in the functional ecology.

Moreover, the rollout of technology in construction, the domain this research focuses on, is no exception to this state of affair (e.g., Miozzo et al., 1998; Harty, 2008; London et al., 2008). The construction industry is well-known for its greater emphasis on project and performance outcome at the expense of innovation uptake and human needs, which can lead to many problems such as demotivated workforce and reforms (Raiden et al., 2006; Dainty et al., 2007). If the realisation of benefits from an ICT-implementation requires changes of work structures and a process requiring knowledge development and learning, which most often is the case in ICT implementations, construction stakeholders' incentives for implementing a new technology would probably be rather low (Linderoth & Jacobsson, 2008).

This may explain why the first reports of the potential of BIM to transform processes in the AEC sector began to emerge in the late 1980s and early 1990s, nonetheless, it was not until the mid-2000s that the frequent reports regarding BIM deployment started to emerge (e.g., Olofsson, Lee & Eastman, 2008; Eastman, 1999). Having said that, it is important to recognise the unique nature of the construction organisation in which the implementation unfolds, including industry characteristics, political agendas and power relations and the extent to which they influence BIM-enabled practices. Accordingly, it is appropriate and relevant to study the construction organisation and how it very much shapes and in turn, is shaped by the existing and emerging construction related technologies and BIM solutions.

1.4.3 The Existing Research Gaps

The third driver for this research is derived from the existing gaps in the body of knowledge in two main areas: the sociological and technological challenges accompanying technology implementation in the construction organisation context. The relationship between technology and organisation has been debated for several years, and different researchers across a number of academic fields have utilised various conceptual frameworks to guide in the implementation of increasingly sophisticated digital infrastructures. Technological and organizational innovation research in general, often share a sort of deterministic explanation, which assumes a linear,

straightforward consequentiality among the actors' choices, actions, and outcomes of the innovation process and attributes to systems "closed, pre-established and non-ambiguous purposes, and provoke impacts accordingly" (Ciborra, 2004). In other words, it is anticipated that designers and implementers have a clear view and stance with respect to what a system should and should not do, and that the system itself will behave to the rule.

In Creanor & Walker's (2011) words, an inherent assumption to the conventional approach to technology implementation is that 'technology itself is implicitly straightforward'. Kling & Lamb (1999) have termed this 'the standard tool' model of ICT which tend to depict the technological implementation as an add-on to the work system to resolve the particular problems emanating from the work context. This is also reflected in Ciborra's discussion of management encounters with information systems (Ciborra, 2004; pp 17).

"A key reason for managers' bafflement and uncertainty lies in the ungrounded expectations created by widely-used managerial and consulting models. Leveraging on the belief that ICT is a powerful means to control processes, people, and resources, these business models and systems methodologies promise a variety of ways in which top managers can align' ICT with strategy by reengineering processes and creating entirely new, competitive e-businesses. And that's not all: even knowledge can now be formalized and managed; workflows centralized; transparency enhanced; and data mined wherever they hide within the enterprise's procedures and the departmental files."

Ciborra (2004) illustrates the discrepancy between understanding of technological innovation and change in organisations. This sequential path has not entailed the dialogue between technology and the downstream organisational processes except through a series of standard engineering procedures embedded in the artefacts (Parsaei & Sullivan, 1993). Hence, conventionally, designers are mainly concerned about their products' performance and functionality and rarely take process constraints into consideration. The emphasis of this is on either to develop pedagogy to fit the technology, or to choose the technology to fit the context and this has been the dominant understanding for technology deployment. Either way, such views oversimplify the process of technology design and use.

Ciborra & Lanzara (1994; pp 62) conclude that "the notion of leveraging ICT as a strategic resource to produce a known outcome seems increasingly naive as a bulk of empirical studies shows a range of unintended consequences following technological change in organizations." The processes and mechanisms that produce conformity (or divergence) from institutions are

seldom unpacked from such perspectives. Generally within these perspectives, there are identifiable gaps in understanding the mechanisms that generate the conditions for the implementation of innovations (Hayes, 2008; Ciborra, 2004).

Moreover, this prevailing literature on ICT that underlie both conventional practices and many proposed reforms is generally not appropriate for a construction context (Pinch & Bijker, 1984; Schweber & Harty, 2010). Construction is often considered to lag behind other sectors in terms of its ability to take on new innovative technologies (Nicolini et al., 2001). A number of the sector's characteristics have been offered as the rationale for this problem, such as the largely bespoke nature of its products and services, and the heterogeneous nature of its knowledge boundaries coupled with transient project teams (Anumba & Pulsifer, 2010).

It has therefore been acknowledged that there is a lack of research directed at a detailed understanding of the construction context (Bresnen & Marshall, 2001) and that, the understanding of ICT research in construction is far from comprehensive (Barrett & Sexton 2006). It has also been acknowledged that, at this stage, most of the BIM potentials are demonstrated on pilot projects and the benefits are not clearly established. The gradual rollout of BIM solutions on projects reflect the experimental and exploratory nature of the development of new innovative technological solutions in construction (Davies & Harty, 2012). Indeed, the outcome of BIM implementation is not just based on the change of technology, but the change of task, structure and personnel. There is a wholesale change in technology through the move to a central repository platform for federated data interchange among heterogeneous professionals. There is a wholesale change in task through the change in organisational processes by adopting new process models external to the organisation. There is also a wholesale change in structure that supervene the existing functional requirements and roles of the workforce. Depending on roles and relationships delegated to the socio-technical entities in the implementing organisation, different challenges arise for the organisation managing the ICT-mediated change processes (Linderoth, 2007).

The theoretical challenge is to accommodate both the technology and organisation and allow for the analysis of their interactive combination in generating condition for organisational configuration and reformation. Accordingly the central issue analysed and discussed in this thesis is concerned with how an enhanced understanding of BIM implementation in construction organisations can be gained. In summary, the three drivers 1) the significant role of BIM in construction organisations 2) prior research into ICT implementation in general and in particular,

construction related technologies and 3) the existing research gap regarding BIM implementation from the construction industry perspective, justify the need for this research. The following section discusses the research questions for this study that emerged from these three key drivers.

1.5 Research Questions

Many are calling for the deployment of BIM in construction organisations. Nevertheless, there is a paradigm shift in the construction practice as a result of implementing BIM. Not only the change accompanying BIM is immense, but it puts enormous challenge on construction organisations to increase their capacity to cope with the drastic shift in paradigm as a result. A number of crucial questions remained unanswered regarding the BIM uptake. Some of these are addressed in this study.

Linderoth (2010) has highlighted the difficulty in the introduction of information and communication technologies (ICT) in the construction environment, as the original expectations about the outcomes of the deployment might be redefined and reinterpreted instead. Furthermore, he raises the importance of understanding the multi-layered context where learning and knowledge development have significant impact on the technology's development or use. Clearly, there is a need to explore how this 'multi-layered context' from the perspective of construction organisations is likely to influence BIM implementation. It is argued that the realisation of original intentions and goals associated to the technological artefacts is linked to the realisations and goals associated to the contextual influences of the organisation where the technology will be deployed. In addition, it is important to gain a better understanding of the sociotechnical mechanisms facilitating and constraining the interaction between the technologies and the context in which it is implemented or used. There are vast gaps in the body of knowledge related to ICT deployment in the construction context relative to other fields (e.g., Jongeling & Olofsson, 2007; Linderoth et al., 2008; Khanzode, Fischer & Reed, 2008; Dehlin & Olofsson, 2008; Schwebber & Harty, 2010). Accordingly, this research focuses on two key questions to address some of the research gaps prior to the exploration of the other issues related to the research:

Question 1: What are the key issues associated with BIM implementation within the construction organisation context?

Question 2: How can sociotechnical systems approach provide a conceptual understanding for BIM implementation in construction organisations?

Whilst the BIM concept is deeply embedded in technology, its objectives in practice, turn attention away from the technology and focus on the issues in the construction industry, crucially, it has implications throughout the design, construction and post construction processes (Succar, 2009; Succar, 2010). The corollary of this is the reliability and readability of project data interchange between various stakeholders. This impinges on the associated management practices, as it calls for a drastic drift from the conventional approach to fragmented data sharing. As contended by Jacobsson & Linderoth (2010) and Davies & Harty (2012), one of the major challenges facing construction organisations is to better understand the transformational processes that shape and better explain BIM-enabled working environment. BIM implementation processes and its influence on the organisation as a whole, have not received much empirical attention to date.

Another important point to consider is that, not only is the consideration of context important in understanding BIM deployment, but that context has itself changed over time. Many changes have occurred in technology deployment environment in recent years that need to be taken into account in updating our understanding of this complex phenomenon (Markus & Mao, 2004). Examples include increased levels of packaged software acquisition and customisation; increased outsourcing of technology development; and widespread development of enterprise-wide and inter-organisational technological integration. These changes have increased the number and type of groups with an interest in the technology development and implementation or use, such as BIM vendors, BIM outsourcing experts and external consultants, and the significance of the interactions between them, as well as the variety of technical and nontechnical development activities involved, such as complementary business or process interventions (Markus & Mao, 2004). Hence, the study seeks to provide a better understanding of the organisational roles and processes that support the BIM uptake. In view of that, three research questions have been highlighted:

Question 3: What are the new processes that emerge from BIM implementation?

Question 4: How do construction organisations integrate with other BIM interest groups at different levels in order to become a BIM-enabled construction organisation?

Question 5: How do the new processes impact on construction organisations?

As in the case of uptake of most technologies, the implementation of BIM implies a redefinition of roles, responsibilities and relationships among actors involved in a project (Linderoth, 2010), or among professionals working in a multidiscipline organisation (Steel et al., 2012). Latour

(1990) noted that, the programme of action inscribed in technological artefacts which originates from designers' intents about the potential user and the context of use, delegate roles and competencies to the sociotechnical components, including human entities of the system. Accordingly, the new roles and relationships among the actors will play an important role in the successful implementation of BIM. However, the inscription in the artefacts imposes on the actors, continuous learning and knowledge development which require management intervention and support in applying an acceptable learning framework – especially as more sophisticated computer tools emerge constantly (Schweber & Harty, 2010). Such a support has generally lacked in the construction sector (Young et al., 2008). Empowerment of staff, to help them find incentives for and value in making relevant changes to their practices is incontestable in this regard. In an industry where staff development, and people management practices are yet to receive more attention (Dainty et al., 2007; Kululanga & McCaffer, 2001), an effort to understand, and manage the impact of BIM on roles and responsibilities cannot be overemphasised. Accordingly, this research seeks to answer these important questions:

Question 6: How do BIM-enabled construction practices influence construction professionals' roles and responsibilities?

Question 7: How do the new roles and responsibilities impact on the empowerment of construction professionals?

The effort to manage implementation of new innovative construction technologies requires an appropriate management framework for its successful implementation. Moreover, Yusof & Aspinwall (2000) state that a successful framework has to be systematic and easily understood: have clear links between elements which are presented and also implementable. Accordingly, the theoretical underpinnings, supported by the literature and the exploratory findings will be used to develop a framework on how to conceptualise the BIM implementation process to suit construction contexts. When developed, the framework would be useful in analysing the concomitant process changes associated with the introduction of BIM. It may also facilitate the efforts of managerial interventions in the implementation of BIM and related construction technologies. In this regard, two research questions are highlighted:

Question 8: How can a framework be developed for managing BIM implementation in construction organisations?

Question 9: What is the construction practitioners' feedback on the proposed framework for analysing BIM implementation?

The next section provides the research aim and objectives that will answer the research questions discussed above.

1.6 Research Aim and Objectives

The overarching aim of this research is to:

Carry out a sociotechnical systems analysis of Building Information Modelling (STSaBIM) implementation in construction organisations.

The aim would help establish appropriate STS analytical interventions to foster BIM uptake by construction firms. The BIM implementation intervention will be based on the mutual dependency existing between the technological artefacts and the construction organisational contextual antecedents.

The following six objectives have been formulated to help achieve the overall research aim.

Objectives

1. Review existing literature and theories related to technology implementation in construction organisations
2. Explore the contributions of sociotechnical systems approach in dealing with technology implementation opportunities and constraints within construction organisations
3. Investigate the new processes associated with BIM implementation within construction organisations
4. Examine the implication of BIM implementation on the changing roles and responsibilities of construction professionals
5. Propose a framework for BIM implementation analysis that addresses the challenges confronting BIM implementation
6. Validate the proposed analytical BIM implementation framework and evaluate its relevance to practice from construction professionals' perspectives.

Table 1.1 shows the relationships between the research aim, objectives and research questions.

Table 1.1 Research aim and objectives, and related research questions

Research Aim	Research Objectives	Research Questions
<ul style="list-style-type: none"> To carry out a sociotechnical systems analysis of BIM implementation in construction organisations 	Ro1. Review existing literature and theories on technology implementation in construction organisations.	Q1. What are the key issues associated with BIM implementation within construction organisation contexts?
	Ro2. Explore the contributions of socio-technical approach in dealing with BIM implementation opportunities and constraints within construction organisations	Q2. How can sociotechnical systems approach provide a conceptual understanding for BIM implementation in construction organisations?
	Ro3. Investigate the new organisational processes associated with BIM implementation in construction organisation	Q3. What are the new processes that emerge from BIM implementation?
		Q4. How do the new processes impact on construction organisations?
	Ro4. Examine the implication of BIM uptake on the changing roles and responsibilities of construction professionals.	Q5. How do BIM-enabled construction practices influence construction professionals' roles and responsibilities?
		Q6. How do the new roles and responsibilities impact on the empowerment of construction professionals?
Ro5. Propose a framework for BIM implementation analysis that addresses the challenges confronting BIM implementation	Q7. How can a framework be developed for managing BIM implementation in construction organisation?	
Ro6. Evaluate the relevance of the analytical BIM implementation framework to practice from construction professionals' perspectives	Q8. What is the construction practitioners' feedback on the proposed framework for analysing BIM implementation?	

The exploratory review of literature has brought to the fore the gaps in knowledge regarding the implementation of BIM and its related technology in construction organisations. As a step towards filling these gaps, eight research questions have emerged, followed by the research aim and an outline of six research objectives to achieve the aim. Figure 1.1 shows the relationship between research gaps, research questions, aim and objectives and the research strategy.

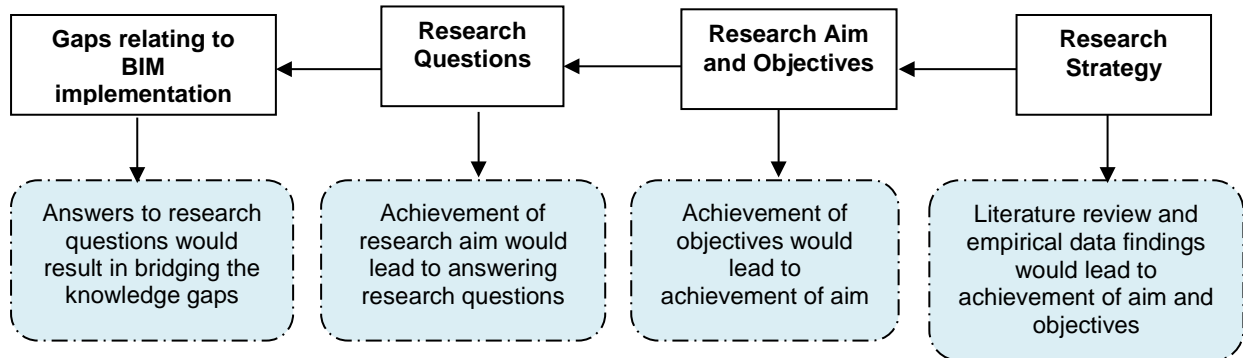


Figure 1.1 Relationship between the key aspects of the research

1.7 Research Strategy

In management study, research usually adopts interpretative epistemology where the focus is on how reality is constructed and shaped by the context and perception of people under study or a positivism paradigm where the emphasis is on causality and generalisability (Myers, 1997; Avison & Myers, 2002). These in turn, influence the actual research methods that are used to investigate a problem and to collect, analyse and interpret data (Bryman & Bell, 2003). For this research, an interpretative epistemology has been considered as the most suitable. In the construction management arena, the use of interpretivist research has become more common, although a quantitative position based on positivist paradigm is still the predominant approach (Dainty, 2008). The interpretivist position stresses the applicability of social research findings to those that exist within the social situational context. Dainty (2008) noted that research methods are inescapably intertwined with research strategy. In this perspective, qualitative method can help to understand the role of people, technology and their interrelationships within construction organisational contexts. Denzin and Lincoln (2003) state that qualitative research “emphasises the qualities of processes and meanings that are not experimentally examined or measured in terms of quantity, amount, intensity or frequency.” Researchers focus on the socially constructed nature of reality and the situational constraints of the inquiry. Hence, this research follows a qualitative approach based on

interpretivist epistemology. Data collected for the analysis is considered as subjectivist, and corresponds to ‘ecological validity’, which stresses on understanding how different realities are constituted in a localised context (Dainty, 2007).

1.7.1 Research Context

To achieve the research aim and objectives, careful considerations were given to the activities in the research process. The process commenced with the identification of the research topic. This was preceded by an exploratory review of previous works and suggested improvements in the primary subject area of the research in order to provide an initial focus for the study. At this stage, an emphasis was placed on reviews of articles from journals, conference proceedings, books and internet searches, as these sources provide more recent developments that are cutting-edge in the subject area of BIM and construction related technological studies. The knowledge, theories and principles acquired from the review were subsequently used in the design of the case study; elicitation of data; analysis of data; and, application of the results from the research findings.

Two distinct research plans overarching the qualitative research method employed, comprise: exploratory study of in-depth interviewing by experts sampling, and carefully selected multiple case studies. Both the exploratory studies and subsequently, the case study approach have been chosen because of its potential to provide a richer picture of the influences towards BIM implementation in construction organisations and the users and their organisations’ response to those influences.

Empirical data was gathered through the following research techniques:

- Semi structured interviews with different stakeholders involved in the selected organisations under study. Those interviews were recorded and transcribed.
- Attendance and observation of different sessions: training sessions; BIM-related appointments and participating in stakeholders’ group meetings.
- Observation of different groups of BIM users within their localised contexts.
- Documentation analysis such as BIM implementation strategy documents, written policies and procedures, and project documents.

This study thus takes the form of literature and theoretical reviews plus exploratory interviews by experts sampling and case studies. The qualitative content analysis technique was adopted in analysing the empirical data. The essential data derived was in response to

research questions that were developed in order to explore the implications of sociotechnical systems in the implementation of BIM in construction organisations.

1.8 Summary of the Research Contribution

The detailed contribution of this research to knowledge is presented in section 8.3 and is summarised in this section. The research has provided an important insight into the deployment of BIM in construction organisations from the perspective of a sociotechnical systems analysis, revealing the complexities associated with BIM as it mutates and is appropriated in different organisational contexts. With respect to the STS perspective, this study accommodated the dualism of the inscribed functions in BIM and contextual issues in the organisations and allow for the analysis of their interactive combination in producing the anticipated effect from the BIM rollout.

Contrary to the dominant understanding of a top-down give-and-take approach to BIM utilisation, the study revealed that different organisations with plethora of visions, expectations and skills combine with artefacts to form or transform BIM practices. The study also showed that the appropriation process of BIM endures in a causal chain of influences across multiple levels of sociotechnical constituencies. The different levels of influences establish their own ‘localised’ ambitions and make logical decisions on their business operations with regards to anticipated visions of BIM. At a higher level of abstraction (e.g., BIM-enabled processes at the project level), a contractual obligation is established by engaging with the different project organisations on ‘holistic’ visions and expectations of preferred artefacts and distributed responsibilities. Thus, as visions are eventually narrowed, the principles of BIM processes are jointly developed and the technological choices and uses become standardised or transformed. It therefore becomes apparent that BIM appropriation is part of broad interconnected systems of rules, structure, actors and groups across multiple levels. Hence, the contractual protocols related to BIM implementation processes are likely better instituted and established in organisations to enforce and firm-up the holistic visions associated with the BIM deployment processes.

During the course of this research, six academic papers have been published in conference and doctoral workshop proceedings and also, in a special issue journal. The full bibliographic details are presented in Appendix 7.

1.9 Structure of the Thesis

The thesis is structured into eight chapters. A flow chart of the thesis structure is depicted in Figure 1.2. The flowchart shows the interrelationships among the different chapters and the activities undertaken to achieve the research aim and objectives. Chapter one provides the background and contexts of the study. In chapter two the current disparate perceptions of BIM implementation strategies in the extant literature are consolidated into a comprehensive implementation framework. The missing-link associated with the current BIM policy mandates and the implementation strategies are highlighted in chapter three. Also in chapter three the theoretical framework which provides the lens for this study is discussed. Chapter three again made the case for the BIM implementation concept to be conceptualised from a sociotechnical systems perspective. The combined insights from different literature, in particular the theories of STS (e.g., Cherna, 1976; Porter, 1990), digital infrastructure in design practices (Whyte, 2009) and technological innovation in organisations (Molina, 1993) are used to develop the STS analytical framework of BIM implementation in chapter five.

Chapter four describes the methodological considerations for this study. The data collection and validation strategy in naturalistic settings is outlined and the analysis strategy of the empirical data to support both the implementation of BIM and the development of theory is also presented in chapter four. Chapter five analyses the first stage of a two-stage process for the empirical investigation. The results of the first-stage exploratory studies reveal a demonstrable coincidence between the findings of the literature review and their potential application to construction organisations. The STS theory discussed in chapter three was further developed and its feasibility and potential application to analysing BIM implementation was also discussed in chapter five. Chapter six presents the within-case analysis of the three case studies. Two of the organisations can be classified as large organisations with multinational market niche and a turnover of circa £1 billion. The third is a small multidisciplinary practice based in the Midlands of the UK, providing design, consultancy and construction services in the structural steelwork and architectural metalwork sectors.

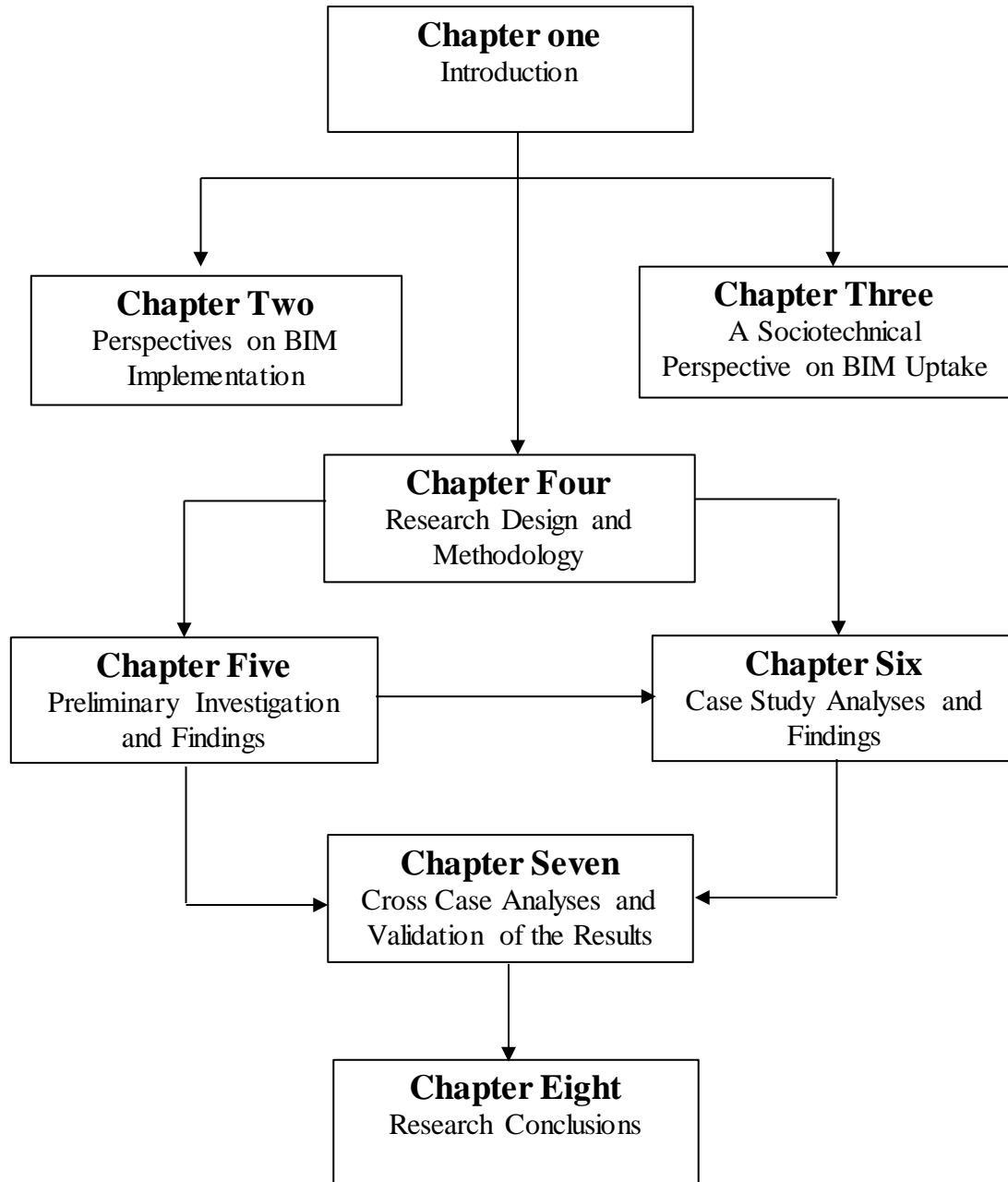


Figure 1.2 Outline of the Thesis

Chapter seven presents the cross-case analyses of the results using the qualitative content analysis. The findings are presented within the contexts of STS theoretical knowledge. Consideration is also given to the analytical generalisability of these findings to other construction environments. The research validation with industry practitioners and academics is also presented in chapter seven. Chapter eight presents the conclusions of the research. The theoretical and practical contributions, limitations and suggestions for future directions are also discussed in chapter eight.

1.10 Summary

This chapter has set out the background of the research. It justifies the rationale of the thesis and presents the research aim, objectives and questions. In addition, the research strategy is also introduced in this chapter. The next chapters review the relevant general and construction specific literature relating to BIM implementation. Firstly chapter two presents the current perspectives on BIM implementation, and finally, chapter three linked the sociotechnical systems theory to BIM deployment with the view of bridging the theoretical gap in the BIM implementation literature.

CHAPTER TWO

2 PERSPECTIVES ON BIM IMPLEMENTATION IN CONSTRUCTION ORGANISATION CONTEXT

2.1 Introduction

This chapter presents the first part of the literature review which underpins the research objective one presented in section 1.6. The main focus of this chapter is to present an overview of the current literature and to explore theoretical foundations which are salient to BIM implementation strategies within the context of existing construction management knowledge. The chapter is in ten main sections. Firstly, the definition and conceptual underpinning of BIM is presented in section 2.2. Secondly, the evolution of technological innovation in construction is discussed in section 2.3. Thirdly, the implementation of BIM is presented in section 2.4. Following this, the sociotechnical interactionist view of innovation implementation is highlighted in section 2.5. Next, BIM innovation product solutions are presented in section 2.6., as well as BIM innovation process solutions (section 2.7). Section 2.8 explores the organisational structures for BIM implementation. The legal and contractual obligations associated with BIM are discussed in 2.9. Section 2.10 presents a consolidation of a comprehensive framework for BIM implementation based on the literature findings. Section 2.11 problematises the BIM implementation processes from a sociotechnical systems perspective. The summary of the chapter is presented in section 2.12. This review thus addresses in part, the first research objective which is to undertake a critical review of existing literature and theories on BIM and related technology implementation in construction organisations.

2.2 Historical Perspective on the Transition from Traditional Drafting to Modelling

The building industry has traditionally illustrated building projects on paper-based platforms with drawing instruments such as pen, T-square, drawing board, paper and irregular (French) curves (Henderson 1995). Drafting on paper is time consuming and laborious especially when it comes to alteration as it is a pen-based process. Changes in the design might necessitate a complete redraft. According to (Weisberg 1995), during the decades following the Second World War, drafting equipment suppliers introduced a variety of devices such as the Universal Drafting Machine to improve the productivity of the drafting process. These

eventually help substantially reduce the time for creating routine drawings. However, this approach for the engineering design process was fraught with human errors and it was time consuming.

The evolution of the building design processes is inescapably linked with the advancement in technological innovation over a period of time. A technological innovation can be defined as “a set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilisation of a new technology and/or a new product.” (Markard and Truffer, 2008 pp. 611). This suggests that the technological development maps the trajectory of the driving components which comprise the technology, actors, networks and institutions. Early computer development in the mid-1940s was mostly funded by military agencies and these machines were used to calculate information such as ballistic trajectory tables. A decade later, few companies began delivering computers to large engineering organisations, especially in the defence and automotive industries. Gradually, a number of computer hardware and software programmes for solving engineering problems were developed. A major catalyst in the development of technical drawing was the introduction of computer-based CAD (computer aided drafting/design) system. There is clear evidence on the contributions of universities, public research organisations and the military in the generation and diffusion of technological advances in industries. Their roles however have been shown to differ in different industries (Levin et al. 1987; Malerba 2005) and for that matter, in construction. Eastman (1975) for instance, published a paper entitled, “the use of computers instead of drawings in building design” which described a single integrated database for visual and quantitative analyses of parametric design. Eastman’s (1977) concept of GLIDE (Graphical Language for Interactive Design) exhibited most of the characteristics of a modern BIM platform. Hence the generation of CAD-based software solutions were designed to fully augment the benefits the existing hardware/software technological platforms could bring to the building industry. In 1982 Autodesk was founded with the idea of creating a CAD programme to run on personal computers and in 1984, the first commercial version of ArchiCAD was released. By 1990, Autodesk has sold over a million copies of the CAD products. CAD in construction was initially introduced as a direct replacement for the paper-based hand drawings, which implies only 2D CAD was used regularly. The early CAD design utilised the computer screen as a work space within which designers could work with both paper and computational images. The CAD drawings were therefore produced on computer hardware but distributed as paper printouts. As an innovation within construction, the 2D CAD offered the same output as the drawing-board – but with the

advantages of easily updatable, reproducible and storable electronic drawings. CAD is therefore defined in this study as:

“the process of creating the graphical abstractions of the intended building design on a computer platform”.

The general trend of the computer-based CAD system ensured that the amount of hours that were necessary for the production of drawings decreased steadily over time in relation with the traditional drawing board approach. By the mid 1990s CAD use in construction was widespread, demonstrated by Autodesk’s position not just as the industry leader; but as a big player in the software company in the world (Bozdoc, 2004).

The representation of the 2D CAD platform was inadequate with many drawbacks in terms of precision and adequacy of the representation (Bilalis 2000). The 2D CAD could not allow the transfer of appropriate levels of object intelligence from one model to another. However, the improvement in the productivity of the CAD system was developed in concert with computer technology. As personal computers became more powerful, the usefulness of these tools to architects and engineers became increasingly evident. The use of CAD files was evolving toward communicating information about a building in ways that a plotted drawing could not. This development ensured that drawings could be amended at multiple scales and across fragmented drawing sheets in ways that had not been possible in the past ‘drawing-board’ era. Electronic file formats originally designed to store only graphics and drive plotters evolved to directly convey information about the building that would not appear in the plotted version of the file. The advances in the CAD system supported geometrical modelling of the building in three dimensions (3D) thereby automating many of the laborious drafting tasks such as generating door and windows schedules. The 3D object-oriented CAD extended the idea of parametric representations of the graphical and non-graphical data ensuring that drawings are updated on a model change and reduce the time required for the drawings updates. A parallel development in the 1990s was the increasing use of the Internet for sharing data digitally. This led to the sharing and delivery of object-oriented CAD systems through web-based communication platform (e.g., Walker 1994).

This historical analysis of the CAD system indicates that the trajectories of and the technological innovation behind BIM have been rapidly evolving for the past 40 years, nevertheless, the use of BIM as a buzzword has recently snowballed within the AEC community. The recent proliferation of BIM technology belies a long iterative software and

hardware development process. Lyytinen and Rose (2003) defined the effect of technological innovation as ‘pervasive’ in that it simultaneously spans new services and new types of development processes which spur subsequent innovations in system development and services. This then clarifies how an organisation can align with an ever changing technological innovation. The reality with the CAD system however is that the very information (textual data) necessary for effective design evaluation and construction, such as material quantities, costs and programme information, specifications, and energy simulation are usually not captured in the 3D graphical data (Hardin, 2009). In parallel to the rise of computing software the big leap for BIM occurred with the introduction of the 4th dimension, or when elements of programme and time were added in, and 5th dimension, or with 5D quantity and cost added in the year 2000. The release of AutoDesk Revit allowed cost to be associated with individual components, thus allowing contractors to generate not only construction schedules, but also cost estimates. NBIMS (2007) defined building information modelling as “...a digital representation of a physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward”. The principles of BIM captures building information at the moment of creation, stores in a cloud-based repository and makes the information available for use and reuse by the collaborative project team at every stage of the project. The current BIM software have the capability of representing both the physical and functional properties of a building as an object-oriented model tied to a database or digital repositories for easy access and collaboration.

Based on the above analysis, the concept of BIM is defined in this study as:

“the process of using the available technological artefacts to produce data-rich, object-oriented and parametric representation of a facility on a digital platform which enables the various construction stakeholders to effectively use and reuse the model to coordinate, design, construct and operate a facility.”

Understanding the concept of the parametric objects is key to understanding how BIM differs from CAD. A parametric object consists of a series of geometric definitions and their associated data and rules, which are integrated non-redundantly and do not allow for inconsistencies between the model and its associated data set. Thus any changes made directly to the model result in an equal change to the data set associated with the model. The parametric integrity of the model ensures that the creation of a 3D model with associated

information reduces errors of design, improves design quality, shortens construction time, and significantly reduces construction costs (Eastman, 1999).

2.3 Evolution of Technological Innovation in the Architecture, Engineering and Construction (AEC) Sector

The architecture, engineering and construction (AEC) sector is often considered to lag behind other sectors in terms of its ability to take on new innovative technologies (Nicolini, 2002). A number of the sector's characteristics have been offered as the rationale for this problem, such as the heterogeneous nature of its knowledge boundaries and also, the largely bespoke nature of its products and services. The complexity associated with the delivery of construction projects by a transient project team made up of individuals with different knowledge backgrounds makes the implementation challenging. The underlying problems inherent in the construction industry have been widely articulated in the literature (Senescu et al., 2013; Ibrahim et al., 2013; Dainty, 2007, Anumba, 2000; Hao & Shen, 2010).

The introduction of BIM in construction is purported to address a range of industry issues such as *inter alia*: producing predictable project outcomes from design phase through to construction with the use of BIM tools and concomitant processes; advocating a collaborative working culture model; overcoming team coordination issues; promoting interdisciplinary collaboration among various project participants to optimise project delivery process; and improving the effectiveness of information sharing among project stakeholders (e.g., Korkmaz et al., 2012).

However, one peculiar phenomenon about the BIM concept is that, it has been branded as “a revolutionary building design and construction technology” (Osan et al., 2012), because it is purported to bring wholesale changes to every phase of the project delivery lifecycle. Over the past few decades, the construction sector has witnessed a number of transformational changes enabled by technological evolution—from the drawing board to CAD then from CAD to BIM as depicted in Table 2.1. The Table (2.1) highlights the parallels existing in the transitional phases of the construction delivery process across time.

When the construction sector transitioned from the drawing board (manual delivery) to “electronic delivery” CAD systems, the products were initially the same, it took about a decade to develop the CAD system from 2D to PC driven basic 3D drafting (Bevan, 2012). The reality with the CAD system is that, too often, fragmented, unreferenced, and inaccurate data is distributed between the construction team and then handed over to the owner to be

used as information for maintenance of the facility (Hardin, 2009; Anumba & Evbuomwan, 1997). Just as the drawing board was once the accepted technology prior to CAD, the era of BIM has begun – but this time, the change is revolutionary. As part of the transitional process from the drawing board, through CAD to BIM, the construction sector is witnessing a fundamental shift in the way projects are conceived and delivered. This is because, the rollout of BIM is not a natural advancement from CAD – it involves a paradigm shift from drawing on two-dimensional media to modelling, which is analogous to actual construction in a virtual/digital environment (Eastman et al., 2011).

Unlike CAD, a BIM project is not drawn in a traditional sense with lines, dots, and texts in multiple documents. Instead it is built digitally as a database in a BIM-based platform as depicted in the construction technology timeline (Table 2.1). Technology has been a key enabler throughout the developmental cycle of the AEC sector. And this presents both challenges and opportunities for the AEC sector organisations to revolutionise working practices with the aim of increasing productivity and efficiency (Morrell, 2010).

It is known that computer technology has one of the fastest evolutions today. Like most office spaces, the development of mass personal computers is inextricably linked to the development of construction innovative technologies such as CAD and BIM solutions (Eastman, 1989; Bozdoc, 2004). In parallel with the developments in the software industry, organisations in the AEC sector are utilising new technologies in support of their businesses and the use of technological tools is now becoming strategically important (Hosseini et al., 2013). However, a technology-centric view of BIM will inevitably lead to fundamental problems in understanding BIM as it mutates through the construction practices (Holzer, 2007). Because, in effect, the process change intrinsic to BIM implementation is substantial and it impacts nearly all activities related to the planning, delivery and operation of buildings on a social, as well as technical levels (Suerman, 2009). Thus it requires new set of skills, new ways of thinking and new approaches to intellection.

Then again, the effort needed to achieve BIM aspirations is prohibitive to a widespread implementation across the mainstream practices. This is because in effects, it distorts the well-established conventional project setups by which construction processes are currently mobilised - from design and procurement, through competitive tendering and contractual relationship to handover and facilities management. Notwithstanding the opportunities BIM is purported to offer the construction industry, all the associated discipline have been challenged by its implementation. It is important to acknowledge the significance of the

challenges that await construction organisations as they prepare to embrace the BIM concept. Weston (2001) has previously emphasised that organisations that realise full benefits of a technology are those that make necessary changes in their organisational structures, strategies and processes. Eastman et al. (2011) also argued that organisations have to change their processes to adapt to this development. Singh et al. (2011) explained 'status-quo loop' where people lack appropriate knowledge and subject awareness, thereby causing institutional conservatism, which in turn affects the introduction of any new idea or innovation.

Table 2.1 Construction technology transformation timeline

Time	Pre 1980s	1980s	1990s	2000s	2010s	Future Anticipation
Practice	Drawing Board	Computer Aided Drafting (CAD)	Basic Computer Aided Design (CADD)	Increased Computer Aided Design (CADD)	BIM Stages	Post BIM
Features	<ul style="list-style-type: none"> • Manual scheduling • Manual collaboration • Constant duplication <ul style="list-style-type: none"> • Zero transparency • Limited efficiency 	<ul style="list-style-type: none"> • Primarily 2D • Mainframe driven • Limited compatibility • Limited collaboration • Relatively reduced duplication 	<ul style="list-style-type: none"> • Basic 3D visualisation • PC driven • Consultant centric • Relatively better consistency • Limited collaboration 	<ul style="list-style-type: none"> • Increased 3D modelling <ul style="list-style-type: none"> • LANs – Networked PCs • Project centric <ul style="list-style-type: none"> • Increased collaboration • Improved coordination 	<ul style="list-style-type: none"> • Single disciplinary use of object-based 3D modelling <ul style="list-style-type: none"> • WAN networked and federated repositories • Limited multidisciplinary sharing of BIM-models <ul style="list-style-type: none"> • 4D & 5D benefits – time/cost • Full coordination • Increased efficiency 	<ul style="list-style-type: none"> • Integrated practice • Multidimensional federated models <ul style="list-style-type: none"> • Synchronous communications • Virtual integrated design, construction and operation (viDCO)

Adapted from (Sackey et al., 2013; Bevan, 2012; Succar, 2010)

The wide gap that exists between BIM capability maturity concepts and the realities of its implementation is testament to the severity of the challenge. As noted by Linderoth (2010), the first reports of the potential of BIM to transform processes in the AEC sector began to emerge in the late 1980s and early 1990s, nonetheless, it was not until the mid-2000s that the frequent reports regarding BIM deployment started to emerge (e.g., Olofsson et al., 2008; Eastman, 1999). And even today, the tangible benefits of BIM are not widespread in the mainstream practices as most of the BIM potential benefits are demonstrated on pilot projects (Davies & Harty, 2012). The key reason for this may be attributed to the fact that the uptake of construction related technologies is shaped by many factors, which have roots in the idiosyncrasies of the construction industry, intertwined with the concomitant process changes as demand by the associated technologies.

Ilozor & Kelly (2012) have reported that, there is a gap with respect to meticulous verification of many assertions made within the literature with respect to BIM's potential positive impact on productivity, cost benefits, ROI, etc. (e.g., Azhar et al., 2008; Giel & Issa, 2012; Dossick & Neff, 2011; Becerik-Gerber & Kensek, 2009; Sacks & Partouche, 2011; Lu & Korman, 2010). Ilozor & Kelly (2012) highlighted some conflicting findings regarding the purported benefits derived from BIM and suggested a need for a more thorough analysis and rigorous independent verification of the many assertions made within the literature with respect to BIM's potential positive impact on productivity.

Different BIM challenges and implementation concerns have been reported in the literature. Hooper & Ekholm (2012) for instance report that practical experience in moving forward with BIM is lacking. There is hitherto, an absence of developed examples of delivery specifications to accompany the developed BIM maturity protocols and government BIM ambitions and policies (Hooper & Ekholm, 2012). Dossick & Neff (2013) acknowledged that, sociotechnical misalignments are a major concern for construction organisations utilising BIM technologies. Misalignment in this context is described as the tensions between technological affordances and a team's organisational needs and functional goals (Henderson, 1999). The fragmented and the often adversarial nature of the industry have also been observed to be an impediment to full realisation of the benefits of BIM (Ilozor & Kelly, 2012). In other words the BIM concept does not unreservedly create solutions to existing problems; instead it might create new issues that need to be solved. In fact, Dossick & Neff (2011) noted that, although BIM makes visible the connections among different project members, it does not foster closer collaboration across different companies. They further

argued that, it may even hinder collaboration through the exposure of previously implicit distinctions among team members' skills and organisational status. Ultimately, the transformation of the construction sector into a fully BIM-enabled sector will require the collective engagement of software vendors, researchers, construction practitioners, and clients together with all levels of government support (Watson, 2011).

There is a widespread consensus in the extant literature regarding the positive effects of utilising innovative construction technologies to address some of the prevailing challenges in construction (Adriaanse et al., 2010; Hartmann et al., 2012). However, the same literature holds the view that the level construction industry has harnessed the potential capabilities of technologies for its own benefit is not as effective as it can be (Hjelt & Björk, 2006, Nitithamyong & Skibniewski, 2004). There is no common practice for dealing with all new possibilities and problems arising as a result of the rapid evolution of BIM software products. In this respect, Peansupap & Walker (2005) opine that the benefits of BIM in the construction industry in both the operational and strategic level are not debatable and further research should aim at finding better approaches for introducing BIM into the construction industry.

Ultimately, mobilising technological solutions for the delivery of construction projects calls for companies to gain better insight of the concomitant innovative processes that are associated with the technology. Grounded in sociotechnical systems theory, the research of Trist (1981) and others have focused on how the condition of organisational, social and technical systems influences uptake of technology and organisational outcomes through the interplay and mutual adjustments of sociotechnical antecedents (Trist & Bamforth, 1951; Trist, 1963). Following the sociotechnical tradition, this study aims to present empirical and theoretical insights into the adaption and appropriation of construction-related technologies through a sociotechnical systems analysis of BIM implementation in construction context.

2.4 Implementing BIM

The term implementation is used in literature with many different connotations. In the context of innovation research and practice the word implementation often causes problems. The question of what is innovation implementation is a crucial issue to both information systems researchers and practitioners. In other words, when practitioners and researchers talk about innovation implementation what theoretical assumption are they making? What are the technical, social and organisational processes which underlie the organisational implementation phenomenon? There have been three schools of thoughts that have

dominated innovation theory and these add to the confusion to how innovation research is conceptualised. These are: 1) technological imperative; 2) organisational imperative; and 3) sociotechnical imperative.

The first is a technology driven approach, and it focuses primarily, on the application of the available technology to address ‘predefined’ problems that have been identified in the organisation through the use of appropriate methodological tools. This deterministic perspective views innovation as an external force, which determines the behaviour of individuals in organisations, and therefore as the major force behind technology-related organisational change. This approach is known as “technological determinism” (Symons, 2000) or “technology imperative” (Markus & Robey, 1988). The second approach is concerned mainly, with creating the link between the business environment, the organisational strategies and the innovation strategy. This perspective views organisations as “brains.” According to Morgan (2006), this “leads us to understand organisations as institutionalised brains that fragment, routine, and bound the decision-making process to make it malleable” (Morgan et al., 1997: p.79). The “organisational brain” is solely relied upon to configure the IT-reliant work system. This approach is commonly known as “organisational imperative” and it has also been labelled “managerial rationalism” and tantamount to Checkland’s (1999) “soft system methodology” (SMM) (Chandler, 1962). And the third perspective is favoured by authors whose focus of interest is the impacts or consequences of innovation implementation in organisations and it hinges on the emergence of IS-related dispositions in the organisation. This is concerned with the interaction between the technology and the social structures of the organisation and the emergent effects arising from such interaction. This approach is also known as “social technology school” (Desanctis & Poole, 1994), “sociotechnical interactionism” (Campbell, 1996) or sociotechnical (Mumford, 2006). The third designation is chosen for this study to define innovation implementation in construction because it is able to encapsulate the various influences impacting on organisations as a result of technological change.

Based on the third disposition, the term innovation implementation, is used both in operational and strategic contexts to mean both a technical and an organisational process (Cornford, 2003). Walsham (1993) argues that innovation implementation, in essence, encompasses all the human and social aspects of the organisation which are relevant to the complete process of introduction of product innovation into organisations. It is thus a decision by an organisation to use or articulate a need to inculcate the innovation as part of

the work process in the organisation. Based on the above conceptualisation, a definition of BIM implementation is therefore proposed. The study analyses BIM implementation as a process of adapting and appropriating BIM software artefacts in the form of organisational strategies that consider sociotechnical factors encompassing contextual elements in organisations and technological functionalities and requirements.

2.5 Sociotechnical Interactionist Approach to ICT Innovation Implementation

Sociotechnical systems thinking (Mumford, 2006) has provided some inklings regarding the fact that implementing innovation is more than just putting together artefacts and organisational procedures and that there is a need to consider other variables within the organisation, which might also influence the ultimate success or failure of the implementation effort. According to the interactionist views, the problems of implementing innovation in organisations cannot be seen as a “one-way” process.

Orlikowski (1992) for instance argues that technology has a dual nature. On one hand technology has objective reality, such as the design intent of the hardware or software. But on the other hand, technology is also a socially constructed product in the sense that new structures emerge in human action as people interact with the technology. Using concepts from Giddens’ (1984) structuration theory, Orlikowski (1992) puts forward a structural model of technology which is intended to unveil key aspects of the phenomenon of integration of innovation into organisations (see Figure 2.1).

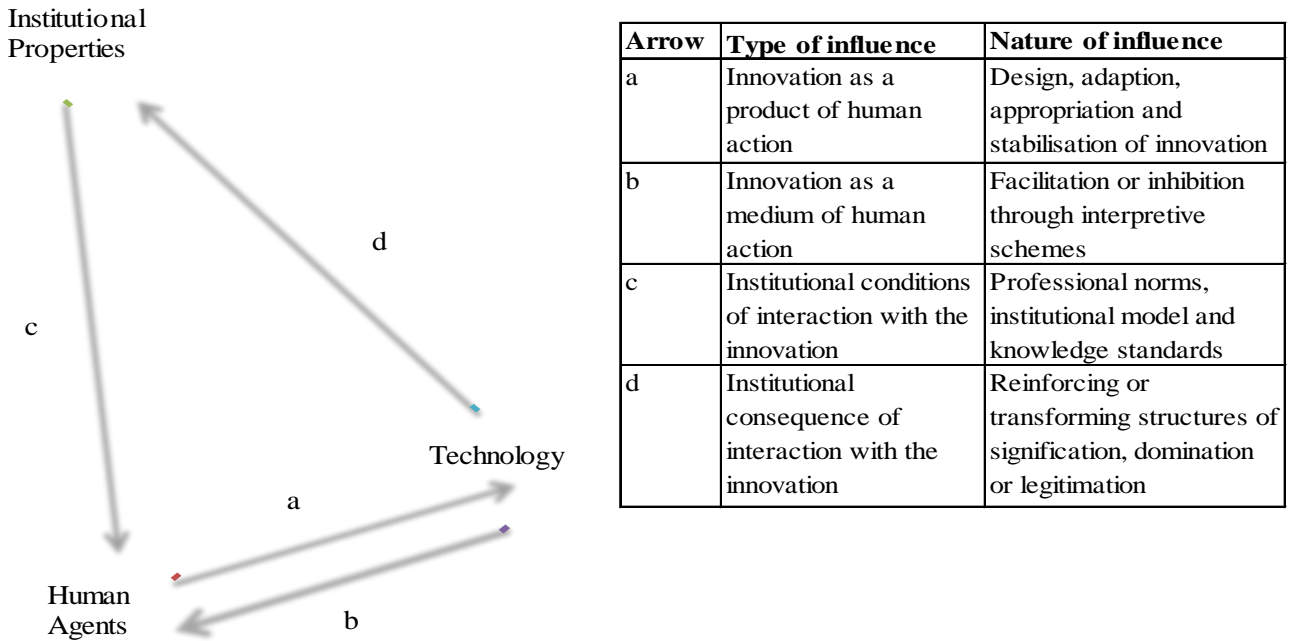


Figure 2.1 Structurational model of innovation

(Adapted from Orlikowski, 1992; Giddens, 1984)

Both Orlikowski (1992) and Giddens (1984) have argued that innovation implementation is not all about technological artefact, methodologies and policies, but it is also the result of individual sense-making, that is, the perception and understanding of the roles and values of the sociotechnical components as they interact to impact on the overall work system or the organisation (Giddens, 2013). There have been suggestions that the sociotechnical interactionist approaches must be complemented with managerial action frameworks. Specifically, organisations that achieve implementation success are the ones that are able to define and build ethos of knowledge from the grounds up regarding technology platforms, business processes and enticements that will guarantee the identification, collection, and sharing of corporate knowledge. Such a concept is discussed under two distinct factions in this study, comprising BIM innovation products and process solutions (e.g., Anumba & Pulsifer, 2010).

2.6 BIM Innovation Product Solutions

Innovative technological products are very important enablers for supporting the implementation of a BIM solution. The innovation product enablers concern trends in the area of enabling technologies and standardisation efforts for ICT in construction and consist of a combination of hardware and software technologies. At a basic level, cloud computing,

in conjunction with fixed and mobile devices, will prove to be an appropriate delivery and collaboration platform this includes existing capabilities such as databases, multi-core processors, the internet, mobile devices, GPS and radio frequency ID tags. Hardware technologies and components are important for a BIM system as they form the platform for BIM software technologies such as Autodesk, Bentley or Solibri products to perform and are the medium for storage and sharing of BIM competences. Some of the hardware requirements of a BIM innovation solution include personal computers or workstations to facilitate access to knowledge, powerful servers to allow the organisation to be networked, open architecture to ensure interoperability in distributed environments, media-rich applications requiring Integrated Services Digital Network (ISDN) and fibre optics to provide high speed and use of the public networks (e.g. Internet) to facilitate access to and sharing of BIM competencies and performance measures. Software technologies also play an important part in facilitating the implementation of BIM.

Whyte (2011) acknowledged that construction technological artefacts often do not exist in isolation, and mobilised the concept of “boundary objects” to articulate how technological artefacts are used in coordination across different organisational context. Drawing on the works of Star & Griesemer (1989) on knowledge boundary object categories, Whyte & Lobo (2010) highlighted three different digital artefacts for infrastructure delivery as:

- **Object geometries**, these are assembly drawings, engineering simulations and other objects used to digitally represent physical realities;
- **Standardized formats**, these allow for structuring and distribution of digital dataset across boundaries, e.g., open BIM formats or proprietary BIM format; and
- **Repositories**, or storage technologies, these are libraries used to store piles of catalogued objects and their role is to transfer data across boundaries.

The ICCI (2004) project supported by the European Commission (EC), also suggested three critical ICT solutions and three ICT enablers for the construction industry. These are shown in Table 2.2 below.

Table 2.2 Criteria for BIM innovation product solutions

BIM innovation product enablers	BIM innovation product solutions
<p>Open standards: the trend towards vendor-independent interoperability that enable integration of multi-vendor components</p>	<p>Model-based: smarter applications and more intelligent support of end-users, enabled by software based on semantic models, by which building objects, structure, shape, time, cost etc. can be defined. This includes “product-based” technologies such as STEP and IFC that can better support for user specific views in the actual work context.</p>
<p>Web-based: the Internet and the future Next Generation Internet (NGI) or Semantic Web being the information infrastructure backbone for the future for all communication in constructions</p>	<p>Object orientation: Integration of functionality and data, product and process information in “objects with behaviour”</p> <p>Adaptive/flexibility: “self-learning” from their own use and user behaviour, and adapting to new situations without manual configuration, maintenance and support, e.g., due to the use of open, modular software design principles and flexible meta-data.</p>
<p>Ambient-access: technologies enabling communication and information access anywhere, anytime in a secure way and sharing via the most appropriate device, e.g., mobile devices on the same level as with fixed devices. Mobility is a prime factor</p>	<p>Information/intelligent sharing: all products and process information available and accessible to all stakeholders, over the whole life cycle in the latest version of the most appropriate device from one logical source.</p>

The effect of technology providers and software vendors is a key matter in the formulation of BIM strategies and solutions, which needs careful consideration. There are a host of BIM software applications in the marketplace that assist the various construction practitioners in their daily task routines and also help them exchange interoperable project information. BIM implementers have the options of acquiring commercial-off-the-shelf (COT) (Kunda & Brooks, 2000; Tsui, 2002) BIM products from the vendors’ store-shelves or through in-house customised BIM products’ development (e.g., Tsui, 2002). Using these BIM applications and tools for the management of construction projects require their use to be enhanced so that benefits, in terms of efficiency gain can be fully realised. Most organisations opt for the COT option. Four of the BIM design applications and their associated set of products currently dominate the UK BIM market. The market shares of the BIM vendors as reported by National BIM Report (2012) are Autodesk Revit (55%), Nemetschek Vectorwork (15%), Graphisoft ArchiCAD (15%) and Bentley Microstation / building suite (15%). Each of the vendors have marketed multiple BIM tools that address different niches of the industry, including design,

engineering, clash detection and resolution, cost estimation, planning and scheduling and energy analysis. This is shown in Table 2.3.

Table 2.3 UK most popular BIM platforms

Popular BIM platforms	Associated applications	Market share
Autodesk Revit	Revit MEP; Revit Structure; Revit Architecture; Civil 3D; Ecotect; EnergyPlus; Green Building Studio; 3D Max; Autodesk FMDesktop; QTO	55%
Bentley systems	Bentley PowerCivil; GEOPAK Civil Engineering Suite; RAM Structural System; RAM Concept; ConstructSim; STAAD.Pro; Tas Simulator; Hevacomp Dynamic Simulation and Mechanical Designer	15%
ArchiCAD	It contains extensive object libraries for users and a rich suite of supporting applications in design, building systems and facility management, including precast concrete, masonry, metals, wood, thermal and moisture protection, plumbing, HVAC, and electrical systems.	15%
Vectorwork	Architect; Designer; Landmark; Machine Designer; Spotlight; and Rendering	15%
Tekla structures	Steel, precast concrete, timber, reinforced concrete, and structural engineering	Not applicable

Adapted from (Eastman et al., 2011; National BIM Report, 2012)

Autodesk Revit currently dominates the UK market with over half the market share. Autodesk has the largest set of associated applications with integrated product suites that provide BIM solution for different professionals’ requirements (Eastman et al., 2011). This perhaps contributes to why Revit is the current BIM market leader. Revit has the largest set of associated applications. Bentley has a wide range of related products for architecture, engineering, infrastructure, and construction. It is however, a major player in the civil engineering and infrastructure marketplace. ArchiCAD is well known for supporting the generation of custom parametric objects through its Geometric Description Language (GDL). It contains extensive object libraries for users, including precast concrete, masonry, metals, wood, thermal and moisture protection, plumbing, HVAC, and electrical systems. Vectorworks has continually underscored stronger customer support and a strong worldwide user base, targeting smaller firms. Vectorworks’ Marine Division is a major player in CNC (computer numerically controlled) cutting forms for shipbuilding. However, its construction portfolio provides a wide variety of BIM tools, which are organised as separate products but

packaged together as proprietary BIM suite. Tekla has multiple divisions including building and construction, infrastructure and energy. Although it has different BIM applications, Tekla structures is one of the widely used steel detailing applications because it has the ability to model structures that incorporate a wide range of structural materials and detailing. It also provides the functionality needed for CNC automated fabrication.

There are two main approaches of utilising the different technological platforms for the delivery of construction projects (e.g., Eastman et al., 2011):

- Using one software vendor's proprietary BIM products by all members of a project team;
- Using openBIM products from different software vendors

The first option may allow easier integration of the different products through proprietary interface since the products are from the same vendor. However, the main challenge with this option is with regards to a typical project team configuration. Construction consists of multiple specialised activities thus a typical construction project in some sense, is expected to integrate different BIM applications for professionals' uses. A single vendor may not have BIM tools that are sufficiently embedded with all the base objects for the manifold users. In planning and developing BIM within a construction context therefore, most projects may require multiple platforms for different uses, depending on the task-specific requirements. The second option thus, could meet the needs of wider BIM users. However, the selected BIM platforms ought to be compliant with publicly-supported data exchange standards such as IFC. The industry-neutral data exchange formats provide mechanisms for interoperability amongst different BIM platforms by allowing objects from one BIM application to be exported from or imported into another BIM application.

2.7 BIM Innovation Process Solutions

There are a variety of mechanisms and instruments for supporting BIM implementation process. However, these are developed to address different aspects of the implementation process. Rarely do any of the different approaches adequately address the complete phases of the BIM implementation efforts. But the combined analysis of these research efforts may help unravel the BIM implementation jigsaws. The ICCI (2004) have for instance suggested four critical conditions for the fulfilment of innovation process solutions in organisational contexts. This is summarised in Table 2.4.

Table 2.4 Criteria for BIM innovation process solutions in construction organisations

Performance driven	Systematic compliance to technical solutions of whole life functional & performance requirements using standard innovation product and process
Knowledge sharing	Enhanced and systematic reliance on experience and best practice from projects and product life cycle performance within and increasingly also between construction organisations.
Collaboration	Distributed virtual teams combine best competences regardless of organisational or geographic boundaries
Procurement and contractual obligations	BIM platform as the pervasive media for communication, coordination and collaboration between individuals and construction organisations fully supported by the collaborative legal and contractual frameworks.
Service orientation	Offering of holistic solutions to clients' needs that combines knowledge-intensive services with products solutions
Total lifecycle	Business processes and supporting systems becoming more focused on total project lifecycle from design through manufacturing, site construction and facilities management

Source (ICCI 2004)

There have been recent research publications and innovation process frameworks, which are developed to, and can help in, addressing different aspects of BIM implementation. These are categorised in the sections that follow as: eLSEwise; BIM capability maturity models (BCMM); strategies and action plans for implementing BIM; BIM data sharing protocols; organisational structures concomitant to BIM uptake; and BIM contractual and procurement strategies. Incorporating these requirements at both corporate and project levels may help in the overall improvement in the BIM project delivery processes.

2.7.1 eLSEwise

The eLSEwise project (EU) focuses on the future needs and opportunities for Research and Technology Development (RTD) of the construction industry. The European Large Scale Engineering wide integration support effort (eLSEwise) project was carried out in the years 1996–1998 (eLSEwise Consortium, 1998) but the work is still relevant for the emergent BIM implementation trend. It focuses on end users' needs, in this case within the large scale

engineering context, and has a bias towards building and civil engineering construction. An illustration of the eLSEwise Virtual Enterprise concept is shown in Figure 2.2.

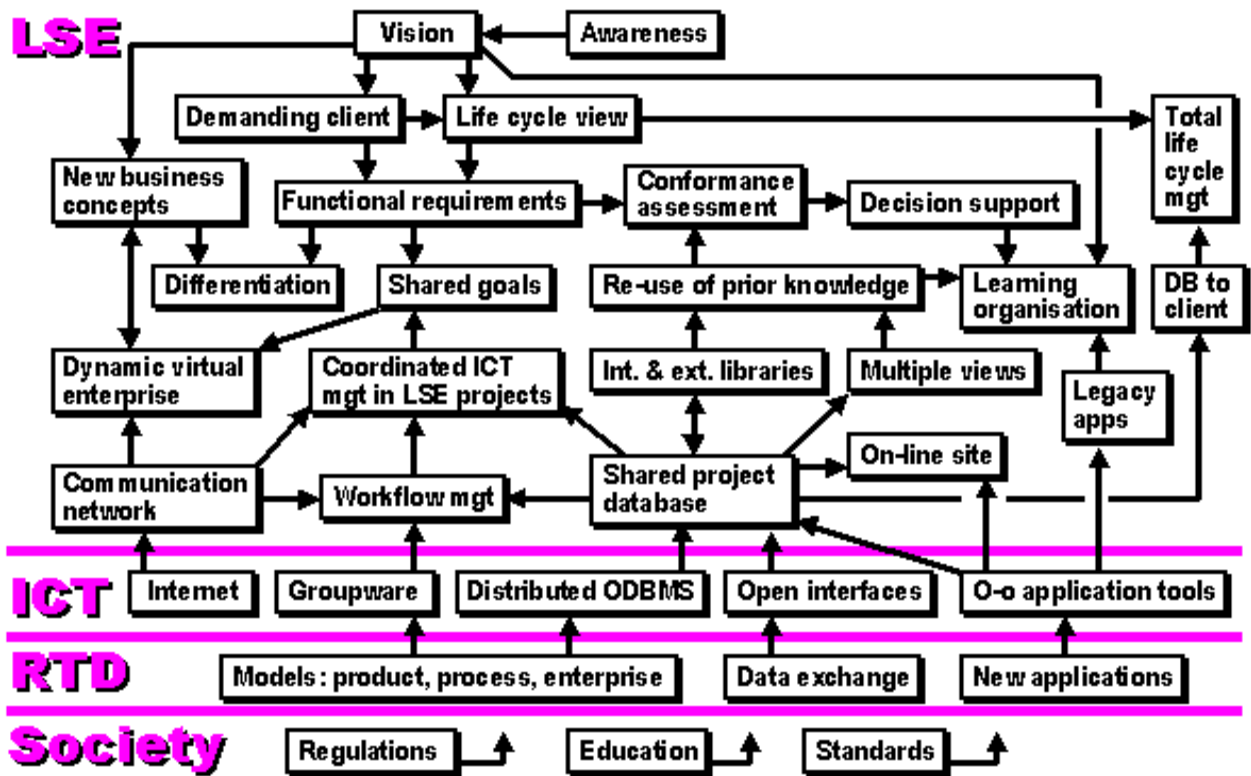


Figure 2.2 Illustration of the eLSEwise virtual enterprise solution (eLSEwise, 1998)

The predominant theme in the eLSEwise vision is the concept of the Virtual Enterprise: an organisation of multiple participants of different companies, at different geographic locations, communicating with each other through advanced IT networks. More importantly, it is directed at understanding the information flows within and then defining the information technology and product data technology needs of the industry. The concept is also designed to support the implementation of new technologies which is most relevant and promote the business benefits that will arise from the effective deployment into organisations. Although the eLSEwise project takes a business-led approach to formalising generic view and model of how AEC sector can deploy product data technology across project lifecycles, it has rarely been pursued further, thus not empirically explored for validation and furtherance.

2.7.2 BIM Capability Maturity Models

Researchers have devised BIM maturity capability models to clearly articulate the levels of competences and standards of expectations and how they can be applied to projects. In

general, the progression from low to higher levels of maturity indicates 1) better predictability and forecasting by lowering variability in competence, performance and costs; and 2) greater effectiveness in reaching defined BIM goals at one level and setting new more ambitious goals at another level (e.g., Succar, 2010). Among these capability models are Richards' (2010) BIM Maturity Diagram model, Succar's (2009) BIM capability stages and the National BIM Standard (NBIMS 2007) Capability Maturity Model (CMM).

2.7.2.1 BIM Maturity Diagram Model

In 2008, Mark Bew of BuildingSmart and Mervyn Richards of Construction Product Information Committee (CPIC) developed the BIM Maturity Diagram model, (Richards, 2010), which is now a well-known diagram. This is shown in Figure 2.3. It acknowledges the impact of both data and process management of BIM and defines four different levels of maturity for BIM, from level zero to level three.

The essence of defining the levels from 0 to 3 is to categorise types of technical and collaborative working to enable a concise description and understanding of the processes, tools and techniques to be used by BIM-enabled organisations. In essence, level 0 provides 2D unmanaged CAD with electronic paper as the likely data exchange format. Level 1 provides 2D or 3D managed CAD format using BS 1192 collaborative methodology to provide a common data environment (CDE) and possibly some standard data structures and formats.

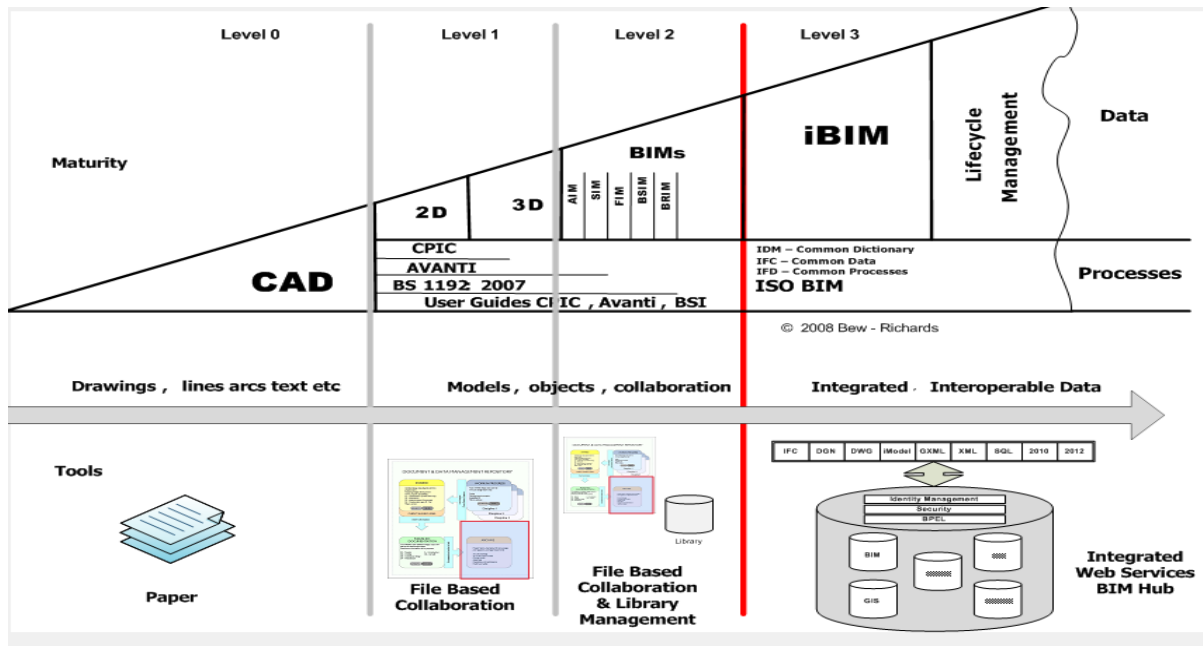


Figure 2.3 BIM Maturity Diagram Model (Richards, 2010)

Data is however, managed by standalone standards and applications with no integration. Level 2 BIM provides information in a 3D format, with the various members of the project team creating and maintaining their own individual models. These federated models are interoperable, or are integrated on the basis of proprietary interfaces. Level 2 may also utilise 4D programme data and 5D cost element.

The level 3 on the other hand, utilises a composite model repository, accessible by all the participating project team members. It is an open process and data integration is enabled by web services compliant with existing and emerging IFC standards, managed by a collaborative model server. Level 3 has also been regarded as “iBIM” or integrated BIM, potentially employing concurrent engineering processes.

2.7.2.2 BIM Capability Stages

There is also a BIM capability stage developed by Succar (2009). It defines the minimum BIM requirements or the major milestone that need to be reached by organisations as they implement BIM technologies and concepts. There are 5 BIM stages as shown in Figure 2.4. The starting point represents the pre-BIM stage, and it identifies with the status of the industry prior to the emergence of the BIM concept. According to Succar (2010) BIM stages 1 to 3 are defined by their minimum requirements for BIM uptake. As an example, for

organisation to be at stage-1 (object-based modelling), it need to have BIM authoring software similar to Vectorworks, Bentley, ArchiCAD, or Revit. At this stage however, data exchange between project stakeholders is unidirectional and communications are asynchronous and disjointed.

At stage-2 (model-based collaboration), an organisation needs to operate BIM effectively on a multidisciplinary collaborative BIM project. At BIM capability stage-3, an organisation needs to be using a network-based repository platform to share object-based models. At this stage, interoperable data interchange across discipline is possible. The final stage (post-BIM) encompasses a variable ending point with ever evolving connotations, which deploys virtual-integrated Design, Construction and Operation (viDCO) tools and concepts (Succar, 2010).

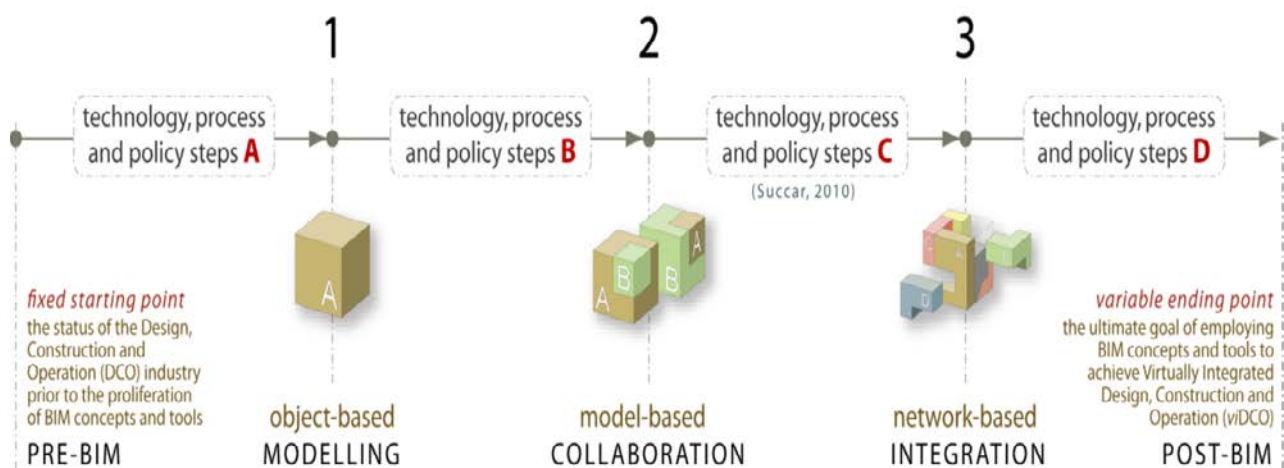


Figure 2.4 BIM capability1 stages (Succar, 2009)

At this stage, model deliverables extend beyond semantic object properties, incorporating all the design information required at each stage of the lifecycle of a facility to include business intelligence, green policies, whole lifecycle costing etc. each stage has different prerequisite for technological, process and policy structure. BIM capability stages cannot, however, detect variations in level of experience and modelling quality between two organisations that are both at the same BIM stage.

2.7.2.3 The NBIMS Capability Maturity Model

The Capability Maturity Model (CMM) of the National Building Information Modelling Standard (NBIMS) is a step towards establishing BIM implementation benchmarks (Smith & Tardif, 2012). NBIMS CMM is designed to measure the “maturity” of a BIM solution and the process used to create it, and it is the most commonly used assessment tool in the USA

(Sebastian & van Berlo, 2010). It was originally developed in 1986 by the Carnegie Mellon Software Engineering Institute (SEI), a R&D centre, as a compendium of principles and practices for assessing the ability of contractors to perform contracted technological innovation projects (Smith & Tardiff, 2012).

The CMM concept has since been further developed by NBIMS and is being applied to the BIM implementation process. It is a matrix that identifies eleven categories of maturity, represented on the y-axis, each of which can be scored on a scale of one to ten levels of maturity, represented on the x-axis with level 10 being the most matured (see table 2.5). The NBIMS testing team conducted a test of the CMM by evaluating the BIM maturity of the 2007 American Institute of Architects (AIA). The test was to measure the variance in scores between individual evaluators independently scoring each other. The degree of variance could be an indicator of how consistently the CMM rating scale would be applied to the same project by different evaluators, and thus, a measure of how useful the CMM could be to the AEC industry as an objective measure of BIM maturity. From the result, the variance in score did not exceed 5 percent in any instance and frequently varied between one and two per cent. Refinements were made to the NBIMS CMM as a result of the test, and this is presented in table 2.5

NBIMS CMM is a tool for BIM users to evaluate their practices and processes. It can also be used for portfolio-wide analysis to establish an organisation's current strategic or operational BIM implementation. In addition, it can be used to set goals to achieve greater information maturity for future BIM projects. However, there are also some limitations associated to the use of NBIMS CMM. It is an internal tool to determine the level of maturity per organisation as measured against the set of pre-defined weighted criteria (table 2.5). CMM is not intended to be used to compare or to measure different BIM users at the same footings or at different stages, but to measure the maturity level of organisations (Sebastian & van Berlo, 2010).

The BIM maturity models including the NBIMS (2007) CMM and Succar's (2009) 5-BIM capability stages as discussed are examples of how BIM is anticipated to drive construction improvement in quality and efficiency and also, bringing about wholesale process changes for the different phases of a project lifecycle. These capability models recognise that different construction clients and their supply organisations are currently at different level of experience with their approaches to BIM and serves as a structured 'learning' progression over a period of time. Without BIM standards and benchmarks, organisations may not be able

to assess their BIM competences, and also to measure their successes or failures, these capability levels are therefore a prerequisite for BIM performance improvement.

Table 2.5 NBIMS BIM capability maturity model (CMM)

Categories	Summary description	Maturity levels									
		1	2	3	4	5	6	7	8	9	10
Data richness	Degree to which BIM encompasses the available information about a facility	Basic Core Data	Expanded Data Set	Enhanced Data Set	Data Plus Some Information	Data Plus Expanded Information	Data w/Limited Authoritative Information	Data w/Mostly Authoritative Information	Complete Authoritative Information	Limited Knowledge Management	Full Knowledge Management
Life Cycle Views	Degree by which BIM can be used appropriately throughout the building lifecycle to reflect each task	No Complete Project Phase	Planning & Design	Add Construction/ Supply	Includes Construction / Supply	Includes Constr/ Supply & Fabrication	Add Limited Operations & Warranty	Includes Operations & Warranty	Add Financial	Full Facility Cycle Collection	Supports External Efforts
Roles or Disciplines	Number of roles that are accommodated in the modelling platform, and thus, shows how BIM can flow from one discipline to another	No Single Role Fully Supported	Only One Role Supported	Two Roles Partially Supported	Two Roles Fully Supported	Partial Plan, Design, & Contr Supported	Plan, Design, & Construction Supported	Partial Ops & Sustainment Supported	Operations & Sustainment Supported	All Facility Lifecycle Roles Supported	Internal & External Roles Supported
Change Management (CM)	Degree to which documented business process (BP) change has been developed	No CM Capability	Aware of CM	Aware of CM & Root Cause Analysis (RCA)	Aware CM, RCA & Feedback	Implementing CM	Initial CM Process Implemented	CM Process in place & early Implementation of RCA	CM & RCA Capability implemented	BP are sustained by CM & RCA & Feedback loops	BP are Routinely Sustained by CM, RCA & Feedback Loops
Business Process (BP)	Degree to which business processes are designed and implemented to routinely capture BIM information	Separated Process Not Integrated	Few BP Collect Info	Some BP Collect Info	Most BP Collect Info	All BP Collect Info	Few BP Collect & Maintain Info	Some BP Collect & Maintain Info	All BP Collect & Maintain Info	Some BP Collect & Maint in Real Time	All BP Collect & Maint in Real Time
Timeliness / Response	Degree to which complete	Most Response	Most Response	Data Calls Not in	Limited Response	Most Response	All Response	All Response	Limited Real-Time	Full Real-Time Access	Real Time Access w/

	information is accessible to users through project lifecycle	Info Manually re-collected-Slow	Info Manually re-collected	BIM But Most Other Data Is	Info Available in BIM	Info Available in BIM	Info Available in BIM	Info From BIM & Timely	Access From BIM	From BIM	Live Feeds
Delivery method	Robustness of the IT platform to support data exchange and information assurance	Single Point Access No Information Assurance (IA)	Single Point Access w/Limited IA	Network Access w/Basic IA	Network Access w/Full IA	Limited Web Enabled Services	Full Web Enabled Services	Full Web Enabled Services W/IA	Web Enabled Services-Secure	Netcentric Service Oriented Architecture (SOA) Based w/Common Access Card (CAC) Access	Netcentric SOA Role Based CAC
Graphical Information	Degree of embodied intelligence of graphical information	Primarily Text & No Technical Graphics	2D Non-intelligent As designed	National CAD Standard NCS 2D Non-intelligent As designed	NCS 2D Intelligent as designed	NCS 2D Intelligent As-Built	NCS 2D Intelligent & Current	3D intelligent Graphics	3D Current and Intelligent	4D Add Time	nD- Time & Cost
Spatial Capability	Degree to which BIM is spatially located in the real world according to GIS standard	Not Spatially Located	Basic Spatial Location	Spatially Located	Located w/ Limited Info Sharing	Spatially Located w/Metadata	Spatially Located w/Full Info Sharing	Part of a Limited GIS	Part of a more complete GIS	Integrated into a complete GIS	Integrated into GIS w/Full info Flow
Information Accuracy	Degree to which information reflects real-world condition	No Ground Truth	Initial Ground Truth	Limited Ground Truth – Int Spaces	Full Ground Truth – Int Spaces	Limited Ground Truth – Int & Ext	Full Ground Truth – Int & Ext	Limited Comp Areas & Ground Truth	Full Computed Areas & Ground Truth	Comp GT w/Limited Metrics	Computed Ground Truth w/full Metrics
Interoperability/ IFC support	Degree to which data is reliably exchanged using IFC	No Interoperability	Forced Interoperability	Limited Interoperability	Limited Info Transfer between COT Software	Most Info Transfers between COT	Full Info Transfers between COT	Limited Info Uses IFC's for Interoperability	Expanded Info Uses IFC's for Interoperability	Most Info Uses IFC's for Interoperability	All Info Uses IFC's for Interoperability

Source: National Institute of Building Science (NBIMS) (2007)

The downside of the BIM maturity models is that, they are rather more descriptive than the sort of coherent implementation approaches needed to deal with the overreaching organisational challenges as a result of introducing BIM. Unfortunately, there are several publications pointing out the inexpediciencies relating to the use of technologies in organisations (e.g., Azhar, 2011; Ehie & Madsen, 2005; Weston, 2001). Thus, while it is important to develop maturity diagrams and stages of BIM capabilities, it is equally important to establish implementation processes consistent with maturity stages and adaptable by different organisational sizes. This is vital to laying the foundation for organisations to develop their BIM competency.

2.7.3 Strategy and Action Plan for Implementing BIM

Moving forward towards BIM implementation efforts, construction organisations can get caught up by ill-defined or misinterpreted deliverables. To counter this dilemma, construction organisations that are implementing BIM, currently find themselves working with a new type of document, the “project execution plan”, which contains strategies and action plans to complement the BIM implementation efforts (The CIC Research, 2012; Holzer, 2007).

In addition to providing a procedural guideline for responsibilities and accountabilities, the plans also include specific role descriptions and duties for the various practitioners based on the specific intents of BIM deliverables. The BIM action plan provides opportunity for the implementing organisations to understand, define, and communicate their goals and procedures for the integration of BIM within organisations. Holzer (2007) has stated that it is valuable to consider how BIM will be incorporated into the organisational workflow. This implies that requirements for BIM including BIM Project Execution Planning, BIM uses, and information exchange should be written into the organisational BIM strategy. Lewis and Seibold (1998, p.101) define strategy as “the general thrust, direction, and focus of the activities that make up the implementation effort” and entails “the more specific actions, messages, and events constructed and carried out in service of some general goal”. The BIM strategy is created to maximise the potential of BIM and it comprises the assessment of the existing organisational conditions, alignment of BIM goals and vision, and the development of a transition plan towards a BIM-enabled organisation.

The computer integrated construction research group (The CIC Research, 2012) of the Penn State University has identified six common elements that should be considered when

developing action plan for BIM implementation. These include: strategy, uses, process, information, infrastructure and personnel. These are expounded below:

1. The *strategy* expands on the purpose of BIM implementation and it encompasses the mission, vision, goals and objectives along with management support, BIM champion and BIM planning committee.
2. The *uses* elaborates on the specific method of implementing BIM for each particular organisation and includes the creation, processing, communicating, integrating and managing the model information
3. The *process* highlights the means by which the BIM workflows (uses) are accomplished including understanding current processes, designing new BIM processes and developing transition processes
4. The *information* focuses on the informational needs of the organisation including the model element breakdown, level of development and project data.
5. The *infrastructure* looks into the resources needed to support BIM implementation including software, hardware and workspaces
6. The *Personnel* concentrates on the effects of BIM on the professional workforce including the roles, and responsibilities, the structure or hierarchy, the education and training programmes and change readiness.

The implementation strategy process requires organisations to provide information regarding their standard practices by defining their standard goals, uses, processes, and information exchanges. The goal of this procedure is to have the team develop a BIM action plan containing deliverables that will be beneficial to all members involved. More importantly,, the content of the CIC research (2012) BIM execution planning guide extends beyond the organisational level to the project and the operational phases of a facility where the strategy for maximising the value of BIM is realised.

2.7.4 BIM Data Management Protocols

It is clear that as new technologies and collaborative techniques come to the marketplace and into practices, even more clear guidance needs to be made available. The BIM data management process provides a practical view of the steps that need to be taken to facilitate effective BIM working among varying construction disciplines. Two critical facets of the BIM data management techniques include: 1) common data environment (CDE) approach compliant to BS1192:2007, (AEC UK, 2010); and 2) construction, operation and building

information exchange (Cobie) format. Both approaches document BIM data and process management issues, and thus, it is anticipated that existing classification and delivery schemes such as the RIBA plan of work may become compliant with these standards.

2.7.4.1 Common Data Environment (CDE)

The Common Data Environment (CDE) approach aligns with BS1192:2007 Collaborative Working, which defines the process for project collaboration and efficient data sharing. A major constituent of collaborative environments is the ability to communicate, re-use and share data efficiently without loss or misinterpretation (AEC UK, 2010). The CDE thus allows information to be shared between all members of the project team. As defined in the BS1192:2007, information within a model is interdependent and changes in one view may affect other views, as such, the BIM files and all associated views are treated as work-in-progress or shared as uncontrolled documents until such time as they leave the BIM environment in a non-editable format (Richards, 2010). Multiple users should be able to simultaneously work on a model file through the use of a *central repository* and synchronised *local copies*. The BIM project information exchange protocol (Figure 2.5) is thus held in a network server and multi-user access to BIM project data is through controlled access.

To facilitate coordinated, efficient working, each party is required to make their design data available for project-wide formal access through the shared repository or exchange protocol. The model data is expected to be accessible by all from a central location, or replicated in the *shared area* of the project folder of each party under the CDE protocol. Prior to sharing, the information model is checked, approved and validated as fit for coordination in line with the BS1197 workflow. Validated models are transferred to the shared area in order that other disciplines can work to the latest validated information as defined in the project BIM strategy document. Validation of the BIM data prior to sharing is checked to ensure that: Model file has been audited, purged and naming conventions and data segregation conforms to the agreed project protocols prior to issue.

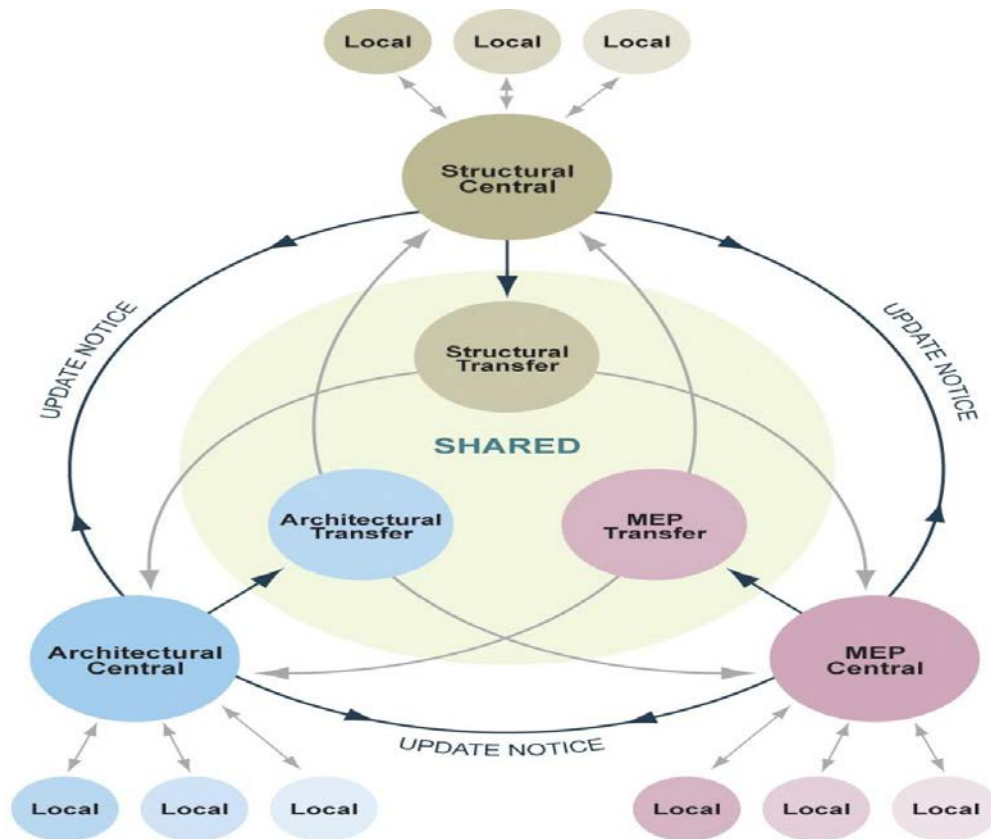


Figure 2.5 BIM project information exchange protocol (AEC (UK) BIM Standard, 2010)

The *shared area* also acts as the repository for formally issued data provided by external organisations that are to be shared across the project organisations. Changes to the shared data are effectively communicated to the team through drawing issue change register or other suitable communication means, such as e-mail, or as defined in the Project BIM Strategy document. Other project team members should be able to obtain shareable intelligent data information via interoperable means from the shared repository to assist in preparing and issuing other accurate project information such as pricing, programming, engineering/energy analysis, material schedule, off-site prefabrication schedule etcetera.

2.7.4.2 The COBie Format

The Construction, Operations Building Information Exchange (COBie) format provides a consistent structure (in terms of quality and quantity) to the supply chain to deliver project information at key stages of the design and construction to support decision-making by the client through the operation and maintenance phase of the asset (e.g., East & Nisbet, 2012). Traditionally, O&M information is provided in an ad hoc structure at the end of construction. COBie outlines a standard method for collecting the needed information throughout the

design and construction processes, as part of the deliverable package to the owner during commissioning and handover (Eastman et al., 2011). One of the key requirements of the UK BIM task group report (2011) is the use of COBie as the main data delivery schema for robust information organisation for facility management at BIM maturity level-2. COBie ensures that the client as owner, operator and occupier receives the information about the facility in as complete and as useful form as possible. Overall COBie provides traceability and visibility of the design and construction information to the client. The information in the COBie format has to be useful to the owner-operator for post-occupancy decision-making, thereby, effectively insulating the client from process complexity, technology change, and competitive issues-which often remain in the supply chain.

COBie can be captured using direct entry into spreadsheet, often, using cut-and-paste from existing schedules and documents. It documents the facility into levels, spaces and zones that make up the function of the facility. These are then filled with the actual manageable systems and assets and details of their product types. During the construction and installation these are amplified with information about the spares, warranties and maintenance requirements. Throughout the process, additional attributes, issues and documents associated to the facility can be linked to the various items of the COBie platform (McAuley et al 2013).

The vision for the delivery of COBie information is to be a fully web enabled transparent scenario based on the Building Smart IFC standard (Sabol, 2008). The BIM vendors have started developing automated standards capable of supporting the creation of COBie dataset to gather project information. A typical example is the BIM 360 field mobile application developed by Autodesk (Autodesk, 2013). The BIM 360 field is a field mobility tool that is designed to enable field level access to information and to collaborate on issues, inspections, equipment, and tasks to be performed, which ultimately, can be assessed by the client. Figure 2.6 shows a screen shot of the BIM 360 Field Mobile Application on the iPad highlighting the areas of the project the application addresses. The application is downloadable from Autodesk website unto an iPad, and it can be used via a WI FI signal or an iPad with 3G capability.

Some of the BIM vendors' FM (facilities management) applications have capabilities beyond the COBie concepts (McAuley et al., 2013). For example, they can be used to upload any information that has been captured in the field to the project database. The applications have tools functionalities such as a field Notebook and a Barcode Scanner. The Barcode Scanner in the BIM 350 field, for example, can be used by field users to scan installed equipment

using the iPad camera, and, as long as the barcodes in the application has been configured, the related details of the model will automatically open.

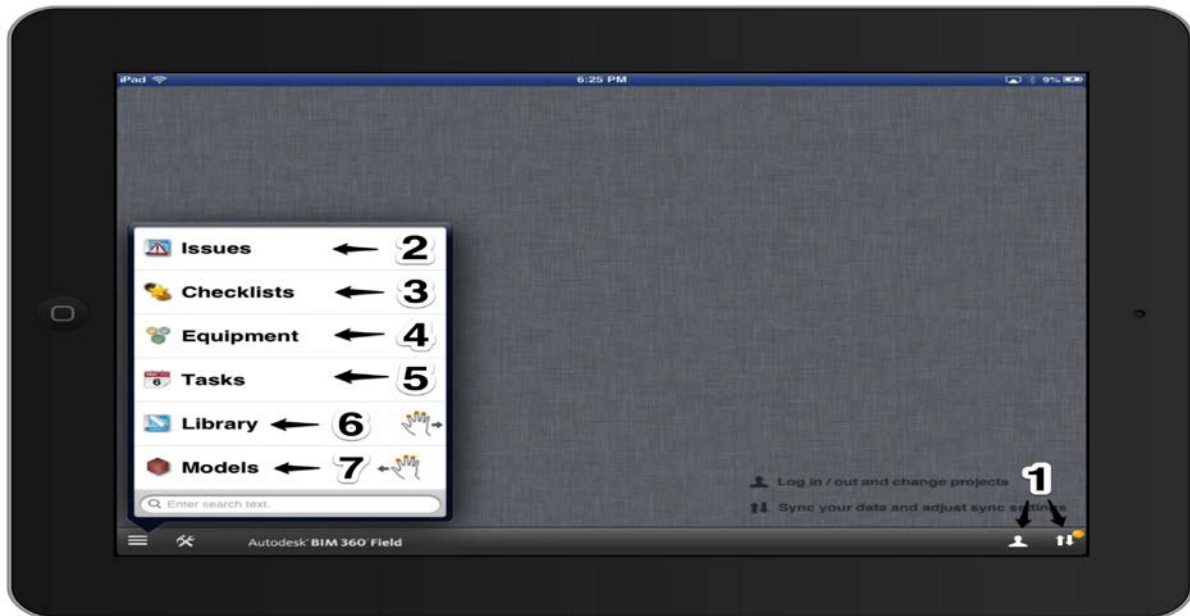


Figure 2.6 A Screen shot of the BIM 360 field mobile application on an iPad

The COBie format improves data exchange between clients and supply chain in three facets: firstly, the format improves the process by which information is requested and exchanged between supply chain and clients; secondly, it enhances the quality and scope of information delivered by projects' supply chain which can be used by parties including the client as a primary document for managing the asset; and thirdly, the format demands more from the supply chain in both information quantity (different phases) in its usefulness and accessibility and delivery mechanism (digital data in a pre-defined format) (e.g., East & Nisbet, 2012; Sabol, 2008).

Both the CDE and COBie can deliberately overlap to ensure there is consistent BIM data management strategy in place that covers the whole project lifecycle as the former assist the project team to manage the BIM project delivery during design and construction, whilst the latter assists the owner to effectively manage the project maintenance and operations.

2.8 Organisational Structures for BIM in Construction

Structure has come to signify the patterned relations of components which make up any system. It is a framework on which different interconnected components are attached, thus it is inevitable to alter an organisational structure without affecting the organisation (Fineman et al., 2009). There are a number of ways of deploying relationships (communication and

authority) that make up an organisational structure; some are structured in *geographical* or *product-based* divisions, others in *functional* areas (such as marketing, finance, technical, customer relations etc.) and yet others form *matrix* structures (Jones et al., 2003; Bryman, 1986; Woodward, 1965).

In a functional organisation structure, tasks are linked together on the basis of common functions. Thus all production and/or financial activities are grouped together in a single function which undertakes all the tasks required of that function. This approach is mainly suited to relatively stable environments (Jones et al., 2003; Green 2011). The product-based is a popular structural form in large organisations having a wide range of products or services; thereby allowing key groups of service providers to be dispersed according to the service they provide (Fineman et al., 2009). The geographical structure is mainly adopted where the realities of a national or international network of activities make the kind of regional structure essential for decision-making and control (Dong, 1995). The matrix structure combines the benefits of two or more of functional, product and geographical forms of organisation (Jones et al., 2003). This has come about as a result of coordination problems in highly complex industries, where the other structures have not been able to meet organisational demands for a variety of key activities and relationships arising from the required work processes (Cole, 2004).

A structure which may serve one organisation well may turn into a recipe for disaster when forced on another (Anumba et al., 2002). Contingency theories argue that no single structure is effective in all circumstances, but that the organisational structure is contingent on the organisational and situational context (Bryman, 1986; Woodward, 1965). Some organisations have rigid mechanical structures dominated by formal roles, rules and regulations, while others have more informal and flexible structures in which people collaborate and communicate in less highly controlled manner. It has been suggested that, organisations operating in particularly uncertain and turbulent environments must adopt an extremely fluid task-oriented structure (e.g., Jones et al., 2003).

The essence of BIM is integration and teamwork that combine technological solution, skills and knowledge to design, construct, and operate facilities. This highlights the important relationship between the BIM concept and organisational structure. In order to facilitate BIM project delivery, the traditional hierarchical and functional structures have to be overshadowed by more flatter, cross-functional ones for the purpose of enhancing communication and integration (Nicholas, 1994).

Several innovative techniques have been observed to enhance communication, increase teamwork and build trust, such as key project personnel from a broad spectrum of disciplines all agreeing to physically relocate into the same project office suite (Evans, 2004). Collocated teams, who have no allegiance to their functional departments and are totally committed to the project help to overcome many of the potential team problems (Prasad, 1998; Dong, 1995). Hence flexible versions of organisational structure in which each element in a hierarchy is connected to every other element immediately above and/or below it, might be more appropriate for BIM workflow as they provide greater flexibility and improved communication (e.g., Anumba et al., 2002).

It is also recommended that the appropriateness of any proposed BIM organisational structure needs to be complemented by collaborative BIM technological tools and related innovation process – a repository for composite model creation, coordination and information sharing, by all team members and is based on the project activities. Such work structure, aids inter alia, in communication, decision making, detailed design coordination, and functionality assessment (Dong, 1995; Anumba et al., 2002).

Thus, when the contingency factors that affect organisational structures are taken into consideration, then the matrix structure, which combines functional structure at the corporate level and a cross-cutting multi-functional team structure at the project level may seem to be more suitable for BIM workflow in the construction context. This is because the matrix structure has the dual benefits of a high level of technical expertise created by the functional structures, and flexibility and teamwork, which enable the achievement of both group and organisational goals. Also, a less rigid functional structure that supports a team working at the project level may also be necessary to maintain a high level of specialisation which is often necessary for problem solving in the construction context.

2.9 Legal and Contractual Obligations Associated with BIM Implementation

For BIM to reach its perceived potential, it is necessary for the project participants to work in a collaborative manner, openly working together and sharing information. Due to legal and situational restrictions, it is often necessary to procure projects using differing contracting approaches, organisational structures and selection methods. These different procurement mechanisms may either restrict collaborative relationships, thus limiting BIM capabilities or enhance collaboration and thus augment the successful implementation of BIM.

Contractual issues have the potential to act as a source of inertia holding back BIM implementation on projects. As the effort to introduce BIM into the construction processes continue to unfold, answers to pertinent questions are being explored, such as; how could the risk and liability associated to BIM be apportioned or allocated? For instance, these concerns have been echoed by (Singh et al., 2011; McAdam, 2010; Sieminski, 2007). The legitimate contractual and legal challenges that have been raised, which are of concern to organisations intending to implement BIM could be grouped into categories such as risk allocation; confidentiality; ownership of the model; and contractual status.

Risk and liability: BIM-enabled project comes with added complications. For example, in addition to design errors, there is the possibility of software errors. These could range from simple loss or corruption of data to unwanted additional data that may have been unintentionally imported into object properties. The BIM model is used as a shared entity involving contributions from designers, consultants, clients, specialist subcontractors, and component manufacturers. The allocation of liability between the contributors becomes an issue. This is because, traditionally, professional indemnity (PI) insurance is based on the individual professional practice as opposed to a collective integrated effort. Demarcation between individual responsibilities will be difficult. Also, a fully integrated BIM model would cause difficulty for insurance purposes (Greenwood et al., 2010). As noted by McAdam (2010), regarding the use of BIM, the industry has to figure out the relationship between the bipartite requisite of contracts with the multiparty requirement of collaborative BIM process.

Ownership of model information: Ordinarily, a design has remained the property of the designer who takes the risks and benefits associated with the design during and after the completion of a project. Now, BIM requires the multidiscipline team to integrate the project information into one BIM database for easy access to the project stakeholders. Given that the model is an integration of different pieces of information made up of a contribution from the multidisciplinary project actors, ownership cannot be vested in a particular party. To what extent then, can any of the contributors claim ownership of their contributions? Sebastian (2010) for example, argues that considering the model as a combined work, the intellectual property right (IPR) is similar to those of conventional teamwork. The IPR of each element thus rests with its creator. The challenge however is that, due to the large amount of information and complex work processes involved in the creation of a fully functional model-server, an automatic authorship registration function is needed to be able to keep track of the

IRP in BIM (Sebastian, 2010). As BIM contains information about the actors in the project teams and their contributions to the model, future exchange standards may have to be developed not only for contract definition of who-owes-what in the model but also for administrative purposes (Greenwood et al., 2010).

Others have also argued that the ownership of the final output of BIM belongs to the client rather than the individual designers (Bedrick, 2006). Olatunji and Sher (2010) reckoned that, such a position is aimed at fostering longer relationship between clients and project teams as extended duty of care occurs not only during construction but throughout the life of the model – which could extend beyond project life span. Meanwhile a clause in the AIA Document 202 BIM contract gives the parties the leeway to use the model as far as it is necessary for the design and construction of the project, however, for the sake of wider use of the model beyond the construction stages, e.g., for lifecycle purposes, a wider license could be separately agreed between the contributing parties and those keen on using the model for wider purposes (McAdam, 2010).

Confidentiality: BIM is used as a digital repository for integrated system where various stakeholders contribute and share data, simulate and visualise possible outcomes during design, embed virtual objects with robust information at different stages and deploy several instruments of collaboration to drive project goals (Li et al., 2008). To this, Olatunji & Sher (2010) added some facilitative attributes such as ability for multiple users to access project database and simultaneously interact on a virtual platform, thereby saving time and improving outcome through real time communication. Other studies have however mentioned how this phenomenon could negatively impact on information confidentiality. For example, virtual model of BIM exposure as internet-based concept comes with cyber security risks such as snooping, theft, virus and hacking (Olatunji & Sher, 2010). There are other issues such as exposure of trade information, copyright issues, and validity and unauthorised use of models. These issues could have devastating consequences to some of the project stakeholders, especially sharing knowledge openly and neutrally within the context of a ‘one-off’ project may prove disadvantageous for a stakeholder who will not be involved in the next project with the same project team (Sebastian, 2010). Indeed, these issues will have to be thoroughly clarified in BIM-based contractual structures prior to the start of a BIM project.

2.9.1 Limitations of the Existing Contractual Platforms

A standard contract document provides a useful point of reference to the construction practitioners and can acquire the status of managerial procedure manual guiding the various contributors through the project (Hughes & Greenwood, 1996). Some problems within the existing contractual frameworks have led to the issue of whether it is feasible to use those frameworks without any amendments or perhaps formulate more suitable contract instruments which align with the BIM concept.

Some of the concerns associated with the existing legal instruments in the industry have been underlined in e.g., (Campbell & Harris, 2005; Ghassemi & Becerik-Gerber, 2011; Latham, 1994; Zaghoul & Hartman, 2003). For example, Zaghoul and Hartman (2003) ascertained that present contractual relationships are mainly based on confrontational situations that reflect the level of trust (or mistrust) in the contract documents. They further advocated that trust actually determines the relationships among the contracting parties, and that trust relationship between the parties provides some opportunities for developing a better risk allocation mechanisms and contracting strategies in construction. Martin & Songer (2004) also made a similar assertion when they stated that the current contractual structure causes disputes and inefficiencies because it encourages each party to concern itself with its own interests rather than the interest of the project as a whole. Loosemore and Hughes (1998) also stressed further that traditional contracts are inflexible, restrictive and ineffective during construction disputes.

Kent & Becerik-Gerber (2010) found similar results. Identified in their study as “trust, respect and good working relationships...” (p.824), many of their respondents felt that collaborative relationship could not succeed without the presence of these interpersonal dynamics as a prerequisite. They also found that to foster collaboration, the construction industry as a whole, requires a broader cultural change among the participants.

It is however paradoxical to note that these conventional frameworks purported to be ‘unfriendly’ have remained relatively unchanged in the industry for many years. Mitchell & Trebes (2005) highlighted that construction organisations attempt to seek certainty in project outcomes by amending traditional contracts, creating their own be-spoke contract forms, thus allowing the use of older versions of traditional contracts. They further stressed that this situation permits a legacy of construction problems associated with traditional contract instruments to remain in the industry. Rooke, et al., (2004) also examined several insidious

practices embedded within the UK construction industry from the vantage point of organisational and integrated culture. They defined *culture* per Tylor (1913, p.2), in its wide ethnographic sense as “... *that complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits acquired by man as a member of society.*” The common practices under evaluation in their study included: exploiting mistakes in the bidding documents, scheduling work to maximise delay impact, and proactive/reactive claims. They argued that these manoeuvres harm the industry, deter competitiveness, and decrease efficiency. They also noted that these practices have become an integral part of the *culture* of the UK construction industry and cannot easily be changed by simply removing any economic incentives (or dis-incentives) that spawned their pervasiveness. This embedded cultural practice, perhaps, explains to a large extent why the ‘unfriendly’ contractual frameworks still perpetuates the industry.

Consequently, to drive forward the development of change being triggered by technological innovation such as BIM and new organisational processes and relationships associated with BIM; existing contractual instruments must be reformulated to align with the envisioned change. The effort towards change is not only about folding down space for adversarial contractual relationships; it is also about unfolding new forms of contracts to improve proactive opportunities, and transaction outcomes. This is emphasised by Latham (1994) when he advocated for new forms of collaborative contracts to improve upon the existing standards contracts by better flexibility, greater clarity and simplicity; and to provide a stimulus for good project management.

The fundamental differences between traditional delivery mechanisms (e.g., Lump Sum Design-Bid-Build (LS), Design-Build (DB) and Construction Management (CM)) and that of new collaborative structures are project team relationship and compensation structures (Lancaster & Tobin, 2010). Ghassemi & Becerik-Gerber (2011) also identified other characteristics that differentiate collaborative contracts from traditional delivery methods. These include:

- Early involvement of key stakeholders throughout the project;
- Roles and responsibilities clearly understood by everyone involved in the project with clear communication lines;
- An integrated project team consisting of client, designers, constructors and specialist suppliers, with input from facilities managers/operators;

- Jointly developed project goals / collaborative decision making; and
- An integrated process in which design, construction, and operation are considered as a whole.

Unlike traditional delivery methods, the collaborative contract frameworks are not yet widely accepted by industry practitioners. Collaborative contracting is not one specific form of contracting, instead, it is a term applied to a range of contracting strategies that work on the principle of collaboration and not on the principle of adversarial practices in project delivery. It is regarded as an approach that enables parties to work together in an open and non-adversarial legal and commercial framework (Bishop et al., 2009). As an 'umbrella' term it is congruous to relationship contracting, open-book contracting, integrated project delivery (IPD), partnering and alliancing and other terms which all link to the application of relationship principles or collaborative framework. Collaborative Contracts afford all parties involved with the prospect to work in a collaborative way, grounded on principles of trust and open communication. They also enable the flexibility and incentive to work together to deliver optimal commercial outcomes for all (McDermott et al., 2004). Collaborative principles, or relationship-based contracts as they are also known, foster a culture of equity, trust, respect, openness, and dispute avoidance.

2.9.2 Envisioned Contractual Structures for BIM-enabled Projects

Akin to the issues surrounding the existing contract forms, a perspective that was reported in Holzer (2007) and subsequently Olatunji & Sher (2010) suggested that BIM may not facilitate lasting solutions due to the limitations of conventional fragmented processes unless apparent issues and gaps in the legal framework surrounding the model are addressed. Greenwood et al (2010) stated that if the full potential of BIM is to be embraced on a project, this would have to be reflected in the form of contract used. Ghassemi & Becerik-Gerber (2011) also identified four major industry barriers to BIM implementation: legal (appropriate contract structures), financial (shared risk and reward), cultural (trust and teamwork), and technological (interoperability between participants). This implies that, where project participants are collaborating via BIM tools and processes to deliver a project, trust and transparency is vital.

Hatem (2008), mentions the use of Integrated Project Delivery (IPD) and its applicability to BIM procurement. IPD is defined by Hatem ((2008) as a form of procurement in which the main players, which at the very least will mean the employer, designer and main contractor,

all enter into a single contract to develop the design of the project, and to share the risk of defective design. IPD envisions a reconfiguration of the design process, shifting design decisions to earlier times in the process and redefining the industry accepted definitions. The Macleamy Curve (refer to Figure 2.7) visually represents this shift in timing and altered classification of design phases. It illustrates the concept of making design decisions earlier in the project when the opportunity to influence positive outcomes is maximised and the cost of changes minimised.

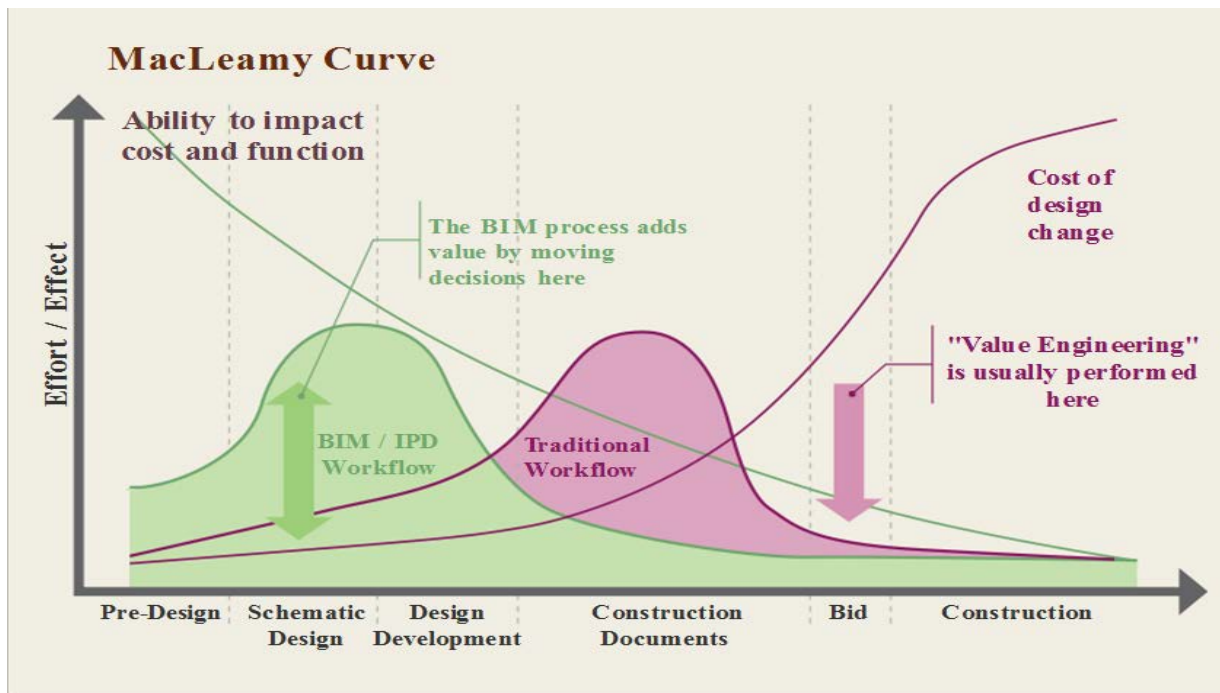


Figure 2.7 The MacLeamy curve (MacLeamy, 2004)

Ilozor & Kelly (2012) argue that the single most important change with IPD is the forward shift of work volume to earlier stages of design. The use of integrated project personnel, including the early incorporation of key subcontractors, IPD training for those new to the system, coupled with trust-building activities, appears to help overcome some of the limitations in the traditional standard forms of agreement.

Ashcroft (2008) also reckons that 'alliancing' may be an appropriate procurement model for BIM. According to McAdam (2010) alliancing is just another name for partnering. Partnering, or collaborative procurement such as the New Engineering Contract's NEC3 (Institute of Civil Engineering), (ICE, 2005). These are contract forms which promote working in a spirit of 'mutual trust and cooperation' (ICE, 2005, C1 10.1). McAdam (2010) opined that collaborative contract forms such as NEC3 endorses a number of features of procurement which echoes some of the contractual issues raised regarding the introduction of BIM. In

addition to the obvious technical and contractual concerns such as risk/reward, computer technology integration, and process integration, the AIA (2008) stresses the necessity of proper team formation, participant behaviour, team building, and communications as critical to BIM success.

Two other contract forms, JCT Construction Excellence and the Association of Consulting Architects' (ACA) PPC2000 have also been found to promote collaborative working and partnering just as NEC3 does (Howe & Dixon, 2006; McAdam, 2010; Saunders & Mosey, 2005). Whereas the Project Partnering Contract (PPC2000) promotes the use of a single contract for multiple parties similar to IPD form of contract, the JCT Construction Excellence are intended to be operated with project participants contracting on the same (or similar) form. These contract forms are based around early involvement of a wide range of participants (McAdam, 2010). They promote trust and cooperation working relationship leaving much of the detailed aspects of who should do what, to be individually negotiated, within the overall team framework (McAdam, 2010).

Other standard forms of agreement have been put forth by industry associations to facilitate the use of BIM: ConsensusDocs 300: Tri-Party Collaborative Agreement (AGC); Standard Form of Multi-Party Agreement for Integrated Project Delivery (AIA); and Standard Form Single Purpose Entity for IPD (AIA).

ConsensusDOC was intended to address many of the process and contractual issues arising out of BIM technology. The standard drafting was led by the BIM forum of AGC albeit with industry wide representation (Lowe & Muncey, 2009) and was intended to be incorporated in identical form into the contract(s) of all those who are to participate in the collaborative development of BIM in relation to a given project. Going further, DOC301 expressly takes precedence over any other contract terms if there is a conflict (McAdam, 2010). ConsensusDOCS regards the model as a contract document and the parties are entitled to rely upon the accuracy of information provided in the model. Each party also retains the copyright of its contribution to the model and agrees to the provision of a licence to the other parties to use its contribution for the purposes of the project.

Although it has been argued that collaborative procurement forms such as NEC3, JCT Construction excellence and PPC2000 may be appropriate contract model for BIM (McAdam, 2010; Saunders & Mosey, 2005), which is good for promoting cooperation or alignment of multiple actors from across different organisation. There appear to be nothing that

specifically addresses the issues associated with BIM processes within these contracts. Meanwhile, the use of BIM on projects requires for it to be stipulated as part of contract agreements. However, in the meantime, the emergent BIM contract forms such as the AIA and AGC initiated BIM contracts forms could provide an appropriate knowledge-base to help in the drafting of be-spoke contract strategies to address more pertinent issue that may arise in a BIM-based project. The anticipated issues could include; level of authorisation and access right in a BIM-based decision making; intellectual property (IPR) of the background information and knowledge; the legal status of the model; the formal roles and responsibilities of the contractual parties; the agreement of the payment features and schemes; and; dispute resolution using BIM for a quicker and more precise retrieval system of errors, liabilities, and for other circumstances.

2.10 Consolidation of BIM Innovation Product and Process Solutions into Comprehensive Implementation Framework

There is an obvious gap between the current AEC work practices and what BIM is purported to achieve as anticipated by the capability maturity models (e.g., NIBS, 2007; Succar, 2009; Richards, 2010). There seem to be no end to the journey as the capabilities of the BIM tools evolve in parallel with existing and emerging technologies. As such, Succar (2010) noted that, the final phases of BIM capability models exhibit mutable ending point with constant evolving inferences, which deploy virtual-integrated design, construction and operation (viDCO) tools and concepts. Within the immediate knowledge context, BIM advocates for a paradigm shift from drawing on two-dimensional media to modelling, which is akin to actual construction in a virtual environment (Eastman et al., 2011). Thus, it demands significant changes in the workflow and project delivery processes; requiring new set of tools, and skills, new ways of thinking and new approaches to intellection (Hardin, 2009).

Using the current construction practices as a benchmark (e.g., Sackey et al., 2013; Bevan, 2012) the transition to the existing BIM technological product and process solutions are highlighted in table 2.1. The Figure 2.8 is simply a combination of the current state and the available capabilities of the technologies and the knowledge and process requirements to ensure the manifestation of the technological capabilities.

Owing to the nature of the AEC practices, the uptake of BIM calls for collaborative contractual frameworks to integrate people and systems from the design phase, and multifunctional team structures at the project-level in order to work together to reduce waste

and optimise efficiency throughout all phases of the project lifecycle (Glick & Guggemos, 2009).

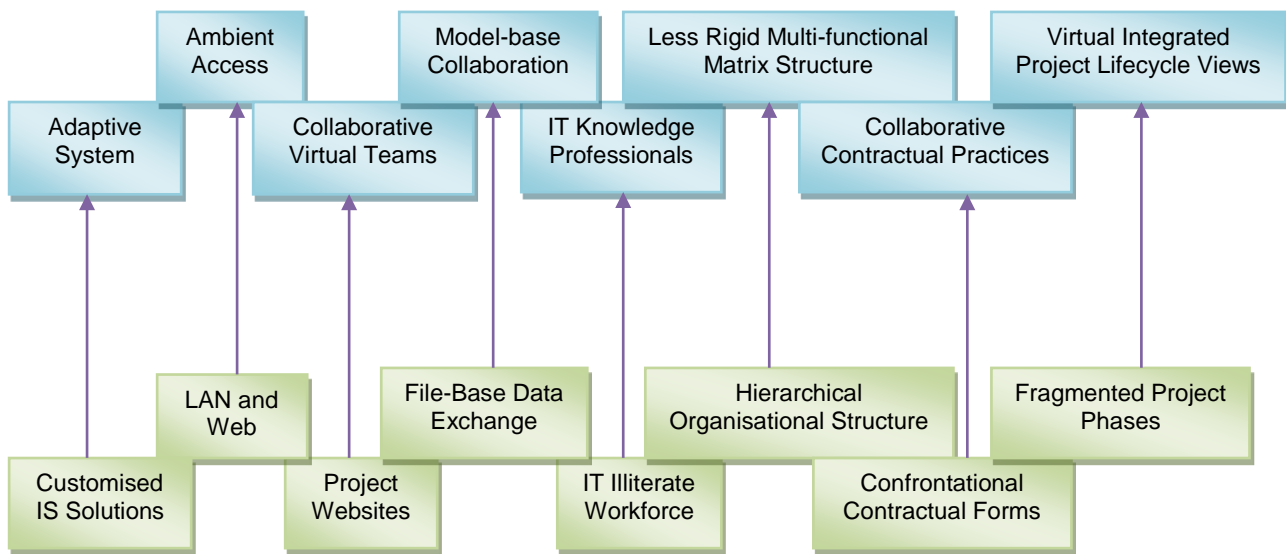


Figure 2.8 Evolving construction innovation product and process solutions

Yet, it is a challenge to establish effective collaboration among participants in AEC project teams (Korkmaz, et al., 2012). Figure 2.9 thus tries to synthesis the various facets of BIM implementation strategies from literature into a comprehensive BIM implementation requirement. At the core of the framework for BIM implementation requirements is the awareness of appropriate organisational configuration, contractual obligations, project-level collaboration and the requirements for the concomitant technological solutions. This might help in articulating the BIM process and product requirements at both the corporate and the project levels.

Popular theoretical frameworks have emphasised structural and contextual fits in the successful implementation of innovations in organisations (Slaughter, 1998; Poole, 2011). In a complex inter-organisational project context, especially, the manner of interactions between the inter-organisational team members and their respective corporate organisations constitutes “makes or breaks” project success (Korkmaz, et al., 2012; Morgeson et al., 2010). Klein & Knight (2005) have argued that many organisations fail to achieve the benefits of technological innovations at the implementation phase; this is because innovation implementation requires proper fits between the organisational and members’ values. Innovation is more likely to be implemented in the intended manner if actors have skills to master the innovation, have incentives to implement, and are beneficiaries of managements’ efforts to remove structural and procedural obstacles to implementation.

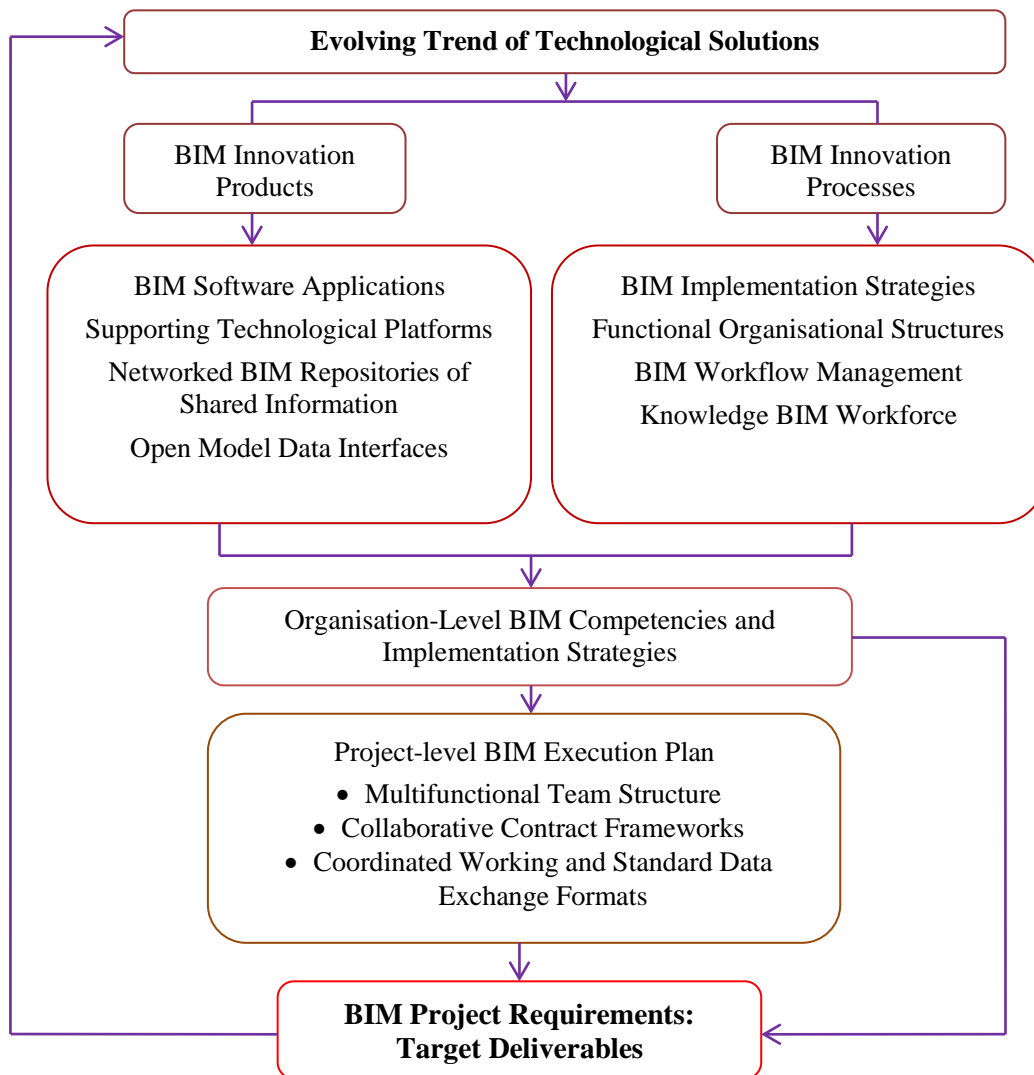


Figure 2.9 Framework of BIM innovation product and process requirements at the corporate and project levels

Nevertheless, effective functional structures alone are not sufficient for ensuring BIM project delivery, this is because, project participants differ greatly in their skills, motivations, and support systems from their corporate organisations (Homayouni et al., 2011). In the project context where each individual (i.e., organisational representatives) brings a unique set of skills and knowledge to the project, it is critical therefore, to find ways that motivate the inter-organisational teams, to innovate, adapt, and learn for the purpose of achieving the intended project goals (Chinowsky & Taylor, 2007).

Adler (1995) argues that considerable coordination and critical ‘buy-in’ among interdepartmental representatives place substantial demands on change agents’ abilities thus multifunctional work structure must be tailored to fit each stakeholder in order to gain and sustain full cooperation (Lewis, 2007). Due to this fragmentation in the AEC context, collaborative contract models have recently been advocated as promoting interdisciplinary

collaboration (Sive, 2009) among various project participants to optimise the implementation process of BIM technological innovations for efficient project delivery (Taylor & Levitt, 2007). The integrated, collaborative contractual frameworks can ensure that the risks, along with the rewards of using BIM are shared among the project participants. Recognising the importance of collaboration, appropriation of different tools to facilitate work delivery, along with the work climate / team structures, and the value-fit mechanisms of the innovation (Klein & Knight, 2005), are key to innovation implementation, especially in inter-organisational team contexts (e.g., Homayouni et al., 2011; Korkmaz, et al., 2012; Slaughter, 1998; Poole, 2011; Taylor & Levitt, 2007).

This study has made the argument that BIM implementation is not only about logically “laid-down” processes that should be followed. It also involves several sociological or people issues and technical challenges (Sackey et al., 2013). These could affect the implementation outcomes in fundamental ways (e.g., Markus & Benjamin, 2012). The next section examines the mutual adjustments required among the sociotechnical antecedents through which the BIM concept and other emerging construction technologies can successfully be implemented.

2.11 Problematizing the BIM Implementation Processes from a Sociotechnical Systems Perspective

The main focus of this section is to evaluate past studies of innovation technology uptake in organisational settings, especially in construction organisations. The section reviews the key challenges that pose threats to successful BIM uptake in construction organisations. These are discussed under two main headings. Firstly, the various BIM implementation policy mandates and implementation guides are discussed (section 2.11.1). And secondly, the socio-organisational and technical issues that are often ignored in the BIM-policy frameworks are discussed to examine the problems these present to the efforts of managing BIM implementation in construction organisations (section 2.11.2).

2.11.1 BIM Implementation Policy Mandates and Dogmatic Methods and Guides for BIM Uptake

It seems there is widespread consensus among the practitioners in the industry, and scholars about the necessity to augment the utilisation of BIM within the construction industry. Aram et al., (2013) noted that extensive worldwide efforts are being undertaken to enhance different aspects of BIM implementation in various domains, such as design, manufacture, supply, installation, and facilities management. Many construction clients and government

organisations have also endeavoured to develop a roadmap for the specific purpose of research and development of BIM for the construction industry. The visions of using BIM as response to the challenges faced in construction are not only articulated amongst construction clients who are interested in augmenting efficiencies, but also within academia. To gain a better appreciation of the trend, the following works are amongst some of the main construction industry's BIM development programmes: BIM standard framework and guide (Richards, 2010); BIM overlay to the RIBA outline plan of work (RIBA, 2012); The business value of BIM (Young et al., 2009); BIM proven tools, methods and workflows (Hardin, 2009); A guide to BIM for users (Eastman et al., 2011); BIM A strategic implementation guide (Smith & Tardif, 2012); Successful sustainable design with BIM (Krygiel & Nies, 2008); Roadmap for BIM (Khosrowshahi, & Arayici, 2012); The project benefits of BIM (Bryde et al., 2013); Owner BIM for FM Guidelines (Teicholz, 2013); BIM planning guide for facility owners, Penn State University (CIC, 2012); The construction industry council's standard BIM protocol (The CIC research, 2013).

Apart from these methods and guides for augmenting BIM in construction organisations, policy-makers and other government institutions are offering to mandate BIM as a procurement requirement with the hope of eliminating misinformation and ensuing economic losses. For instance, the Danish government's construction task force developed a set of regulations regarding BIM implementation that demanded that large public construction projects information be collaborated, communicated and handed over through digital infrastructure (Plesner & Horst, 2013). Like the Danish government, the UK government also has a top-down BIM strategy as it would be made a mandatory part of public procurement projects from 2016. The primary aim of the UK BIM strategy is to: "examine the broad construction and post-occupancy benefits of BIM and the development of a structured Government/sector strategy to increase its take-up over a five year horizon" (BIM task group, 2011). The Strategy emphasises the need to deliver sustainable projects, by demanding significant reductions in energy use, reduction in public procurement costs and envisions information reuse throughout a project's lifecycle by virtue of implementing BIM.

There is substantial industry and policy interest in BIM (Whyte et al., 2011). This may demand radical changes in the management and delivery of technical information for public projects to address issues of cost, value and carbon (Whyte, 2011). Having synthesised the construction industry needs and requirements in relation to BIM uptake, the question remains to be answered: How would BIM be implemented for its benefits to be realised by

construction stakeholders? Peansupap & Walker (2006) opines that the benefits of technology in the construction industry are not unsettled, but rather, further research should aim at finding the methods of implementing ICT innovation into the construction industry.

2.11.2 Missing Arguments on BIM Implementation and Concomitant Innovative Processes

Aside the public sectors' BIM mandates and the frameworks of implementations, there have not been any deliberate efforts in examining how the enabling BIM tools are shaping, and in turn, being shaped by the contexts where they are being introduced. History has shown that a deterministic way of introducing technology into a social context may at best, not fulfil the intended benefits. According to Whyte & Sexton (2011) policy-makers have particularly struggled to understand innovation in building and infrastructure design, where work is distributed across global networks of design, manufacturing, installation and use. Rezgui & Miles (2011) have shown why socio-organisational and technical changes should accompany BIM deployment efforts. The challenge that policy makers face, however, is to construct BIM policies and strategies through which change and innovation become enacted into practice while avoiding what Clarke (1999) called "fantasy documents." The fantasy documents represent policies that fail because their end results are abstract and they contain uncertainties that are unacknowledged. These plans can be a "little more than vague hopes for remote futures and have virtually no known connection with human capacity or will" (Clarke, 1999, p.16).

For the transition towards BIM to be effective, new organisational setups need to emerge around the new range of design and production solutions. These innovative assemblages, if they are to achieve the position envisioned and dictated by the policy and regulations, some criteria have to be first met. The missing link between BIM technological and policy orientations and the inhibiting organisational conditions are discussed under six main themes. Firstly, the disconnects between innovators' intents and users's translations are presented in section 2.11.2.1. Secondly, there are unknown unknowns that lead to intended or unintended outcomes during new innovation uptake; these are presented in section 2.11.2.2. Thirdly, the notion of 'innovation assemblage' and its implications in technology implementation are highlighted in sections 2.11.2.3. This is followed by section 2.11.2.4 which discusses the concept of multilevel perspectives (MLP) of innovation uptake among inter-organisational knowledge groups. Section 2.11.2.5 also discusses the need for ongoing mutual adaptation of technical and organisational processes fuelled by continuous technological and business

change. And lastly, section 2.11.2.6 looks at the lessons that could be learned from previous research on BIM and related digital technology uptake in construction organisations, and how these could inform the direction of the research, moving forward.

2.11.2.1 Disconnects Between Innovators Intents and Users' Translations

Over the course of the years there have been some theoretical beliefs that have entrenched innovation research. In his seminal work on the diffusion of innovations (DOI), Rogers' (1966) central concern was to understand how and why users adopt a technology, and how communication was seen as a central medium through which the diffusion process takes place. Likewise, Davis' (1986) technology acceptance model (TAM), focuses on perceived ease of use and perceived usefulness of technology, whilst Venkatesh et al.'s (2003) unified theory of acceptance and use of technology (UTAUT) considers factors that influence users' intention and subsequent use of a technology. Also, Akrich (1993) has argued that developers of new technologies define actors with specific tastes, competences, motives, aspirations, political prejudices, and the rest, and they assume that morality, technology, science and economy will evolve in particular ways. These then become the *raison d'être* on which innovation proponents and developers define their new "technological promise" (van Lente, 1993) and expect users to attain or realise the predefined promise through the use of the technology.

The technological determinism views have however, been criticised by STS researchers, arguing that an innovation is not a stable object, endowed with a certain set of characteristics which will decide how it is diffused (Latour, 1991; Callon et al., 1986). Similarly, Plesner & Horst (2013) have emphasised that the technological determinists live in the certainty and in the promise phase of innovation but not in the localisation or the appropriation phase of it and argue further that, the objectives and outcomes of technology users are most often, not similar to the original intention of the innovators or the systems developers.

Accordingly, some STS thinkers conceptualise technological innovation as a process of translation, in which users would be engaged with an innovation if they deem it useful to help further their own ends. Indeed, STS theorists do not accept an organisation and its contextual issues as a stable domain through which the innovation is brought to the intention of the users to achieve a predefined agenda. Rather, the implementing organisation is considered a part and parcel of the innovation implementation process, which comprises development, adaption and appropriation.

2.11.2.2 Unknown Unknowns in the use of New Innovation Leading to Intended or Unintended Outcomes

While new and innovative forms of material (digital and non-digital) artefacts are emerging in construction practices, and are intended to support the practice, there are however, intended as well as unintended consequences (Whyte, 2013) and there is the potential for significant failures when the underlying assumptions for implementation of the digital models are wrong (Cebon, 2009). In examining the organisational practices involved in changing mediums from digital to physical artefacts in the pursuit of organisational goals, Whyte (2013) suggested the need to conceptualise digital infrastructures as always incomplete and, at overlapping timescales, in development. This is because technological innovation in construction is inherently fragile. While some aspects of the fragility may be related to the maturity of the technology, other challenges are intrinsic to those that use it and try to integrate it into their practices.

Indeed, Stasis et al. (2013) have cautioned that, there are ‘unknown unknowns’ arising as a result of utilising a platform of visually-enhanced and parametrically-referenced coordinated models by expert teams to address concerns in AEC practices and projects delivery. Thus, such panoply of BIM tools and applications may introduce new challenges at the same time as responding to existing problems. Though research demonstrates the advantages to using computer-based methodologies in practice (Hartmann & Fischer, 2007) there are pre-existing social structures that may prove to be unexpectedly resilient to champions for change (e.g., Harty & Whyte, 2010). For example, an important factor is the way that BIM practices and the competing technological ranges may be unevenly understood and differently incorporated into pre-existing practices.

Also, another strand of literature, involving empirical studies of practice that draws on theories of organisations, raises a different, but a more general concern that digital technologies may have unintended as well as intended impacts. For example, technologies are often introduced to increase managerial oversight and control (Thomas, 1994), yet as they take control away from users, digital technologies can hinder the ‘mindful’ actions of users, increasing the potential for mistakes and accidents (Weick, 1985). Orlikowski (1992) writes on how technologies become a more local “mechanism for technical control, delimiting the ways” users themselves perceive and interact with their work (p.417). However, “technology is built and used within certain social and historical circumstances and its form and function will bear the imprint of these conditions” (Orlikowski, 1992, p.411). This raises questions

about the circulation of technology from the contexts of design into its contexts of use that are under-explored in the discussions of technology and construction organisations (Whyte, 2010).

Another concerns of the ‘unknown unknowns’ ensue at the operation and maintenance phase. The concept of BIM enables the project information to be captured, stored and handed-over to the owner in digital formats; for example COBie spreadsheet or BIM 360 field. When physical infrastructure is handed-over, the contextual knowledge embedded in the digital dataset, as well as in the physical asset itself, disconnect from the skills, rationale and context in which they were created by the diverse professions. Thus the asset owner has to make sense of these disjointed memories for the new purposes of operations and maintenance. This may pose a challenge to the ‘non-technical’ facilities managers. The concerns about “unknown unknowns” or the unintended consequences arising from the broader use of digital technologies which can have negative impact on practice have a particular relevance to the challenge of considering digital innovation uptake in construction organisations.

2.11.2.3 Innovation Assemblage

It is commonly recognised that one of the key challenges of the construction industry arises from an organisational setup characterised by ad hoc tasks and changing configurations of partners (van Marrewijk et al., 2008). Likewise, visions, levels of capability, and the use of construction technologies vary from one organisation to the other. The concept of BIM innovation thus does not refer simply to the visions of the innovators or the functions of the technical objects alone, but also, to what Plesner & Horst (2013) termed, ‘innovative assemblages’. In order to capture the non-stabilised character of the innovation process, the term, innovative assemblage is used as the analytical unit for exploring. The use of this concept is inspired by Irwin & Michael (2003) and also, Callon (1986), who understood innovation as a process of translation initiated by the articulation of a problem to which other actors can be mobilised to agree to solve in a particular way. Whereas Irwin & Michael (2003), define an assemblage as a set of relations which integrate heterogeneous elements in a relatively stable network, the type of assemblage focused upon by Plesner & Horst (2013) in their study of digital construction innovations, can be seen as constituted of interrelated, and interdependent in an area as unstable and emergent as construction innovative technologies.

The innovative assemblage is intended to make technical artefacts part of a solution to the problems of construction organisations. The assemblage emphasises on how actors envision and mobilises a combination of different sociotechnical elements (e.g., type of BIM platform, technological tools and workstation types, expertise, vision, clients' specifics, BIM strategies, politics, etc.) in different ways, and thereby create different visions, and understandings of reconfigured workflows to suit a particular circumstance. This perspective has a potential of unravelling how different organisations articulate visions of their potentials to solve work related problems by mobilising their preferred BIM platforms as enablers or catalysts, and how this accounts for their more or less successful adaption and appropriation of BIM. It also presents a particular way of analysing the linkage between social and technical elements in an organisation, or a network of organisations in relation to an overall vision of how to solve a problem in construction.

The study aims to account for how construction organisations are constructing their BIM visions as important enablers or catalysts for sociotechnical configuration in their work practices. It is believed that the concept of “innovation assemblage” could offer a useful orientation map for this study when pursuing different organisational contexts as they mobilise and converge, the linkages between social and technical elements to their overall BIM visions and ambitions.

2.11.2.4 Multilevel Perspectives (MLP) of Innovation Uptake among Inter-Organisational Knowledge Groups

Faced with an exponential proliferation of connections (Plesner & Horst, 2013), construction organisations are focused on relations between in-house expertise and external stakeholders with references to each other in their efforts to assemble the world. In broad terms, the MLP emerged from the early works of Kemp (1994) and Schot et al. (1994) which brought together innovation, science and technology studies, and institutional considerations to understand the co-evolution processes that require multiple changes in sociotechnical systems. The understanding that technology and knowledge circulates across such ML contexts is elaborated in a trajectory of theorising in the sociology of technology studies (e.g. Gherardi & Nicolini, 2000; Granqvist, 2007). The multilevel perspective (MLP) recognises the myriad institutional, managerial and sociotechnical aspects – the strand of complementary work that intertwines to influence durable and complex sociotechnical transitions (Whyte & Sexton, 2011). It is holistic, aiming to accommodate all of the important determinants of innovation.

The introduction of MLP of innovation shifts attention to adaptation across organisational boundaries and hierarchical structuring around inter-dependent levels of diverse groups and their technological priorities (Whyte, 2011).

Granqvist (2007) has referred to the MLP as social structure that brings together the range of organisations interested in the development of a set of artefacts and techniques and uses it to address questions about technological change. The organisations are engaged either peripherally or in close communication in development, use, regulation or exploitation of technology, and are in varying contact with one another.

The MLP in construction innovation is particularly apt for this research as it stresses interdependence, and acknowledges the role of external sources of innovation and inter-organisational networks. Such a theory could provide a useful lens in aligning the knowledge, visions and technological ambitions of an organisation with its external counterparts.

2.11.2.5 Ongoing Mutual Adaptation in Technology and Innovative Process Change

In setting out BIM agendas and strategies to achieve longer term goals, the idea of BIM and related innovation technologies suggests that government strategists and industry practitioners need to be aware that technology deployment changes the boundaries between disciplines, innovators, users, teams and roles (Whyte & Lobo, 2010). It shapes social relations as it develops new practices and changes the visibility of information. Organisational contexts have long proven not to have a stable environment for technological uptake, but rather, demanding mutual adaptation in cooperative behaviour between the social and technical elements.

Adaptation is a concept with a long history in biology, referring to the ways in which fit is brought about between two units or organisms that are dependent on each other (Hawley, 1950, Steward, 1968). It is also assumed to be important for the joint efficiency of the involved units. In the organisation literature, mutual adaptation has been described to include the creation and transfer of knowledge by establishing strong ties between two different communities of practice (Garrety et al., 2001). Also, in IS-related research, McLaughlin (1987) has established that, interventions are successful when the implementation involves mutual adaptation, in which the technological products and the concomitant reform proposals are adapted to fit local conditions and local conditions are adapted to fit with reform proposals. This shows that, the mutual adaptation process between a user organisation and a technological interface consists of two adaptation processes: one is a user's adaptation to an

interface, and the other is an interface's adaptation to a user. Spillane (1999) notes that one sided adaptation at the local context often results in deleterious adaptations that can change the innovators or reformers' core intents. Brygstad (2005) also reveals in innovation research that a formal approach of introducing a new technical innovation without altering the work practices has often proved unsuccessful. Thus, mutual adaptation requires careful analysis of the congruence between existing and desired work practices (Brynjolfson et al., 1997).

Majchrzak et al. (2000) indicated that it is not the nature of structures (whether it is technological, political or social) that limits the adaptation process, but rather the malleability or flexibility of the structure. Ciborra (2000) introduces the concept of technological drift to suggest that the mutual adaptation cannot be planned for by the systems interface. Technological drift describes a discrepancy between plan and outcome, in respect of the implementation of technology, in which the implementation outcome is basically unpredictable and different from what was planned for. Ciborra (2000) thus concludes that the solution cannot be more managerial control, which has proven to be part of the problem. The best solution is not an intellectual construction (like a written specification or technical manual), but a negotiated situation with mutual learning and adjustment taking place.

Crucially, there is mutual adaptation across boundaries of organisations – between contexts of technology design and contexts of use. The proliferation of mediating roles being occupied by for example, BIM consultants and BIM champions is a part of the adaptation process. For instance, Friedman & Kahn (1994) notes how, from the 1960s onwards, the typical IT specialist comes to occupy a mediating position between bought-in computer systems and non-IT specialist users within the user organisation and there was a progressive increase in wider computer literacy. In this, the idea of mutual adaptation is very crucial for allowing the mediating roles to be made visible as new knowledge and roles are created.

Construction organisations are often users of “off-the-shelf” or bespoke software products that are developed elsewhere. There are thus spatial and temporal disjoints between development and use (Whyte, 2011). The disjoint between construction stakeholders which may be spatial and sectorial, drive different sets of priorities for technological development, adaptation and appropriation. The theories of MLP and mutual adaptation provide a context for understanding the “idiosyncratic strategies of individual organisations” (Hung & Whittington, 1997) as firms engage in strategic choices across pluralistic local contexts relating to technology and business.

One way to plan for mutual adaptation is to involve practitioners in the design of the implementation of the reform, and to create a context that is supportive of learning and reflective adaptation. The mutual adaptation is an ongoing process, fuelled by continuous technological and business change (Leonard-Barton, 1988). The goal is to engender better understanding and stronger commitment to the spirit of the reforms. This indicates the importance of why participants in a sociotechnical work context should be conscious of the emergent nature of such environment, and of the need to establish and observe feedback loops to facilitate double-loop learning and mutual adaptation.

This concept may illuminate the BIM developers' and users' models of effective pedagogy, and may reveal how reforms can be adapted to a local context. The use of this mutual learning and adjustment framework represents an interesting arena to study technology deployment in construction, because it allows both innovators and the user organisations to learn, and to act on new learning, during the ongoing mutual adaptation process.

2.11.2.6 Lessons from Past Construction ICT Innovation Implementation Research

Within construction ICT innovation literature, there have been widespread publications related to BIM and concomitant innovation implementation and the ensuing consequences (e.g., Howard & Bjørk, 2008; Ashcraft, 2008; Chao-Duivis, 2009; Rezgui & Miles, 2011; Dossick & Neff, 2010; Plesner & Horst, 2013; Whyte, 2013; Harty, 2008; Bell, 2008). These literature perspectives are varied ranging from the acknowledge uncertainties about the legal, contractual and the overall organisational implications of construction technologies to socio-object challenges related to digital infrastructure. Howard & Bjørk (2008) for example, identified four main issues which are often cited as barriers to BIM implementation, these include: 1) technical challenges (e.g., compatibility and reliability of BIM tools); 2) fragmented project teams; 3) resistance to change; 4) lack of a well-trained workforce; and 5) business process related issues.

Dossick & Neff's (2011) research into the use of BIM by multiple knowledge groups found that users were having opposing interpretations of its promise neither was it fostering closer collaboration across different companies. The kinds of problems that were articulated by architects using BIM have to do with its political imperative, its cost, its heaviness and its influence on the creative process of users (Plesner & Horst, 2013). Whyte (2011) draws on organisation studies and sociology to understand the diverse patterns of activity that emerge to manage digital coordination of design. Arguing that the processes observed, and the

relationships that emerge between various professionals and shared digital models are significantly different from those proposed in industry and policy documents such as the BIM standard framework and guide (Richards, 2010). Accounts of these experiences are clearly important to take into consideration in relation to realising the visions related to BIM.

Researchers have begun to examine how digital mediated work practices translate to moving away from the well-established construction practices. Whyte & Levitt (2011) argued that rapid change in digital infrastructure in construction is shifting the practices of project delivery, away from those described in traditional project management developed in the 1950's and the 1960's. The 20th century approach contains assumptions that undermines its potential to deliver change for the 21st century because, work was essentially seen as an emergent feature, negotiated in the context of a fragmented and antagonistic pattern of relationships amongst supply chain partners (Plesner & Horst, 2013), and influenced by patterns of authority and learning on construction sites (Rooke & Clark, 2005). However, with the digital enablers, workflow is particularly, becoming highly formalised, flow of information within hierarchies and across hierarchies have become systematised, whilst digital tools and methods are integral to the project's processes. The existing and emerging digitally-enabled processes alter the information that is available at site. With building modelling, for example, greater detail is developed earlier in a project.

The introduction of BIM and its standardised forms into construction organisations alters boundaries between firms and their social relations by making information sharing instantly visible across project teams and providing an archive of these object geometries through the repositories (Whyte & Lobo, 2010). The virtual world allows the digitalisation of the construction practice where different actors represented as avatars may interact synchronously with parametric object models in project repositories (Bell, 2008). BIM and the facilitated computer networks may now enable different construction actors to enter a virtual reality and become active participants in the shaping of a given project (Plesner & Horst, 2013).

Harty (2008) uses the notion of 'bounded' and 'unbounded' innovation to problematise the socio-object reality of construction practice in the face of the existing and emerging 3D digital artefacts. The bounded innovation in construction can be contained within a specific firm, and have limited effects on wider, inter-organisational relations, for instance, the use of 2D CAD systems. However, the concept of 'unbounded innovation' has been used to characterize situations in which technology development spans organisational contexts (Harty,

2005) such as the use of BIM as 3D digital object among different knowledge professions. Construction is seen as one such context. The concept of BIM as a solution for integration and coordination and the related digitalisation of the construction practice are potentially highly unbounded. This is tantamount to the theory of loose coupling and tight coupling, where loose coupling paradoxically combines connection and autonomy (Orton & Weick, 1990). Dossick & Neff (2011) contrasted loose organisational coupling, as characteristic of the construction industry, and tight technical coupling, as characteristic of the digital coordination technologies. Actions are coordinated in a loosely coupled system across different knowledge boundaries (Weick, 1985). Ewenstein & Whyte (2009) also regard the role of digital objects in the design process as boundary objects mediating interactions between organisational units. Nevertheless, the 2D CAD drafting and the traditional paper-based drawings are tightly coupled and bounded within the specific practices and the professional working space. The bounded innovations can have very little repercussions beyond their immediate domain, but the unbounded innovations may have far reaching consequences on wider inter-organisational relations, depending on where and how they are implemented (Harty, 2008).

BIM may hold much promise for the integration of the disparate elements of the construction design process, and the reconfiguration of construction practices, and potentially offer huge increases in efficiency. However, Harty (2005) argues that as an unbounded innovation, the appreciation of the specific challenges this presents is less than common within construction research. Discussions and models of construction innovation tend to overlook this distinction between bounded and unbounded innovation, by either positioning innovation as led by external demands, which force firms to change their practices or go out of business, or by concentrating on firm-level strategies and benefits, where the bounded nature of an innovation, and the ability to enact necessary changes to implement it is implicitly assumed. This neglects the consideration of the challenges and mechanisms of gaining inter-organisational support and transformation, which would be essential if BIM-enabled work practice is to become a reality. The major concern is that, without the capabilities of accounting for the unbounded implications of BIM, this could be potentially damaging to the wide-ranging inter-organisational project participants. This could further be complicated by the lack of a single way of using BIM in the heterogeneous organisations. Currently, different organisations often outline a particular BIM platform or approach and bring with them implicit hierarchies and distributions of power within construction practices.

Drawing upon what they call the ‘sociology of expectations’ Plesner & Horst (2013) argue that, technology users and their various sociotechnical networks should be understood as part and parcel of the innovation process itself. However, the multiple knowledge boundaries and significant coordination associated with the design and construction of physical infrastructure present substantial challenges to digital infrastructure uptake (Whyte & Lobo, 2010), requiring the AEC organisations to pay serious attention to coordination and knowledge integration.

The various researchers have acknowledged that as work in the AEC practices continue to be further digitised and integrated through increasingly sophisticated digital infrastructures, there is a need to create open systems in which systemic risks are mitigated by comparing and contrasting across the digital and physical objects. What these studies did not however achieve, was to articulate on the creation of open systems or loose coupling systems in which an evolving and fragile digital infrastructure can be used to achieve goals beyond the “technological promise.” Whyte (2013) points out that the idea of BIM in the AEC sector provides a starting point for further research into the changing nature of BIM-enabled project-based work. This work is needed to understand how the ‘virtual world’ is involved in different sociotechnical practices, the purpose that BIM serves across different local practices, and in particular how the roles, both through cooperation and through controlled and managerial approaches coexist in different knowledge works.

This study thus aims to draw on the sociology of technology to carry out a sociotechnical systems analysis of BIM implementation in construction organisations, thereby providing an understanding of innovation assemblages and patterns of activities across varying perspectives.

The concept of sociology of technology being considered here is different from such concepts as “technological determinism” or the “standard tools” model (Kling & Lamb, 1999) in the dominant innovation literature as these give little attention to the character of the users and the uses to which the technology is put (Friedman & Kahn, 1994), but rather, privileging the machine’s functionality over the application domain. As technology becomes more complex, others have argued that there is a need for such broad technological, as well as sociological approaches that holistically articulate and situate studies within the particular historical patterns of technology development and use (e.g., Whyte, 2011; Schweber & Harty, 2010). This is backed by Bijker & Law’s (1992, p.7) assertions that implementation of technological innovations are not purely technical in its contexts but rather heterogeneous and contingent,

as they ‘embody social, political, psychological, economic, and professional commitments, skills, prejudices and constraints’

This perspective is found to be fruitful for this research, because it broadens the interpretation of BIM implementation beyond simple technological capabilities, the vendors’ intents, and governments’ strategies or about individual professions or clients acting from specific interests. But rather, the implementation will emerge out of an assemblage of innovative relations between individual and collective actors and their sociotechnical interests. Within a heterogeneous context such as construction, the implementation can be regarded as a multilevel assemblage of sociotechnical interests. In the next chapter the theoretical foundation into sociotechnical systems is reviewed as the findings of this research will draw on STS studies to provide an understanding of innovation assemblages and the diverse patterns of activities that occurs during the discourse of BIM uptake in construction organisations.

2.12 Summary

Whilst the AEC industry begins to demonstrate a strong interest in BIM (Hooper & Ekholm, 2012) there is a lack of practical knowledge in applying current BIM technologies and leveraging the much argued benefits of BIM. The issues associated to BIM implementation resides in the under-developed strategies for implementation and the immaturities of the available technological tools (Hardin, 2009). There are already calls made, by the number of written and documented literature on the subject and research conducted, that, the understanding and appreciation of BIM solutions and related organisational changes is truly necessary and essential if the industry is to be transformed into a BIM-enabled environment.

It has been established through the literature that competing and complementary BIM technological platforms and supporting products, implementation strategies, knowledge and competency development, and collaboration among multi-functional teams are the hallmarks for successful BIM implementation, although no linkages among these are recognised in the extant literature. This chapter has also shown that, within the AEC community, there is a widespread interest in BIM implementation due to the efficiency savings proponents purport that BIM-enabled organisations may relish from implementing BIM. Thus, numerous suggestions have been put forward on how BIM protocols could better be integrated into the main stream organisational practices by way of governments-backed BIM policy mandates and other implementation strategies from academic sources and other research and

professional institutions. These implementation frameworks are able to identify technological maturities and devise policy directions to facilitate the implementation. Nevertheless, beyond the technological capabilities and the policy frameworks, there are other critical issues which are generally missing in the current implementation frameworks. In particular, the AEC sector is a highly collaborative, dynamic domain that fails to exhibit the underlying assumptions that seems to govern technological systems deployment. Clearly, these implementation frameworks often oversimplify the complex social settings of the modern enterprises (Dillard & Yuthas, 2006). Neither do they discuss about how BIM may displace other work practices, or about how the technology need to be augmented in the work contexts. Indeed, promising ideas about BIM face substantial challenges in moving into practice due to the concomitant change processes, especially, reforms that seek substantial transformations of extant practice (Firestone, 1989; Fullan, 1991) Local implementation of reform necessarily involves adaptation rather than “pure embrace.”

Convincingly therefore, the need to identify and jointly optimise the sociotechnical antecedents that impact upon the successful implementation of BIM, as advocated by the aim of this research, can be justified. Eventually, the analysis of literature findings on BIM implementation approaches, together with the review of the sociotechnical systems theoretical underpinnings (chapter three) and the exploratory investigations in chapter five will form the basis for the development of an STS analytical framework. This framework will then be used to analyse three BIM-enabled construction organisations (chapter six), thereby providing critical theoretical insights regarding BIM implementation processes in construction organisations.

CHAPTER THREE

3 A SOCIOTECHNICAL SYSTEMS APPROACH TO ICT INNOVATION IN CONSTRUCTION CONTEXT

3.1 Introduction

This chapter presents the second and final part of the literature review. The main focus of this chapter is to explore the theoretical foundations of innovation technology uptake in organisational contexts. The chapter will also review the sociotechnical systems (STS) literature to provide a conceptual understanding for the research objectives and the appropriate research methodology. The chapter also evaluates sociotechnical systems theories and models to provide an analytical framework for the appropriation and stabilisation of BIM products and process solutions in construction organisations. This review addresses research objective two, which poses the question; how can STS systems approach provide a conceptual understanding for BIM implementation in construction organisations.

3.2 Evaluation of Sociotechnical Systems Theories and Models

There are a number of approaches to theorising interactions between objects/artefacts and work practices or between the socio and the technical in the wider literature. Practice-base theorising of work contexts and social studies of science and technology have sparked a wider resurgence of interests in sociotechnical studies within organisations. This section evaluates STS theories and models and how they might provide an analytical framework for analysing BIM implementation in construction organisations. Accordingly, this section begins by discussing the evolution of the STS theory (section 3.2.1). Following this, the relevance of STS in the contemporary organisational paradigms are presented (section 3.2.2), and the critique of STS are explained (section 3.2.3). The various models that bridge STS from theoretical perceptions to analytical models are highlighted (section 3.2.4). Finally, a comparison of the various STS analytical frameworks is undertaken and their influence on BIM uptake is discussed (section 3.2.5).

3.2.1 Evolution of Sociotechnical Systems Theory

Recent history in organisational design is connected to a shared 'industrial age' mindset (Beringer, 1986). Formal rationality is a projecting part of the inherent theory that has guided modern organisational design since the industrial revolution (Weber, 2009; Ritzer, 2007; Trist, 1978). Rationalising organisations exhibit a tendency towards hierarchies, reductionism,

predictability, quantification (of task) and controls (with rules, regulations and structures) (Ritzer, 1993, p.20). According to Trist (1981, p.27), “*in the fifties societal climate was negative toward sociotechnical innovation*” because Max Weber and Frederick Taylor’s *technocratic bureaucracy* has become pervasive at that time. Taylor’s concept of scientific management approached the study of management from the workshop or technical level and Weber’s “bureaucracy” stems from rules and other controls that govern an undertaking in the pursuit of specific goals (Wren & Bedeian, 2009). The need Weber identified for efficient organisation is reliant on rationality and legalism, as a result another metaphor for a bureaucracy is ‘organisational machine’ (Arnold et al., 1995). Studies however suggest that, the emergence of *continuous production industries* in the post-war era, (i.e., mining, textile, automotive and manufacturing) which are advancing in automation are also developing requirements that lead in a direction counter to the autocracy and bureaucratic mode prevailing in (and prior to) the fifties (Murray, 1960; Emery & Marek, 1962).

Likewise, the post-war era fostered science-based industries to rise to prominence in the wake of knowledge and information explosions. This led to the emergence of large-scale organisations characterised by a higher level of interdependence at various geographical boundaries and a higher level of complexity as regards heterogeneity (Chein, 1954). The higher level of interdependence, complexity and uncertainty now to be found in the new era of the post-industrial age surpassed the limits within which *technocratic bureaucracies* were designed to cope, given its primarily mechanistic authoritarian control structure, and its tendency to devalue human resources (Trist, 1981; Pava, 1983; Weber, 2009; Ritzer, 1993). The old organisation forms seem not to be able to absorb the environmental turbulence, far less reduce it. Findings from several major pioneer studies during this era began to draw attention to the counterproductive consequences of the extreme job fractionalisation and the emergent complex work environments (Walker & Guest, 1952). For example, Burns & Stalker (1961) observed a new management pattern which they call ‘organismic’ as contrast with ‘mechanistic’ in a more technologically advanced industry. Fensham & Hooper’s (1964) studies also show the increasing mismatch between conventional management structures and the requirement of the emerging technologies.

The post-industrial era witnessed contentions between the old organisation form and the new, science-based organisation forms. It was claimed that the old systems belong to “the past era” which had the indulgence of operating in a relatively stable and predictable business environment. The new era sees the interconnectedness between the ambiguous, unpredictable

business practices and the rapidly evolving nature of the scientific paradigm (e.g., Avison & Fitzgerald, 1995; Burns & Stalker, 2000). The emerging era of the scientific paradigm was oriented towards a wider human-social-organisational consideration – thus, strongly aligning towards sociotechnical viewpoints. Table 3.1 has articulated the contrast between the old paradigm and the new paradigm, which eventually led to the widespread interest in sociotechnical systems design (Pasmore & Gurley, 1991; Pasmore, 1988; Trist, 1981).

Table 3.1 Contrasting organisational conditions prevailing in the pre and post-industrial era

Key descriptors	Pre-industrial era	Post-industrial era
Nature of context	Stable environment	Unstable environment
	Predefined outcomes	Emergent outcomes
Nature of work	Defined	Undefined
	Repetitive	Non-repetitive
	One right way	Many right ways
	Clear, shared goals	Multiple, competitive goals
	Information readily available	Information hard to obtain
Nature of decision making	Rules applicable	Rules inhibiting
	Experience counts	Experience may be irrelevant
	Authority-based	Consensus-based
	Authority by position	Authority by virtue of expertise
	Complete operational specifications	Incomplete operational specifications
Nature of success	Efficiency	Effectiveness
	Technical perfection	Human perfection
	Productivity measurable	Productivity un-measurable
	Physical technology	Knowledge technology
	Standard information	Non-standard information
Related organisation design	Man as an expendable spare part	Man as a resource to be developed
	Technological imperative	Joint optimisation
	Tall organisation chart, autocratic style	Flat organisation chart, participative style
	Organisation's purposes only	Members' and society's purpose also
	Alienation	Commitment
	Low risk-taking	Innovation
	Competition, gamesmanship	Collaboration, congeniality
	External controls (supervisors, specialist staff, procedures)	Internal controls (self-regulating subsystems)
	Maximum task breakdown, simple, narrow skills	Optimum task grouping, multiple broad skills
	Man as extension to the machine	Man as complementary to the machine

Adapted from (Pasmore & Gurley, 1991; Pasmore, 1988; Trist, 1981)

Table 3.1 sets out the sharp contrast of organisational conditions prevailing between the pre- and post-industrial eras. The prevailing conditions in the past era resulted in autocratically

managed organisations with tall hierarchies- “regarding man simply as an extension of the machine and wherefore as an expendable spare part” (Trist, 1981, p.17). Thus, the outcome had typically been jobs that were highly fractionated and simplified. By contrast, the organisational design in the post-industrial era required concurrent adjustments of technical and social systems to create work designs which were improvements in terms of both efficiency as well as meeting social and psychological requirements. The emerging era of the scientific paradigm also required a capable knowledge workforce of a much higher degree of internal controls, with flexible resources to meet a greater degree of environmental variance (Trist, 1981). These rising contextual organisational conditions legitimised a series of major sociotechnical field experiments concerning work reform to be launched, and in most cases to be sustained (Emery & Thorsrud, 1969).

Emery (1959) put forward a first generalised model² of the dimensions of social and technical systems, stressing that an appropriate structural setting has to be created before desirable social climates and positive interpersonal relations would have the conditions in which to develop. The technical and social systems are independent of each other in the sense that the former follows the laws of the natural sciences and is a purposeful system, and the latter functions as one of the major boundary conditions of the social systems in mediating between capabilities and outputs. Their relationships represent a coupling of dissimilars which can only be jointly optimised. This brought to the fore an increased interest in the social and political implications of new technologies and helped to establish the sociology of technology as a vibrant field of enquiry (Pinch & Bijker, 1984; Cherns, 1976).

Generally, the technical perspective focuses on the technical quality of the system, the social perspective focuses on the desirability and feasibility of change as major qualifications for the rollout, and the sociotechnical perspective emphasises on the fit between the technical and social subsystems (Iivari & Hirschheim, 1996). An attempt to optimise the technical or the social system alone will result in the sub-optimisation of the sociotechnical whole (Ackoff & Emery, 1972; Trist, 1981). Such logical ideals were held in a sociotechnical framework to

² At the Tavistock Institute, Emery (1959) developed the first model of sociotechnical systems, which are broken into components for easy analysis. Seven were identified on the technical side, including a level of mechanisation/automation, unit operations, the temporo-spatial scale of the production process, the natural characteristics of the material, the degree of centrality of the various productive operations, the character of the maintenance and supply operations and the immediate physical work setting. On the social side, rigorous attention has to be paid to occupational roles and their structure, method of payment, the supervisory relationship and the work culture; and the psyche group concerns with interpersonal relations and group behaviours.

underlie job and organisational design. Failure to build it into a primary work system could prevent the work system from functional optimisation.

3.2.2 Sociotechnical Systems Theory in the Contemporary Organisational Paradigms

The use of new innovative technologies is restricted by the social conditions into which they are inherent and endeavour to flourish. Ignoring the complex social settings can result in failure-prone innovation implementation and/or reduced value of the innovation (Davenport, 1998) due to users' resistance (Grabski et al., 2003), lack of social commitment and misalignment between the technology and organisation (Sia & Soh, 2002). The original concept of STS advocates the consideration of both technical and social factors when seeking to promote change within an organisation, whether it concerns the introduction of new technology or a business change program (Cherns, 1976). Designing a change to one part of the system without considering how this might affect or require change in the other aspects of the system will limit the work system's effectiveness, or may yield 'sub-optimal' results.

The underlying principles and applications of STS have evolved to reflect the changing nature of work, technology and design practices. The broad understanding gained through the continued study of technological design has enabled a reinterpretation of sociotechnical principles to reflect the challenges of contemporary information and communications technologies (Clegg, 2000). Nevertheless, the basis of STS methods still focuses on how strategies can be devised in order to jointly optimise the social and technical subsystems in a work system context (e.g., Clegg, 2000; Mumford, 2006). The STS principles have achieved some success in helping inform the design of technology-led organisational changes (e.g., Baxter & Sommerville, 2011), redesign of work roles (Challenger & Clegg, 2011), and user-controlled autonomous work groups (Grant et al., 2011; Wall et al., 1986). The STS framework has also provided insights on how new technology may be used and integrated within existing work systems (e.g., Mumford, 2006).

3.2.3 Critique of STS

The classical STS concept has gradually evolved and has been used in series of theoretical and practical studies in various knowledge areas. It has therefore been dissected, influenced and shaped from a number of scholarly viewpoints. For example, the main features of the classical STS approach are outlined and appraised by Kelly (1978) and Mumford (1985). Furthermore, Trist (1981) explores in detail the evolution of the sociotechnical perspective

and in a supplementary explanation, Hackman (1981) acknowledges a number of problems in the sociotechnical approach.

Although STS has been recognised as a powerful system-based approach to effectively utilise product and process innovations such as BIM, it has also received some criticisms. In particular, Mumford (2006) has pointed out how the STS approach by itself is more akin to philosophies than the sorts of design methods that are usually associated with organisational procedures and engineering. The implication is that, STS at its best, mostly provides advice for advocates rather than a coherent analytical framework to deal with organisational challenges. In its design form therefore, STS is a stronger descriptive theory than a predictive tool (Nardi, 1996; Waern, 1998). The concern however, is that, it is not enough to simply analyse a situation from a sociotechnical perspective and then explain this analysis to organisations (Baxter & Sommerville, 2011). Scacchi (2004) explained that prescriptive design of STS by itself will not lead to or induce radical changes in the way a given information system is intended to support its users, their workflow, or their workplace. Such approach though necessary are not sufficient to affect changes that address the political order of an organisation or its institutional surrounds. Instead, reinvention and transformation of existing organisational information systems and work practices is central to achieving radical change (Scacchi, 2002). Consequently, the STS literature has been accused of producing an understanding of the anatomy of technological change instead of an understanding of the root forces that drive technological change. This raises the question as to the appropriateness and usefulness for any work domain to which an STS approach in its raw form is meant to intervene.

Ehn (1993) also noted that sociotechnical tools and design methods are very useful and in theory, favour democratisation, however, in practical application, the democratisation elements seem to disappear. This is because, the duality of the social as well as the technical contains many different elements making it difficult to identify and give equal attention to them. Scacchi (2004) explained however that, though much of the legacy of STS design was prescriptive, the contemporary scholars of human-computer interaction prefer empirically grounded studies with descriptive results or proactive “action research” agenda, and thus work towards development of an STS design practice that builds on such grounds.

Clearly, one of the important theoretical challenges with respect to STS is to explain the integrated synergy between the social (e.g., organisation and knowledge about practice) and technical (e.g., requirements and functions of technologies). Nevertheless, some proponents

of STS have begun to address these shortcomings, such as Molina (1998) who clearly links the role of individual, organisations and even nationwide institutional and technological change to changes in the day-to-day routines of constituency aligners, recognising the unique contributions of both the technical and social world in the constituency building process. Others have also attempted to develop context-specific sociotechnical systems frameworks, aiming to equip organisations with strategies of sociotechnical systems approach to organisational change strategies. Some of these approaches are discussed in the next section.

3.2.4 Bridging from STS Theory to Analytical Frameworks

Practice-based theorising of work contexts and socio-organisational studies of science and technology have generated a broader renaissance of interests in sociotechnical studies within organisations (e.g., Lewis et al., 2010; Checkland & Holwell, 1993; Trist & Bamforth, 1951; Pinch & Bijker, 1984). Innovation design, adaption and use are integral parts of sociotechnical systems, and take on social significance through the way social actors intentionally or unintentionally use it to influence each other and the rest of their social world.

Since the development of the classical STS theory to the current contemporary approach to STS, it appears that the concept has become eclectic, drawing on a wide range of ideas from different contexts, thus the meanings given to the notion of sociotechnical system have been generally broad (Olerup, 1989). There is not a single sociotechnical school of thought; instead sociotechnical theory has developed in a number of directions (Kelly, 1978). A number of descriptive approaches have been proposed by different STS researchers for the analysis of sociotechnical systems that embody the interaction of human-technology systems as frame of reference.

Among the most well-known ones are Actor Network Theory (ANT) (Callon, 1986; Law & Hassard, 1999); Social Construction of Technology (SCOT) (Pinch & Bijker, 1984); Distributed Cognitive Framework (DCF) (Zhang & Norman, 1994; Hutchins, 1995); Activity Theory Framework (ATF) (Kuuti, 1996; Engeström, 1999); Cognitive Systems Engineering (CSE) (Rasmussen et al., 1987); Leavitt's Systems Model (LSM) (Leavitt, 1964; Lyytinen & Newman, 2008); Work System Model (WSM) (Alter, 2006); Soft System Methodology (SSM) (Checkland, 1984; Checkland & Scholes, 1990); and Sociotechnical Constituency (STC) (Molina, 1998; Molina & Kinder, 1999). The basic principles of these STS design analysis are intended as guidelines that could be used as a way of focussing discussions about STS design rules in specific contexts. They mostly deal with abstract issues relating to

organisational and social aspects of the system (e.g., Baxter & Sommerville, 2011). These frameworks draw on a wide range of ideas that are concerned with both people and technical artefacts (Pasmore, 1988) such as social and behavioural sciences, IS, architecture and engineering disciplines seeking to rearrange workflows, staffing, and related resource configurations in order to discover better ways of accomplishing tasks. The attributes of such a body of knowledge are worthy of exploring for this study. Thus, the individual STS frameworks are briefly discussed in the following sections.

3.2.4.1 Actor Network Theory (ANT)

ANT describes a much more fluid and iterative circulation of artefacts and actors within and between networks of design or development and of use of an artefact, and where the entities involved are transformed and translated into new arrangements. ANT avoids technological determinism by stressing contingency; it asserts that both technological artefacts and people are constituted within sociotechnical settings, within networks³ of heterogeneous elements (Callon, 1986; Law & Hassard, 1999). Thus, the effect of an innovation introduced in a network, is seen as a result of a larger number of connections and reconfigurations at local and macro (global) levels (Callon & Law, 1982; Graham & Marvin, 2001). One of ANT's main objectives is to link the chasm existing between society and artefacts. Latour argues that society relies on the “*complete separation between the natural world (constructed, nevertheless, by man) and the social world (sustained, nevertheless, by things)*” (Latour, 1993, p.31). ANT's task is to reconnect these two spheres through the multiple networks that compose the social, and that, in turn, are composed of actors, human actors and nonhuman actants, which possess the same ontological status. The social is constituted by networks, or sets of relationships created among people through the use of artefacts. ANT grants actors and actants with agency⁴ through the context of *coexistence*. The argument made by ANT is that agency can be extended to all artefacts (human actors and non-human actants), since their existence already cause change in behaviour, routines and abilities. For instance, by

³ Networks are sets of heterogeneous relationships which connect, and in the process of connecting, define different entities. By being constituted of humans and nonhumans, networks are hybrid in nature: they are and create beings that bestride the boundaries of nature and culture. What an entity is, is determined in its total existence, that is, in the network of relationships that sustains it.

⁴ Agency is associated with intuition and common sense that is located in actors and actants in their relationships or networks. Thus it characterises how knowledge or devices are disseminated in a network (Callon & Law, 1981).

virtue of BIM artefact's *existence* in a network, it inevitably acquires, and virtually grants, the network the agency to transform design, construction and operation of a facility.

ANT has been accused of offering a concept of an 'on-going' process and emergence through constant reconfiguration of network interactions at the expense of seeing elements of stability or robustness over time in a network of configuration (Sørensen & Levold, 1992). Harty (2008) has also pointed out that technological innovations become established over time, and are institutionalised as a 'normal' part of organisational routines in a network-something ANT does not acknowledge. Another frequent critique of ANT is that by levelling the status of human and nonhuman actors, it loses the particularities of both. Suchman (2000), for example, argues that one needs to find a discourse that allows one to recognise the relational character of agency and the mutual constitution of humans and artefacts while retaining their differences. This could be done by acknowledging the differences between things and non-things in a network. Other factors influencing its applicability include the clarity over power relations and the relative importance of natural, technological and social factors in a network (Winner, 1993).

3.2.4.2 Social Construction of Technology (SCOT)

The trends in SCOT move away from technological determinism and the distinctions between social, technical, economic, and political aspects of the development of technology and have replaced the distinctions between society and technology with the metaphor of a *seamless web*⁵ of society and technology (Bijker et al., 1987). The SCOT concept questions the idea that technological development has occurred through a logical, rational self-selective path. It also suggests that "*successful technologies are constructed through a process of strategic negotiation between different groups each pursuing its own specific interests*" (Webster et al., 1994). The notion of *interpretive flexibility* in SCOT (Pinch & Bijker, 1987) indicates the ability of the technological artefact to sustain divergent opinions (i.e., actors able to *interpret flexibly* the emergent of innovative products and processes) especially in a heterogeneous settings plays a key role in explaining how technical artefacts are socially constructed in the work system. Orlikowski (1992) emphasises that there is "flexibility in how people design, interpret and use technology, but this flexibility is a function of the material components,

⁵ Hughes (1987) originally coined the useful metaphor of a 'seamless web' in which physical artefacts, organisations, resources, systems elements, legislative artefacts are combined in order to achieve functionalities. According to Hughes, components of technological systems include physical artefacts, organisations, scientific (e.g., article, teaching, research and development programmes) and legislative artefacts such as regulatory laws. Thomas Hughes has been influential to the development of SCOT.

comprising the artefact, the institutional context in which a technology is developed and used, and the power, knowledge and interests of human actors” (Orlikowski, 1992, p.421). The divergent interpretation of the system’s scope and functions influence how the system is appropriated and exploited by the actors thereby influencing the work system’s alignment or maintaining stability.

A number of scholars have criticised the formulation of SCOT as insufficient or lacking relevance in sociotechnical setting. Despite some conceptual contributions to the STS theory, Klein & Kleinman (2002) have asserted that the SCOT approach “*has made only limited contributions to illuminating how social structures can influence the development [adaptation and implementation] of technology*” (p.28). The assumption that the social group interactions and interpretations is typically consensus merits critical rethinking (Williams & Edge, 1996) because it overlooks how power differences are rooted in structural features of social life. Diverse groups from heterogeneous knowledge boundaries may be rife with intergroup conflicts and power relations. Another criticism is that, simply because a multitude of individuals share a set of meanings does not ensure that they will organise themselves into a group to participate in a design process. Potential groups may exert significant barriers to organisation and participation (cf. McAdam, 1983; Lukes, 1974). Thus, some collective meanings with relevance to an artefact or a particular interest group might not become organised to participate in the design process. SCOT has also been accused of describing the relationships among the technical, social, and economic parts of society as parts of a *seamless web*. This creates a problem, because, even though the social and technical world is interconnected, there are analytical distinctions between them. SCOT however, undercuts the predictive and explanatory distinction between the social and technical by suggesting that the world is too seamless to make distinctions.

3.2.4.3 Distributed Cognitive Framework (DCF)

Distributed cognitive framework is concerned with how cognitive activity is distributed (distribution of information and knowledge) between internal and external representations and how it is distributed across space and time (Hutchins, 1995; Zhang & Norman, 1994). Internal representations are the knowledge and structure embedded in human minds; and external representations are the knowledge and structure in the external cognitive artefacts (Zhang & Norman, 1994). The premise of DCF is that task execution is not a sole pursuit by either the internal or the external cognitive activities, but is shared with mediating resources

found within the organisational environment. In essence, the task is distributed across minds that are connected by way of the activity within which they are collectively participating.

No one particular entity embodies knowledge, rather it is a property of people's engagement with the particular situation at hand; it is spread over the entire contexts which include social attributes, technical artefacts, and organisational rituals and norms (Hutchins, 2000; Steketee, 2006). Duffy & Conningham (1996) opined that there is always "dialogic" connection to distributed cognition either directly as in communicative action or indirectly via some form of semiotic mediation (signs or tools appropriated from the sociotechnical context). In this way, quality of work is dependent on the affordances of the work environment (Resnick, 1991). Salomon & Perkins (1998) refer to this bi-directional effect as a spiral of reciprocal relations between socially distributed technical artefacts, organisational mediating resources and individual cognition.

Distributed cognition is thus of the view that both the internal assets of the person, the external organisational structures and technological artefacts support the intelligence or cognition in a given human action. There is no particular bias in this perspective towards human actors or material artefacts; all elements are evaluated on the same plane – i.e., exploring for cognitive processes wherever they may occur on the basis of the functional relationships of elements that participate together in the process (Nardi, 1996). Distributed cognition thus allows a system to dynamically configure itself to bring subsystems into coordination to accomplish various functions (Hollan et al., 2000).

The concept of DCF has received some criticisms. For example, the DCF is conceived on a basis of shared beliefs, constituting a thought collective in the form of a community of persons mutually exchanging ideas or maintaining an intellectual interaction. Following this line of thought, Walenstein (2002) has asserted that the current field of distributed cognition is deeply rooted in a set of incorrect assumptions originated in a commitment to the notion of all intelligence being trapped on the inside of an internal/external dichotomy, leaving little or no room for the influences posed by culture and other human-related issues. Generally, the exploration of individual accounts of innovation implementations makes it explicit how people assemble their world on the basis of their visions, which is based, not only on negotiations with artefacts, but also political ideals and norms. The main issue with the DCF with regards to the study however is, the interrelationship existing between the internal (i.e., human cognition) and external cognitions (i.e., external artefacts) is largely ignored in the analytical process. Other factors influencing its applicability include the clarity of distinctions

(similarities and differences) of internal cognitions and external artefacts, as well as intra- and inter-level distinctions.

3.2.4.4 Activity Theory Framework (ATF)

Activity theory provides a holistic theoretical framework as a basis for analysing complex sociotechnical phenomenon for many areas of IS research and practice (Crawford & Hasan, 2007). Activity theory has its roots in the work of the Russian psychologist Vygotsky during the first half of the 20th century (Vygotsky, 1978). Vygotsky saw human activity as quite distinct from that of non-human entities in that it is mediated by tools, the most significant of which is language (Crawford & Hasan, 2007). The core attribute of activity theory thus focuses on dialectic analysis on the interaction between subject (human) and their objects (mediated tools or artefacts) in an effort to achieve some purpose or an outcome. These tools expand possibility to manipulate and transform objects but also restrict what can be achieved within the limitation of the tools. Essentially, Vygotsky (1978) defines human activity as a purposeful, dialectic relationship between subject and object, i.e., a person working at something. The subject dynamically learns and grows 'always active' while the object is interpreted and reinvented by the subject in the ongoing discourse of the activity (Crawford & Hasan, 2007).

Engestrom (1999) explicated seven key components framework as the standard lens of activity theory. Engenstrom's (1999) model is useful for understanding how a wide range factors work together to impact an activity. To reach an outcome it is necessary to produce certain objects (e.g., experiences, knowledge and physical products). The relation between subject (human activity) and community is mediated by rules and the relationship between object and community is mediated by the division of labour (Hettinga, 1998). Each sub unit or division of effort within the community imposes rules that impact on the activity in diverse ways. The value of activity theory stems from the analysis of the individual, in pursuance of their activity and objective through an examination of their tools and its mediation through rules, community and history (Hashim & Jones, 2007). The framework sees the integration of technology as tools or artefacts (e.g., instruments, machines and computers) which mediate social actions.

3.2.4.5 Leavitt's Systems Model (LSM)

Leavitt (1964) presents a sufficiently rich STS analytical tool which he developed through his experience of undertaking organisational change and focused on a balanced approach to the

integration of work system's components. This STS model examines the mutual constitutions or co-development of people and artefacts, socio and technical or human actors and non-human actants – to avoid the situation where one outcome is supported or privileged by one element over another. Typically, it depicts the mutual dependency in four sociotechnical components, which comprise people, tasks, structures and technologies. Thus, the work system will comprise actors (with varying attitudes, requirements and abilities), who use a range of technologies and tools, and work within a context with structures and regulatory framework to achieve assigned tasks. Leavitt argued for the interrelatedness of these system components and for the need for their joint consideration.

According to Leavitt (1964), the four elements are highly interdependent and a change in any one of the elements results in a compensatory (or retaliatory) change in the other elements so that the system maintains equilibrium (Lyytinen & Newman, 2008). Each of the sociotechnical components can become the source of the system's misalignment (e.g. Lyytinen & Newman, 2008) because the entity or forces that impinge on everyday practices of the system are coproduced by the system's elements within the confines of the work system. At any particular time, the work system is either in equilibrium where the system is balanced or it is not in equilibrium and the system is not balanced. When it is in disequilibrium, the system contains a gap between one or more of its elements (i.e., either there is an issue with the task, the technology, the actors or the structural arrangements) that call for action - an intervention event to remove the gap, thereby reverting to its equilibrium state (Mumford, 2006). The Leavitt framework has, subsequently, been used by others in different sociotechnical contexts, including, for example, Handy (1993); Scott (1991); Lyytinen & Newman (2008); and Challenger & Clegg (2011). The potential value of applying the Leavittian model is that it provides a structured and systematic way of analysing a variety of complex work systems. Also, it is simple, yet, reasonably well defined and sufficiently broad for analysing the STS implications in different organisational situations.

3.2.4.6 Work System Model (WSM)

Alter (2006, p.12) defines a work system as “a system in which human participants and/or machines perform work using information, technology and other resources to produce products and/or services for internal and external customers.” The work system method is intended to bridge the gap between research and practice (Pettersson, 2008) by considering a broadly applicable set of ideas that use the concept of work system as the focal point for understanding, analysing and improving systems in organisations.

Work system can be organised or designed around the work system framework (Alter, 2006). The framework is organised around nine elements that are included in even a basic understanding of a work system's scope and operation. These *comprise work activities, participants, information and technologies*. These form the basic components of the work system that performs the 'work' (Alter, 2010; Petersson, 2008; Winter, 2010). The rest are *products and services, the customers, environment, infrastructure and strategy*.

According to Petersson (2008), the WSM has explicit pragmatic scope by describing work and prescribing design at the same time (Petersson, 2008), this is because, the WSM comprises an analysis model for creating what is referred to as 'work system snapshot'. The snapshot is time-dependent business definition and time dependent delimiter of the universe of discourse, or of a particular context (Petersson, 2008).

The framework has received some criticisms. Benbasat & Zmud (2003) have argued that the relevance of IS research is dependent on its contributions (or the degree of applicability) to practice. However, the main challenge for a design oriented IS field has been the development of a descriptive framework (Gregor & Jones, 2007). That is, a framework that gives explicit action directions and describes 'how to do something' (Gregor & Jones, 2007, p.313). This approach has been applied in wider IS context, however, it is based on individual organisational environment. Its generalizability to multiple organisation alliances still remains to be proven.

3.2.4.7 Soft System Model (SSM)

SSM as a methodology, or a framework of enquiry, enhances the awareness of the political aspects, the organisational culture, the appreciation of the various perspectives of groups and individuals and the realisation of the need for a holistic approach to the problem under investigation (Maqsood et al., 2001). Unlike hard systems thinking, which may be appropriate for well-defined technical problems, soft systems thinking (i.e., SSM) is usually applied to nebulously ill-defined situations involving human beings and cultural considerations (Checkland & Scholes, 1990). The former, hard approach assumes that goal can be attained through hypothesis-testing experiments in the manner of natural sciences, whereas the latter, SSM approach aims to explore how people make sense of their perceived world so as to bring about improvement (Tajino et al., 2005). The hard system thinker or observer perceives the real world as a system which can be engineered, whereas the soft

system observer sees the real world as complex and confused place, but it can be organised or be explored as a learning system.

The basic structure of SSM rests on the idea that in order to tackle real-world situations, one needs to make sure that the 'real-world' is separated from the 'systems thinking world'. The real world has a complexity of relationship. This relationship is explored through models of purposeful activities based on explicit world-views which are best conducted with wide range of interested stakeholders. According to Checkland (1984) a real-world problem situation is not well-defined, because it is multifaceted and complex, thus, it resist solution by any single technique or by a single person. He thus proposed a purposeful activity systems model. The models are used in the problem situation to provide structure to a debate about what to do. The purpose of the debate is to uncover the different constructions people in the situation place upon events and to find some kind of accommodation between different, conflicting interests (Checkland, 1984). The change being sort should be culturally desirable and systematically feasible. Once desirable and feasible changes are defined, then the new problem situation engrosses the implementation of the change. SSM represents one of set of ideas that has demonstrated how progress can be made in resolving difficult problems embedded in complex social systems.

SSM has however been criticised for its lack of 'objective' standards; it is regarded as conservative in nature and management driven (e.g., Ulrich, 2012; Ivanov, 1991; Mingers, 1984). It aligns more to social activity systems rather than holistic sociotechnical system. This is understandable, because it was developed in the 1970s in an action research programme (Checkland, 1984; Checkland & Scholes, 1990), at a time when it was thought that, a well-established system engineering approach (hard system thinking) could unequivocally be defined with precision, allowing organisational system to be engineered to achieve the objectives, using a range of well-tested hard system techniques (Checkland, 1999). Also, in the study of the use of SSM, the findings of Mingers & Taylor (1992) are that, majority of people chose SSM to develop an understanding of the situation, and not to bring about change.

3.2.4.8 Sociotechnical Constituency (STC)

The basic tenets and evolving conceptual aspects of the sociotechnical constituencies (STC) research programme are found in various papers (Molina, 1990; 1998; Molina & Kinder, 1999). Sociotechnical constituencies (STC) are defined as ensembles of institutions

interacting with each other through and within the development of specific technologies. The development, adaption and appropriation of a given technology become a single process of interpenetration of technical, socioeconomic, political and cultural factors. Each sociotechnical constituency is a unique and dynamic fusion of technology constituents (e.g. technologies, expertise, tools, machines and systems) and social constituents (e.g. people, organisations and institutions coupled with their goals, values and governances) stressing the point that no single element can alone explain the shape of technological processes. Each sociotechnical constituency is unique and contextually specific depending upon the particular constituents assembled to appropriate a particular innovation. On the other hand, all innovations share the characteristic of being dynamic processes, aligning and re-aligning social and technical constituents, in order to become a successful innovation constituency.

Constituencies are built by processes of alignment and re-alignment of active constituents parts. The concept of alignment is used more generally, to deal with the mutual adaptation process involving new technologies or an innovation and user-organisations (Leonard-Barton, 1988). Molina uses sociotechnical alignment to define the process of creation, adoption, accommodation (adaptation) and interaction of technical and social factors and actors which underlie the emergence and development of an identifiable constituency. The key conceptual instrument developed by Molina (1998) to analyse alignment processes is the diamond of alignment. The concept of 'diamond of alignment' has been used to illustrate the multiple dimensions of alignment required for successful constituency-building in intra and inter-organisational contexts. At the centre of the analysis in the diamond comprising the social and technical dimensions combined to form the sociotechnical constituency. The content of the diamond of analysis for any constituency building comprises four key elements: 1) nature of target problem; 2) constituents perceptions and pursuits; 3) intra- and inter-organisational governance; and 4) nature and maturity of interacting technologies. Molina (1990) argues that no recipe for successful innovation exists; rather the ingredients contributing to constituency alignment can be assembled and analysed. Each level of aggregation requires grounding in social activity and events to capture the intense debate and contested results of alignment processes. Thus, there are no grand connections as they are bound to be different for any constituency building.

3.2.5 Comparison of STS Analytical Frameworks and Influence on BIM Implementation Analysis

The various STS theoretical frameworks can guide in understanding the sociotechnical requirements for innovation activities in organisational contexts. These approaches tend to look at innovation activities from different levels (i.e., level of abstraction), examine it from different empirical cases and apply different conceptual tools and so may get very different pictures of it. Table 3.2 summarises the differences amongst these STS analytical frameworks. In many cases they complement each other and enrich the understanding of innovation development, adaptation, and utilisation

The key findings from the STS reviews show that the different theoretical approaches to STS analysis are not alternative approaches. Rather they suit different analytical purposes. For example, the ANT approach is particularly suited to networks which are looser in the sense of being less directed towards a designated outcome, whereas, the STC approach is more suitable to analysing the processes of innovation where a particular outcome is privileged (example being, STC alignment where effective utilisation of BIM is the ultimate goal). While they are conceptualised to serve different analytical purposes, the STS analytical frameworks complement each other in many ways. While SCOT, ANT, LSM and STC focus on the dynamics of social change, SSM and ATF focus on how the individual is shaped by (and shapes) the nonhuman actors that are available in the work system.

Some are particularly conceptualised at multiple dimension, traversing multiple layers of social and technical constituents, particularly ANT and STC, where they are often utilised for multilevel analysis e.g., individual, intra- and inter-organisational network/constituents. Some are also often, utilised at a single level for analysis e.g., WSM and SSM. And yet, others can equally be used for single or inter-level sociotechnical analysis, e.g., LSM.

Some of the STS conceptual frameworks are biased either towards social construction or technological determinism. SSM and SCOT for example, lean towards social constructivism. SSM in a way was developed to contest the hard system mindset. Some however advocate for mutual adaptation for both the socio and the technical. STCs position on mutual shaping is similar to that of ANT, LSM, DCF and ATF: ANT allows one to introduce shades in the character of agency in human and the artefacts while maintaining their equal status and mutual constitution. ANT argues that artefacts are the glue that holds the social together (Latour 1991). The interaction between humans and artefacts is not neutral, both are

transformed by it. In this mutual interaction artefacts become part of the network identity. Likewise, LSM points to mutual constitution or co-development of work system's sociotechnical component in order to maintain equilibrium. STC also talks about sociotechnical *alignment*, whilst LSM talks about sociotechnical *equilibrium*, *balance* and *deep structure*. Both DCF and ATF emphasise the importance of mutual shaping at the mental or cognitive level. They argue that artefacts do not simply facilitate certain activities or mental/cognitive functions, they shape and transform them, and they transform the ways in which one interacts with, and think about, the world.

STC holds that artefacts are socially constituted; that is, their patterns or governance is not uniform across different constituencies. This means, when a new artefact is introduced, there is a potential of misalignment which calls for appropriation or realignment. LSM holds similar view to that of STC, however, with LSM, there is constant interaction and each of the contextual elements (actors, structure, task and technology) can cause *disequilibrium* of the system's deep structure at any given time. SCOT also calls for *interpretive flexibility* of artefacts by relevant social groups until *closure* and *stabilisation* is achieved. While SSM advocates the need for relevant social groups to engage in a *structured debate* to develop *purposeful activity* system about desirable and feasible change to accommodate perceived real-world problems.

The various frameworks indicate that the development, adaptation and appropriation of innovation products and processes occur in a sociotechnical context. The context or constituency in which the technology is introduced will readapt itself in order to remain in equilibrium, or fall apart, but it will not remain unchanged (Latour, 1991; Winner, 1993; Suchman, 2000; Callon, 1986). Thus, being seamlessly located in a sociotechnical context, the use of BIM in the workplace will affect the practices and the routines of users; it may also increase the inter-organisational communication and relationships with other BIM users, vendors, and policy makers. The implementing organisation, the products developers and the construction organisations are connected in different ways and each one of these constituents has to adapt to the others and the distinction between them are reconstituted.

As shown in Table 3.2, some of the STS analytical frameworks have been applied within the AEC contexts. For instance, to provide theoretical understanding of the implementation and use of innovations within construction contexts, Harty (2008) mobilises the ANT approach to emphasise the roles that both human actors and non-human agents play in the performance and outcomes of interactions. Drawing on empirical material from the implementation of new

design and coordination technologies on a large construction project he further argued that both the rhetoric of the ‘improvement agenda’ within construction and theories of innovation fail to account for the complex contexts and disparate perspectives which characterize construction work. The ANT-informed approach treats both the innovation and the appropriation as processes of translation within networks through the manoeuvres of various actors for increased influence on technological artefacts (Harty, 2010; Sage et al., 2011).

Schweber & Harty (2010) delineated the types of insights which the SCOT approach offers for research into the built environment. This approach is distinctive for its analysis of the technical and social as mutually constituted within sociotechnical network. From the SCOT perspective, Schweber & Harty (2010) draw out the ways in which the content, meaning and use of technology is negotiated in practice, how particular technical configurations are elaborated in response to specific problems and why certain paths or solutions are adopted rather than others. Linderoth & Pellegrino (2005) also use the concept of SCOT to create a framework for describing the technology and its role in the process of IT-dependent change project, thereby developing a deeper knowledge about the implications for management of IT-dependent change projects. The SCOT approach is thus offered to be particularly relevant for research into the development and use of construction technologies.

Perry (1997) also draws from the theoretical underpinning of cognitive science within the analytic framework of distributed cognition in an interdisciplinary study of design performance in the construction industry. Perry’s (1997) findings demonstrated how design processes operate simultaneously at personal, organisational and inter-organisational levels. The study demonstrates that the DCF can be used in the analysis of cognition within a setting involving multiple individuals in concert with technological artefacts.

Table 3.2 Summary of STS analytical frameworks

No	STS analytical frameworks	Framework	Units of analysis	Sociotechnical constituents	Reference	Application in the AEC sector
1	ANT	Centering on network of human actors and non-human actants	Connections and reconfiguration of social (actors) and technical (actants) as agencies to shape networks	Social artefacts and technical artefacts in a network	Callon, 1986; Callon & Law, 1982; Law and Hassard, 1999	Harty 2008; Harty 2010; Sage et al., 2011
2	SCOT	Centering on the ‘seamless web’ of the social, technical, economic, and political aspects of innovation development, adaptation and use	Groups and social interaction to the understanding of social shaping of technology	Interpretive flexibility, relevant social group, closure and stabilisation, and wider social context	Bijker, et al., 2012; Pinch & Bijker, 1987	Linderoth & Pellegrino, 2005; Schweber & Harty, 2010
3	DCF	Centering on integrating cognitive acts in the context of attaining a common goal	Cognitive system composed of internal /actors cognition and cognitive artefacts	Human actors, cognitive artefacts, mediating structures	Hutchins, 1995; Hollan et al., 2000;	Perry, 1997
4	ATF	Centering on purposeful direction of the subject-object domain mediated by tools and community through rules and division of labour	The whole of the work activity broken into analytical components of subject (person), object (intended activity) and tool (mediating device by which the action is executed)	Subjects, objects, mediating artefacts, rules, community and division of labour	Vygotsky, 1978; Kuutti, 1996	Martin & Hartmann, 2010
5	LSM	Centering on the alignment of the four aspects (actor, structure, task and technology)	Alignment and mutual dependence of component in work system’s context	Actors, structure, task and technology	Leavitt, 1964; Lyytinen & Newman, 2008; Lyytinen &	Sackey et al., in press

					Damsgaard, 2001
6	WSM	Centering on describing work activities and prescribing time dependent work design	IT-reliant work activities	work practices, participants, information and technologies	Alter, 2006, 2010; 2013
7	SSM	Centering on solutions to real world problem situations which conflicting interest can find to be both desirable and feasible	Finding common grounds between people's conflicting goals and real world problem situation	Problem situation, purposeful activities, desirable and feasible action	Checkland, 1984; Maqsood et al., Checkland & 2001; Finegan, 2010 Scholes, 1990
8	STC	Centering on interrelation and adaptation of social and technical factors in a constituency building process	Sociotechnical constituencies of technical, socioeconomic, political and cultural influences in a diamond of alignment	Constituents' perceptions, goals and resources, and nature and maturity of technologies	Molina (1990; 1998; 1997); Molina & Kinder (1999)

The appropriateness of the activity theory as yet another STS analytical approach to technology uptake in the AEC context is highlighted by (Martin & Hartmann, 2010). They highlighted that the ATF appears to better encapsulate the underlying dynamics by linking individuals to the tools they use, the values and belief systems they adhere to, and the community (organisational) patterns they are part of. In particular, this proves to be of use for an analysis of micro-level processes, linking back to macro level circumstances within the multilevel nature of the construction organisation setting.

Sackey et al. (in press) adopted LSM to understand and analyse BIM implementation in a multidisciplinary construction context. The LSM helps to depict the mutual dependency in the STS frames of actors, structure, technology and tasks-in particular, pinpointing significant issues requiring management attention during BIM uptake. Their study reveals that the interrelations among the STS elements are the main drivers that depict work systems' disruption, maintenance and stability in attempting to engender BIM work practice (Sackey et al., in press).

Maqsood et al. (2001) also illustrated the approach of applying SSM to problems of knowledge management in construction project management, especially those confusing situation associated with the human, organisational and technical aspect of the work system. They concluded that the SSM approach is ideal as a group decision-making approach and is ideal for analysing the construction setting by the active participation of different participants and stakeholders and encourages joint ownership of the problem solving process. Thus, it is more appropriate for organisations seeking to achieve changes in workplace culture and transformation into a learning organisation as it encourages joint ownership of the problem solving process (Finegan, 2010).

This research study aims to draw freely from the sociotechnical systems frameworks as deemed fit to inform the analysis of the findings. Thereby help to build on the existing conceptual tools to develop a new framework for analysing sociotechnical alignment for BIM uptake in construction organisations. Miles & Huberman (1994) distinguish between two types of theoretical frameworks. One is classified as tight and prestructured — the other as loose and emergent. Bryman & Burgess (1994) state that analytical framework provides the researcher with a set of general guidelines. In aiming at theory development, the researcher needs to be open to the multitude of meanings that a certain concept can give rise to. Thus, the study adopts a “*tight and emergent*” STS theoretical framework (Dubois & Gadde, 2002). The tightness reflects the preconception of, and the degree to which the STS theoretical frameworks have been articulated, whilst the emergent indicates that the theoretical framework would evolve simultaneously and successively with empirical observations. The successive refinement of

concepts implies that they constitute input, as well as output of an abductive study, where empirical information inspires changes of the theoretical viewpoint and vice versa.

Focussing on the various conceptual platforms of the STS analytical frameworks provide an ideal focus point to determine the influence of BIM, as a socially constructed and socially shaping cognitive technology and how it impacts the changing construction context. Studying BIM uptake in construction context via the lenses of STS makes possible the different assumptions that are negotiated by the different actors and how they are inscribed into the innovation process and product to influence the appropriation and stabilisation of the technologies. Drawing on the current STS analytical frameworks will guide in understanding the requirements for innovation assemblage and the consequence of mutual adaptation that might occur during BIM uptake in construction contexts.

Although these STS analytical frameworks as discussed above, such as LSM (Leavitt, 1964) and STC (Molina, 1998) are important in explaining the complex STS requirement for innovation activities in organisations, they are not particularly developed to suit the construction context. These approaches tend to examine innovation activities from different empirical cases and organisational contexts and so may get very different pictures of it in enriching the understanding of innovation development, adaptation, and utilisation. It seems Molina's STC framework is reasonably well defined and sufficiently broad for analysing STS implications in the construction context. Also, it provides a structured and systematic ways of analysing multiple constituents with localised visions and ambitions in a 'diamond of alignment' by establishing a consensus on holistic ambitions situated on feasible and purposeful activities. Although Molina's STC is comparatively suitable to the construction context due to its multilevel considerations (e.g., causal linkage of constituency at organisational projects, BIM vendor levels etc.) nonetheless, Molina's diamond of alignment is not particularly structured according to the configuration or the arrangement of construction organisations. As such, there is a need to further extend the STC theory in this study to provide a potential framework for analysing BIM-enabled work practices in the construction environment. Chapter five therefore synthesises the STC with the exploratory findings and other STS analytic concepts to help establish an optimal fit between the STC's concept of 'diamond of alignment' and multi-functional settings such as found in BIM-enabled construction environments. This provides the basis for building on the existing STS conceptual tools to help develop a new framework for analysing sociotechnical alignment for BIM uptake in construction organisation context.

3.3 Summary

This chapter has argued that, a useful conceptual framework for studying the process of BIM implementation can be derived from STS approaches (e.g., Molina & Kinder, 1999; Checkland, 1984; Leavitt, 1964; Alters, 2006; Hutchins, 1995). The importance of STS application in relation to ICT uptake in construction has rarely been discussed in the AEC literature.

The strength of the STS is not only in its usefulness in identifying the technical constituents (e.g. technology, process and system) and social constituents (e.g. people and institutions, their goals and perceptions) which interact in a specific circumstance to shape the work system. It is also in its ability to offer a holistic theoretical framework for analysing the process of alignment between these technical and social elements involved in the implementation process. The STS approach also conceptualises both the inter-organisational and intra-organisational networks to form a multilevel sociotechnical constituency, and is therefore particularly suitable for analysing complex multi-level interacting activities in the AEC environment such as BIM project delivery.

Overall, the STS theoretical frameworks represent an important progression towards bridging the knowledge gaps relating to BIM uptake and other concomitant technological solutions in construction organisations. In order to develop empirical understanding of BIM implementation, and also apply the STS for analysing BIM-enabled construction organisations, there is a need for a robust research design which stipulates how data will be collected and analysed, the strategy of enquiry, and their underpinning philosophical position. This is addressed by the next chapter.

CHAPTER FOUR

4 RESEARCH DESIGN AND METHODOLOGY

4.1 Introduction

At the beginning of any research project the researcher faces myriad choices as to how to capture the phenomena they wish to study. The term 'research design' is used here to capture the interacting elements of philosophy, research methods and analysis which constitute the research process. The selection of these elements and the strategy of their combination are formative in producing research capable of providing a contribution to knowledge. Producing a coherent and manageable research structure to guide the research process must therefore be considered an essential stage. This means that the researcher should give very clear indication as to the philosophical, methodological and analytical choices made; recursively and reflexively examining the justification for each methodological step.

This chapter presents the research methodology and design adopted for the empirical investigation of the study. The chapter begins with a discussion about the philosophical and methodological position of the study. Following this, the chapter identified research approaches and discussed different research methods to ascertain the method that might best help address the research objectives and also be compatible with the philosophical position of the research. The justification for choosing the research method and the data collection procedure are also presented.

4.2 Research Philosophy

Research philosophy is concerned with the nature and development of knowledge (Saunders et al., 2007). One's philosophical perspective influences the way data about a phenomenon is collected and analysed (Greenwood & Levin, 1988). An understanding of philosophical issues is necessary to help researchers identify, clarify, and create appropriate research designs (Easterby-Smith et al., 2002). Making decisions about research design is fundamental to both the philosophy underpinning the research and the contributions that the research is likely to make (Dainty, 2008). In the technological innovation discipline, the question of which research philosophy is most appropriate has been a subject of a debate for some time. Orlikowski & Baroudi (1991) have identified that the three viewpoints of research philosophy are also applicable in STS research context. These are epistemology, ontology and axiology (Saunders et al., 2007).

4.2.1 Epistemological Position

Epistemology, defined by Hirschheim (1985), refers to beliefs about the way in which knowledge is constructed. Every philosophical paradigm contains an epistemological position to the extent that certain forms of knowledge are privileged or rejected as more or less valid. Consequently, many epistemological issues confront the social scientist; for example the question of the possibility of knowledge – to what extent is genuine or pure form of knowledge achievable? The origin of knowledge impacts upon its very substance; whether it is derived from the senses, the conscious mind, experiences or some other origin (Delanty & Strydom, 2003). Hence it is possible to distinguish between the nature of knowledge and what constitutes truth. Three views of epistemology, positivism, interpretivism and realism are discussed below.

Positivism: Positivist postulates that reality is objectively given and can have measurable features. Positivism therefore aims to present reliable predictions and accounts of events or inquiries. Under positivism research, the researcher attempts to reduce the field of inquiry, focusing on some specific areas to gather quantifiable data. For positivism, causal relations are investigated with structured instrumentation, including formal propositions, quantifiable measures of variables, hypotheses testing, and the drawing of inferences about a phenomenon from the sample to a stated population (Orlikowski & Baroudi, 1991).

As a philosophy of science, positivism has been subject to criticism, from the interpretive perspective in particular. The interpretive critique has focused on positivism's inadequate view on the nature of social reality. Kuhn (1970) argues that positivism cannot account for the way in which social reality is constructed and maintained, or how people interpret their own actions and the actions of others.

Interpretivism: interpretive epistemology tries to gain understanding of the phenomenon in the context in which it is produced and through the different perceptions of the people or groups involved (Orlikowski & Baroudi, 1991). People's perceptions are interpreted by their own circumstances and experiences; consequently, there is not a universal reality but as many as different perceptions. Interpretive research philosophy lies in the belief that meanings arise out of social interaction and developed and modified through an interpretive process (Boland, 1979). Such a process, as Blaikie (1993) notes, requires the researchers to grasp the socially constructed meanings and to reconstruct these meanings in social scientific language, which is designed to explicitly capture complex, dynamic, social phenomena (Orlikowski & Baroudi, 1991).

Interpretivism has also been subject to criticism. For example, Rex et al., (1998) is critical of interpretive social scientists for dissociating themselves from any form of structural analysis,

while Giddens (1984) argues that it is the important and typically unintended consequence of human action which reinforces beliefs, roles, and meanings, and sustains the structure and practices of the society as a whole over time.

Realism: realists are pragmatists. They propose that positivism and interpretivism are not necessarily regarded as opposing and irreconcilable viewpoints. They assert that there is no one correct method of science but many methods (Morgan, 2005; Polkinghorne, 1983; Hirschheim, 1985). The adoption of particular research methods for a study, as Benbasat (1989) emphasises, depends on the objectives of the researcher, the amount of knowledge in the field, and the nature of the topic under investigation. Kuhn (1970) argues that the single perspective designed for research in normal science overlooks the anomalous quality of human experience. Thus, social science research requires breadth of vision, tolerance and a willingness to accept different approaches and objectives instead of conformity (Mumford, 2006; Orlikowski & Baroudi, 1991).

4.2.2 Ontological Position

The ontological assumptions concern the nature of the social world being investigated, whether it is, for instance inherent or peripheral to the individuals concerned. It broadly refers to conceptions of reality (Dainty, 2007), and in broad terms, it is objective or constructive.

The philosophers who concern themselves with the objective viewpoint believe that objects or social entities exist autonomous/external to the individual/social actors concerned with their existence, and can be studied as such (Weber, 2009; Bryman & Bell, 2003). This viewpoint is the basis of the scientific method of inquiry. The scientific method chooses from the total number of elements in any given state, thereby, missing some vital or relevant elements. This selection is performed in order that elements that can be subject to a quantitative analysis are investigated. By its nature therefore, the scientific method is reductionist (Creswell, 1994; Newman, 1998; Williamson, 2002).

Constructivist ontology in contrast, believes that objects of thought/social phenomena are created from the perceptions and consequent actions of those social actors concerned with their existence. The philosophers of the subjectivist school of thought surmise that social phenomena are produced through social interaction and are therefore in a constant state of revision (Bryman & Bell, 2003; Babbie, 2013).

One's epistemological perception (beliefs about how knowledge is constructed) is inextricably linked to ontological perspective (i.e., conception of reality). The positivist epistemology is linked to the objectivist ontology (i.e., single objective reality) whilst the interpretivist epistemology is linked to the constructivist ontology (i.e., multiple realities) (Sutrisna, 2009).

The question to be answered is whether social reality is internal or external to an individual? In this study, the analysis of BIM implementation is interpreted through individual experiences in their work context, as such, the human perception of reality is paramount. It is therefore argued that social reality in organisations is internal and thus follows the constructivist school of ontology.

4.2.3 Axiological Position

Axiology is the domain of values and ethics. Axiology has been noted to have emerged from the Greek word, “*axia*”, which can be literally translated to mean “*value*” or “*worth*” (Dawood & Underwood, 2010). Axiology is therefore the study of value. Testing the value of knowledge can be achieved by testing the value it creates to humans and their work-settings (Saunders et al., 2007). This can be done in research by investigating end users’ views and opinions through qualitative and or quantitative means to better assess the value of their products.

4.3 Approaches to Research

Aside from the philosophical positions, researchers also have to decide on the *research approach*; to provide specific direction for procedures in a research design, and *method of enquiry*; for collecting and analysing data (Franz & Robey, 1987). Researchers contemplate the links and interplay between theory, case method and empirical phenomena when designing research approach. Developments in research depend on what empirical phenomena the researcher is able to capture, how theories are developed (existing-theory testing or new-theory building) to understand and explain these phenomena and what methods are used in the process for empirical validation. In the disciplinary area of social sciences, there are three schools of thought when it comes to connecting theory, method, and empirical phenomena, albeit in different ways. The first one relies on a deductive approach in that empirical data is either presented before or after theoretical considerations or “sandwiched” between them (Dubois & Gibbert, 2010). The second uses a deductive approach where hypothesis are deduced from existing theories to be empirically tested or validated. And the third uses an abductive approach, where theoretical frameworks evolve simultaneously and interactively with empirical observation.

Järvensivu & Törnroos (2010) relate the three research approaches to research philosophy and argue that positivist researchers usually adopt deductive research process wherein they begin the research with theoretical argumentation and validate these arguments with empirical observations. In contrast, critical realists often start with subjective account of lived experiences and from thereon, build theory inductively. Whereas, constructivist research philosophers often adopt research logic based on abduction. The three underlying research approaches – induction,

deduction and abduction (Dubois & Gibbert, 2010), each with its specific links to theory, empirical phenomena and methods are briefly described in the following sections.

4.3.1 Deductive Research Approach

The deductive research approach is a theory testing process, which commences with an established theory or generalisation, and seeks to see if the theory applies to specific instances (Hyde, 2000). A deductive study is characterised by the testing of theoretical proposition through empirical research (Saunders et al., 2007). Järvensivu & Törnroos, (2010) relate deductive research approach to research philosophy and argue that positivist researchers usually adopt deductive research process wherein they begin the research with theoretical argumentation and test these arguments with empirical observations. Thus, from its objective ontological reality, deductive approach involves the testing of a priori hypotheses or theories using quantitative data that incorporates standardised measures and statistical techniques (Bryman & Bell, 2007). The roots of quantitative data are in the natural sciences and are based on quantifying and measuring the information that is observed and collected by the researcher (Myers, 1997), requiring preconceptions to be set aside in order to identify objective facts based on empirical observations.

The goal of deductive research is to identify generalizable laws that are based on the identification of statistical relationships, and statistical generalisations are made from a sample of a wider population (Ackroyd, 2004.). The deductive approach has been accused of particularly bringing a very restricted relationship and sequence between theory and empirical data (Bryman & Bell, 2007), because developing a priori theory with literature is far different from coming to the field to verify, falsify, or modify a unified, firmed-up theory of social research. In that path, deductive research only manages to strip-off intricacies in the research context in order to produce generalizable, reproducible results to contribute to the 'objectivity' and 'testability' of social research (Kauber, 1986), which may not reflect the social reality of the context under investigation. Methods that are associated with the positivist paradigm outlined in McEvoy & Richards (2006) include: structured interviews and questionnaires, randomised controlled trials, systematic reviews and statistical analysis of empirical data.

4.3.2 Inductive Research Approach

From the logical ordering of the theory generation process, induction is the inverse of deduction (Anvuur, 2008), because it moves from a specific empirical facts or a collection of observations to developing, not testing theory (Danermark, 2002; Spens & Kovacs, 2006). The observation of the empirical world leads to the formulation of concepts to explain the observation. In contrast to the deductive research process, the inductive approach often start with subjective account of

lived experiences and from thereon, build theory inductively (Järvensivu & Törnroos, 2010), placing a much greater emphasis upon the way in which the world is socially constructed and understood (Blaikie, 1993). Participants are selected using purposive or theoretical sampling approaches on the basis of how useful they are likely to be for the pursuit of the inquiry, and the interaction between the researcher and the participants in the study is seen as an integral part of the research process (Philip, 1998). Qualitative data is therefore predominantly used in inductive research work to explain social phenomenon (Goering & Streiner, 2013; Strauss & Corbin, 1998). Rather than trying to quantify the information under study, qualitative researchers try to understand the phenomenon and the context in which it exists (Myers & Avison, 2002). Hence, typical of an inductive research is that, it moves from a particular case or empirical observations to creating general facts and finally developing theories based on the findings from that context (Spens & Kovacs, 2006).

4.3.3 Abductive Research Approach

The aim of the abductive research process is to develop the understanding of a new phenomenon (Alvesson & Skoldberg, 2009) and to suggest new theory with the application of the new theory in an empirical setting (Andreewsky & Bourcier, 2000). The abductive approach differs from deduction and induction in its research process. The deductive approach for instance, derives theories from literature review, reaches logical conclusions, and presents the theory in the form of hypotheses and propositions (H/P), tests these H/Ps in an empirical setting and then presents its general conclusions based on the corroboration or falsification of the H/P to specific instances (e.g., Kovacs & Spens, 2005; Danermark, 2002). Thus the logical sequence of deduction is from *rule to case to result* (Danermark, 2002a). In inductive on the other hand, empirical observations about the world lead to the development of emerging propositions and their generalisation in a theoretical frame, thus, it follows the logical pattern of *case to result to rule* (Danermark, 2002a). However, the abductive approach follows yet another process; from *rule to result to case* (Danermark, 2002a, Kirkeby, 1994). Abductive research questions the often assumed independence between method and theory development or testing, and proposes knowledge development through the iterative dialogue between data and an amalgam of existing theories or propositions (Dubois & Araujo, 2004; Van Maanen et al., 2007). That is, the initial proposition or theoretical framework of the research phenomenon evolving simultaneously with empirical observation towards new knowledge development.

Abductive reasoning emphasises the search for suitable theories (rules) to an empirical observation (result), which Dubois & Gadde (2002) call “theory matching”, or “systematic combining.” In this process, data is collected simultaneously to theory building, which implies a

learning loop (Taylor et al., 2002), or a “back and forth” direction between theory and empirical study (Spens & Kovacs 2006; Dubois & Gadde, 2002). This iterative process aims at suggesting new knowledge, however, the generalisation of the new theory only occurs after applying it in further empirical studies, i.e., after its corroboration in a theory-testing phase (Spens & Kovacs, 2006).

It is argued that qualitative research methods such as case studies and action research present idea setting for abductive research due to the possibility of simultaneous data collection and theory-building process with such methods (Dubois & Gadde, 2002), i.e., revolving between empirical observations and theory (McEvoy & Richards, 2006). As such, qualitative studies enable a researcher to study phenomena in a real setting, where boundaries between context and the phenomenon being studied tend to be blurred. The importance of qualitative methods in the context of theory construction stems from researchers’ ability to revisit the phenomenon they study in light of existing theoretical accounts. Revisiting research site compels the researcher to reevaluate and rethink mundane experience to break the habituation of perception (Kilpinen, 2009), heightened through qualitative data such as detailed field notes, transcriptions, and documentation analysis. Data that have not been very “luminous” (Katz, 2001) in the field, or in theory, often yield insights through repetitive abductive methodological processes (Timmermans & Tavory, 2012).

Some concerns have been raised regarding abduction based on its middle-ground position between induction and deduction (Tavory & Timmermans, 2012). While the strength of the approach is that it is based on iterative dialogue between empirical observation and conceptual inquiry, “it is vulnerable towards achieving unexpected empirical evidence and unorthodox theoretical insights.” It has however, been suggested that abductive researchers must provide explicit description of the research process as well as rigor concerning research ethics in order to increase the reliability of the research in question so as to render it possible for other researchers to replicate the research and its findings (Timmermans & Tavory, 2012; Spens & Kovacs, 2006).

4.4 Research Methods

The research methods exemplify step-by-step approach for collecting data. The rationale of the research method guides the whole research procedures or how the research findings are accumulated (Franz & Robey, 1987). According to Tashakkori & Teddlie (1998, p.3) these two models, quantitative and qualitative, are known alternatively as the ‘positivist’ approach or the ‘constructivist’ orientation. The positivist paradigm underlies what are called ‘quantitative methods’ whilst the ‘constructivist’ paradigm underlies qualitative methods. Typical quantitative research methods outlined in Galliers (1992) include: laboratory experiments, field experiment

and surveys. And typical qualitative research methods include action research, case studies, ethnographic research and grounded theory. The following subsections discuss briefly these research methods.

4.4.1 Quantitative Research Methods

There are two main quantitative research methods: survey and experimental research. These are discussed in the following sections.

4.4.1.1 Experimental Research

Experimental research is usually carried out in laboratories where there is full control on the variables and it aims to test the relationships between identified variables, ideally holding all variables constant and changing only one variable to examine the effects on the dependent variable (Fellows & Liu, 2009). It is thus, mostly understood to be better suited to bounded problems in which the variables are known with some degree of certainty (Fellows & Liu, 2009). It usually involves using quantitative analytical techniques to make generalizable statements applicable to real-life situations. The strength of this method rests in the ability of the researcher to fully control all the independent and intervening variables being studied that may affect the dependent variables (Stone, 1978). This approach is often criticised by social scientists due to its over-simplification and isolation of variables found in real world situation (Selvin, 1957). Galliers & Land (1987) also argue that experiments are more applicable in the natural sciences than in behavioural research. Hence, experimental research in general, is less likely to be applicable in societal or organisational contexts, such as technology implementation studies (Galliers & Land, 1988; Lewin, 1951).

4.4.2 Survey

Survey approach involves quantitative statistical analysis where data sample of a large number of organisations is collected through methods such as mail questionnaires, published statistics or telephone interviews (Gable, 1994). Pinsonneault & Kraemer (1993) noticed that survey method has three main features: first, information is collected by asking pre-defined questions, second, the information is generally collected from a sample of the study population in such a way as to enable generalizable findings to the population of interest and third, the purpose is the generation of quantitative descriptions-survey approach involves quantitative statistical analysis where data sample of a large number of organisations is collected through methods such as mail questionnaires, published statistics or telephone interviews (Gable, 1994). Galliers (1992) indicated that the survey approach is a good means of obtaining snap shots of practices, situations or views at a certain time, from which significant results can be identified and

inferences can be made. Jick (1983) also suggests an increased confidence in the generalizability of survey results.

Nevertheless, Galliers (1992) argues that, little insight can be obtained using surveys regarding the causality behind the phenomena under investigation due to possible bias in response, such as the self-selecting nature of questionnaire respondents. This view is reinforced by Gable (1994), pointing out that “*often the survey approach provides only a snapshot of the situation at a certain time, yielding little information on the underlying meaning of the data.*” Locke (1989) also stated that survey research is inflexible to discoveries made during data collection, suggesting that survey research could serve well as a method of verification rather than discovery or exploration.

4.4.3 Qualitative Research Methods

Although there are several qualitative research methods, Cresswell (2009) identified four main commonly used strategies. These include grounded theory, ethnography, action research and case study. These are briefly discussed in the sections that follow.

4.4.3.1 Grounded Theory

The novel intention of the co-originators of the grounded theory research methodology (Glaser & Strauss 1967) was to systematically derive theories of human behaviour from empirical data. Charmaz (2006) indicated that by grounding theory development in data, Glaser & Strauss (1967) were able to bridge the void between theoretically uninformed empirical research and empirically uninformed theory. The approach commonly starts with a general problem conceived in a particular disciplinary perspective, focused towards an area of social concerns (Dey, 1999). The process involves multiple stages of data collection and the refinement and interrelationship of categories of information (Strauss & Corbin, 1997). The process of data analysis (open, axial and selective coding) is sequential and consecutive and runs parallel with data collection. The coding categorises the data to reflect the emerging issues, and each phase guides the next stage until the final theory is grounded (Jones & Alony, 2011). Over the years, however, there have been different perspectives on the grounded theory, aiming to elucidate, expatiate, and even debate the process (Urquhart, 2001). Very public differences between the co-originators of the Grounded Theory approach were clear in their latter academic publications (Glaser, 1992; Strauss & Corbin, 1998). This situation has positioned the theory into two distinct variants. For example, Glaser (1992) leads with the principle that researchers should have an empty mind to allow theory to emerge, while Strauss & Corbin (1992) permit a general idea of the area under study and use structured questions to lead a more forced emergence of theory. . From a scholarly

perspective, it is important for researchers to be aware of what version they use and the impact of adopting one version over the other on the research output (Urquhart, 2001; Kendall, 1999).

4.4.3.2 Ethnographic Study

The fundamental concept of ethnography is the belief that what individuals believe, understand, and act upon cannot be detached from their context. Thus, ethnographers immerse themselves in the lives of the social settings they study (Lewis, 1999), in all sorts of human interactions, be it a tribe, a recreational park, a hospital, a classroom or a social organisation of work (Whitehead, 2005). This approach has widely been used in technology innovation studies such as information technology management (Davies & Nielsen, 1992), the development of information systems (Hughes et al., 1995), and design and evaluation of information systems (Myers, 1997a). Field work is key part of the process and it involves documenting people's beliefs and practices from the people's own perspective. The ethnographer aims to produce vivid cultural interpretation, which entails the ability to describe what the researcher has heard and seen within the framework of the social groups' view of reality (Fetterman, 2010).

Ethnographic research is on the extreme end of the inductive research domain, hence, the ability of a researcher to interpret culture from the "*emic*" or the insider's view of reality is paramount in this research approach (Harris, 1976; Pike, 1967). Parallel to 'emic', an 'etic' or the outsider's perspective on reality also becomes fundamental to ethnographic research. The ethnographers' task according to Fetterman (2010) is not only to include insider's meanings, but to translate them into concepts comprehensible to individuals outside the context or the society under study. Parallel to 'emic', an 'etic' or the outsider's perspective on reality also becomes fundamental to ethnographic research. The balance between insider and outsider perspectives places special demands on the researcher. He must then remain open and non-judgemental about the actions and beliefs of the social groups under study, while making these understandings and practices lucid and meaningful to outsiders (Fellows & Lius, 2009; Riemer, 1997).

4.4.3.3 Action Research

Action research aims to contribute both to the practical concerns of people in an immediate problematic situation in a joint collaboration within a mutually acceptable ethical framework" (Rapoport, 1970). The research takes place in real-world situations and aims to solve real problems. It is also known variously as "participatory research" and "emancipatory research. Action research is based upon the principle that the researcher is within the field of the research and becomes a partner in the action and process of change (Baskerville & Wood-Harper, 1996; 1985). The role of the action researchers is to actively associate with the practical outcomes of

the research, other than to seek to identify theoretical outcomes (Foster, 1972). By emphasising collaboration between researchers and practitioners, action research represents an ideal research method that address complex real-life problems and the immediate concerns of practitioners; researchers in return gain feedback from the practitioners to modify or improve on the research outcome. They acknowledged that successful action research is unlikely where there is conflict between researchers and practitioners or among practitioners themselves (Avison et al., 1999).

4.4.3.4 Case Studies

As a social scientist, Yin (1989, p.23) defines a case study as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident and in which multiple sources of evidence are used. The underlying idea for case research is said to be the many-sided view it can provide of a situation in its context. Instead of statistical representativeness, case studies offer depth and comprehensiveness for understanding the specific phenomenon. Gable (1994) contends that case study research provides the opportunity to ask penetrating questions and to capture the reality in considerably greater detail of organisational behaviour, although the conclusions drawn may be specific to the particular organisations studied and may not be generalisable to a wider population.

Yin (2003) suggests that case studies are appropriate where it is not necessary to control behavioural events or variables, but rather focuses on issues relating to processes. Benbasat et al. (1987) also emphasised that case study research allows the researcher to learn about the state-of-the-art⁶ and generate theories from practice; to understand the nature and complexity of the process taking place; and to gain insights into new topics emerging in the field under investigation. In innovation research, the case study method has previously been used variously, such as in the study of IS implementation effort (Amabile et al., 2001; Leonard-Barton, 1990); impact of IS on organisations; role and effects of IT on society (Nauman et al., 2005).

4.5 The Sociotechnical Systems Approach to Research Design

From the reviews of the sociotechnical systems literature in chapter, three, the STS concept can be characterised as holistic, and take a more encompassing view of organisational contexts or the environment in which it operates (e.g., Cloakes, 2003). The word sociotechnical, in its origins, is a combination of two paradigms - the social and the technical. It intends to describe a broader view of the role of technology in an organisation than either paradigm could offer on its own

⁶ Case study has been recognised to be particularly useful in the study of contemporary events, or otherwise state of the art or emerging phenomenon in organisations (e.g. Yin, 2003)

(Mina et al., 1999). STS researchers have argued that, technology should be seen, discussed and developed not just as a technical artefact but also in the light of the social environment in which it operates (Orlikowski, 1992; Bijker et al., 1987). Stowell et al., (1997), for example, advocate the adoption of the interpretive paradigm, for information systems design (ISD), arguing that the social context cannot be detached from information systems studies. This being the case it is therefore argued that the BIM implementation process (and the resultant construction technologies and processes) under investigation must be studied in its organisational (social) environment. Also, when investigating information systems operating within an organisational environment, one is, inevitably, investigating social systems, irrespective of whether or not physical artefacts are involved (Orlikowski & Gash, 1994). It is therefore necessary to make realistic assumptions of, and also to cater for, the social world that is being investigated (Cloake, 2003); assumptions that are both explicit and implicit (Pinch & Bijker, 1984).

Further, when examining sociotechnical phenomena undergoing process of planning, one should also be cognisant of the fact that implementation of any information system, whether new or modified is, by its very nature, implementation of a change in the human and social systems that it impacts. Thus the process of planning for IS implementations (Performix Technologies, 2002; Coakes & Elliman, 2002) is also the process of planning for organisational change.

The question thus arises as to where in the continuum between positivist and interpretivist research schools it is appropriate to place this study of BIM implementation in construction contexts. The key difference is that positivist research is independent of the complex nature of organisations and organisational behaviour (Harvey et al., 1999). Checkland (1981) summarises this approach with three characteristics of reductionism, repeatability and refutation. The interpretivist approach maintains that studies of people and their actions are legitimate sources of evidence, which contribute to theory development. It thus follows the natural course of events looking for patterns of behaviour and results in the social contexts that can contribute to a theory development.

Interpretivism is a well-established research philosophy in innovation and the STS research fields (Doolin & McLeod, 2005; Nandhakumar & Jones, 1997; Orlikowski & Baroudi, 1991). Arguments supporting the interpretive approach as a valid basis of inquiry into the social implications of technology in organisations are well documented in the literature (Klein & Myers, 1999; Markus & Lee, 2000). While the emphasis of an interpretive approach is on how people experience and interpret their social world, this does not deny the materiality of their social reality, which in relation to technology is the artefact. Technology uptake has physical components such as hardware, software and networking. Although individuals experience and

understand a technology differently through their ongoing and situated use of it (Orlikowski, 2000), they also develop a shared understanding that is constituted through their social interaction in relation to it (Orlikowski & Gash, 1994; Pinch & Bijker, 1987). Galliers (1992) suggests that innovation research should be considered more of a social science or a sociotechnical subject, and not simply a technical one, due to the focus of IS research questions, changing from technological to organisational and managerial decisions.

Putting those suggestions together, a conception can be discerned that the ISD as practiced with its interpretivist epistemological perspective (Stowell et al., 1997), is oriented towards a wider socio-organisational considerations and the concomitant technological change processes – thus, strongly aligning towards sociotechnical viewpoints in organisational contexts. Guided by the sociotechnical approach to research design, the section below discussed the assumptions underlying the adopted research approach.

4.6 The Adopted Research Approach and Method

Disciplined inquiry is generally guided by what the researcher believes about the nature of physical and social reality (ontology) and what constitutes valid knowledge (epistemology) (Guba, 1990). Ultimately, it is the ontological and epistemological beliefs held by a researcher that determine how the research proceeds, what approach to research is taken, and how data is collected, analysed and interpreted. As Zuboff (1988, p.428) explains:

“Behind every method lies a belief. Researchers must have a theory of reality and of how that reality might surrender itself to their knowledge-seeking efforts [...] researchers ought to indicate something about their beliefs, so that readers can have access to the intellectual choices that are embedded in the research effort.”

The research problem outlined in chapter one, and also a section of chapter three, describes practical challenges for construction organisations wishing to implement BIM. The research seeks to both support the implementation of BIM and to add to the body of academic knowledge about concomitant construction-related innovation uptake. This is achieved by exploring the relationships and interactions that occur between actors and contextual factors and the negotiated actions of the sociotechnical elements involved in the BIM implementation process. The aim is set to:

“Carry out a sociotechnical systems analysis of BIM implementation in construction organisations.”

The main consideration for the research strategy is not only that it should enable the research aim to be achieved but that the aim and the strategy should be epistemologically and ontologically commensurate. Credibility in the research outcomes will not be demonstrable if this is not found to be the case. The focus on interpretive social action reflects the researcher's belief that humans construct and reproduce social reality through the way they intersubjectively make sense of the world in social interaction. From this perspective, social reality can only be interpreted, not 'discovered'. Knowledge of that reality is therefore a human construction, rather than an objective truth (Doolin & McLeod, 2005; Guba, 1990; Orlikowski & Baroudi, 1991; Walsham, 1993). As a consequence, a positivist epistemology such as that used in the natural sciences is considered by the researcher to be inappropriate for studying complex behaviour. Instead, the research approach taken in this study is broadly interpretive (Walsham, 1993).

Interpretive research generally takes a pluralistic, rather than unitary, view of social settings because organisational behaviour can act to shape or transform organisational reality (Putnam, 1983). Thus, while "meanings are formed, transferred, and used, they are also negotiated, and hence [...] interpretations of reality may shift over time as circumstances, objectives, and constituencies change" (Orlikowski & Baroudi, 1991, p.14). Interpretivists also attempt to draw on multiple perspectives and views from different levels in the organisation (or the BIM implementation process).

The underlying premise of an interpretive approach to sociotechnical research is the need to study technology implementation in the organisational context and for the researcher to get alongside the informants. This reflects a desire to access organisational participants' interpretations, but also a need for familiarity and close engagement in order to understand the complex social and contextual interactions surrounding technology deployment or use (Nandhakumar & Jones, 1997).

Interpretive researchers "gather rich data: thick descriptions saturated with contextual and cultural overtones" (Putnam, 1983, p.44). The emphasis on closeness to the phenomenon under study, rich description and the perspectives of organisational participants means that interpretive researchers tend to utilise methods that generate qualitative data required for an inductive or abductive process of inquiry, such as interviews and observation of activities. This study adopts an abductive research approach because it allows a continuous interplay between theory and data interpretation, and the data collection process evolves in response to prior observations, interpretations and literature (Putnam, 1983).

The study adopts abductive research approach, the underlying epistemology is interpretative and two-stage process is formulated for the empirical data collection - comprising: 1) initial

exploratory study to help establish the framework for analysing BIM implementation in construction context; and 2) case studies approach to provide a context for formulating novel understanding and validation of theory regarding BIM implementation in construction organisations. As the aim of the study has been to analyse the implementation of BIM through the context of construction organisations and the stakeholder groups or the construction professionals involved in the systems implementation, the construction of reality therefore, is shaped by the interpretation of the reality of the social groups under study (e.g. Walsham, 2006). Multiple case studies research method, with associated data collection techniques including participant observation, interviewing, and documents analysis is considered the appropriate research method for the main study.

It has been argued that abductive reasoning very commonly uses case studies method. This is because the method enables simultaneous data collection and theory-building process (Dubois & Gadde, 2002; Spens & Kovacs, 2006). Case study is a versatile research method and very flexible to adapt to different research needs (Walsham, 2006; Yin, 2011). It is commonly used in information systems research and fits particularly well in this context where the focus is on contemporary events in construction organisations (Benbasat et al., 1987). There is not a unique definition of case study. From compilation of previous works, Benbasat et al. (1987) conclude that case study investigates a phenomenon within a context, gathering data from one or multiple sources within that context. They identify some characteristics which are relevant to case studies. These include:

1. Phenomenon is examined in a natural setting
2. Data can be collected by multiple means
3. One or few entities / units of analysis (individuals, group, organisations, processes) can be examined
4. More suitable for exploratory studies and classification or hypothesis development stages of knowledge building process
5. No experimental controls or manipulations are involved
6. Useful for the study of “why” and “how” questions because it permits the operational links to be traced over time rather than with frequency or incidence.
7. The focus is on contemporary events.

The study aims to analyse sociotechnical alignment for BIM deployment in construction organisations. Case study research method is chosen because it provides the process and the context as a whole. The contexts in which this research is conducted: construction organisations are as relevant as the BIM system itself. The system could not be understood in isolation of the

organisations in which it exists: construction organisations, their products (building and infrastructure projects), construction professionals and their interactions with one another.

Case study is particularly useful in contemporary events. Existing and emerging list of construction related technologies, and in particular, building information modelling, are a relatively new area. Although the use of BIM was reported in some decade ago (Eastman, 1999; Olofsson et al., 2008), it is still in an emergent state but evolving rapidly (Pike Research, 2012) thus the knowledge, the concept, the process and the benefits associated with the use of BIM has not fully been assimilated into the construction practice. Given that the object of much technology-in-use research is the study of IS in organisations (Markus & Lee, 2000), case studies approach has become a commonly used and legitimate method of inquiry in sociotechnical research (Myers, 1997). As Vickers (1999, p.266) puts it, in arguing for qualitative research approaches to technology deployment:

“Technology is part of the organisation along with key elements including people, structure, operating procedures, politics and culture elements that require qualitative, reflexive studies. Only by uncovering the subjective, the earthy and the serendipitous will deeper understanding of the difficulties associated with IS implementation be explored.”

Within STS enquiry, abductive case study approach has been advocated and used by various researchers (e.g. Benbasat et al., 1987; Walsham, 2006). Technology deployment unfolds within constantly changing contexts and conditions, (Heiskanen et al., 2000; Kirsch & Beath, 1996; Wynekoop & Russo, 1995). The method thus enables technology deployment to be followed as it unfolds, describing events as they occur and accessing participants’ interpretations at the time. Such an approach is more likely to reveal shifting interpretations and the political nature of organisational activities, rather than retrospective rationalisations and legitimised interpretations (Franz & Robey, 1987). The abductive process also lends itself to a “multifaceted treatment of change” (Pettigrew, 1990, p.270), which recognises that “multiple and conflicting representations of reality are generated in organisations” (Knights, 1995, p.247). Pettigrew (1990) emphasises the complex dynamics of organisational change. He highlights its historically and contextually specific nature, stressing the importance of analysing multiple and interconnected levels of context in case study design.

A commonly expressed concern about case studies is the issue of universal generalisation of research findings (Flyvbjerg, 2006). Nonetheless, Yin (2011) has argued that analytic generalisation (as opposed to statistical generalisation) is the goal of case study research. Accordingly, case studies “are generalizable to theoretical propositions and not to populations or universes” (Yin, 2003, p.10). Walsham (1993) also offered some insight to generalisation,

arguing that case studies can be used to develop theoretical concepts that inform further theoretical development, to generate or refine theoretical frameworks, to draw specific implications from one particular domain that can be useful in understanding similar phenomena in other contexts, and to contribute rich insights or implications on a wide range of issues. Walsham (1995, p.79) argues that while such generalisations “are not wholly predictive” they do provide “explanations of particular phenomena derived from empirical interpretive research in specific settings, which may be valuable in the future in other organisations and contexts.”

4.7 The Research Design

The aim of the study is to carry out a sociotechnical systems analysis of BIM implementation in construction organisations. The term “abduction” captures well the research approach taken in this study, i.e. a close interaction between empirical data and theory (Dubois & Gadde, 2002). This way of working is exemplified by Eisenhardt’s (1989) description of the researcher’s need of moving back and forth between research sites and the theoretical phenomenon, effectively comparing the empirical findings with the existing theories and to eventually generate a new theoretical understanding and knowledge regarding the phenomenon under investigation. A “*tight and emergent*” approach to theory development to provide clearer insights with regards to BIM implementation is adopted (Dubois & Gadde, 2002). The combined insights from different literature, in particular the theories of STS (Cherns, 1976), digital infrastructure in design practices (Whyte, 2011) and technological innovation in organisations (Molina, 1998) are used to form the major framework in this research.

A two-stage research approach is employed. The first stage of the strategy consists of an exploratory study of some selected BIM-enabled construction firms in order to gain initial understanding of their BIM implementation practices, review queries developed during the literature review and identify emerging themes to help formulate an appropriate STS analytical framework for the case study research analysis. This is followed by the second-stage, which consists of case studies of three different construction organisations, focusing specifically, on their BIM implementation processes. The findings of the exploratory studies augment the findings of the second stage and also provide a much broader views of the intricacies of BIM implementation process. Such a multidimensional construct is crucial for a thorough understanding of events and processes in qualitative enquiry because it helps “break the more linear view on relation, and provide much deeper understanding between empirical data and theory development or testing” (Quintens & Matthyssens, 2010). This is in line with Dubois and Gadde (2002, p.555) argument about theory matching in abductive research which points to the importance of fit between theory and empirical observation:

“We have found that the researcher, by constantly going ‘back and forth’ from one type of research activity to another and between empirical observations and theory, is able to expand his understanding of both theory and empirical phenomena.”

The two-stage data collection process is simultaneous to the theory building process, indicating a back-and-forth direction between theory and data. Specifically, the results of the exploratory study are compared with the STS theoretical frameworks and the literature consulted. Through this iteration, a matching STS analytical framework is formulated to help collect and analyse the empirical data from the case studies. The iterative process between the second-stage empirical observation and the theoretical framework also seeks to unveil new knowledge by testing and validating the issues that emerge from the first-stage exploratory findings. The first stage provides the platform for identifying how empirical phenomena interplay with theoretical notions and the second stage provides the platform for applying, reviewing and validating the emerging theoretical framework (see Wilson et al., 2010). The newly found insights can help in two ways: (a) advance understanding of the BIM implementation process in construction contexts and (b) produce better-informed advice for policy makers and company managers relating to BIM deployment.

4.7.1 Exploratory Studies

The first stage of the research consists of a exploratory investigation of BIM implementation in selected organisations. This method is chosen to mainly augment the case studies (Gable, 1994). The exploratory investigation serves as a preamble prior to or in addition to a more detailed case study research. With the nature of exploratory study, the need to document phenomena in order to gain empirical evidence is recognised. Pettigrew (1990) emphasises that context and action are interwoven in the study of strategy and it is important to consider the past and present when looking to the future. Abbott (1997) acknowledges the nesting of processes within organisations, and recognises the need to understand the network of intertwined processes within an interactionist field. It is important, therefore, to explore the current BIM practices in an attempt to designing an STS analytical framework of BIM in construction organisations. Thus, a exploratory study, designed to document current practices in a BIM-enabled construction environment is recognised as being important in understanding BIM implementation issues and challenges.

4.7.1.1 The Purpose of the Exploratory Studies

The purpose of the exploratory study is to capture the views of construction professionals who are involved in the implementation of BIM. Through narrative descriptions and documentation

analysis, accounts of BIM stakeholders and their interests/concerns, as well as the management processes and their outcomes, and also, the challenges of BIM implementation are captured. Some of the specific objectives developed for the exploratory studies include:

- Detailed description of BIM implementation processes (1)
 - Identification of main issues and understanding what problems are experienced by BIM stakeholders that are likely to threaten successful implementation of BIM (2)
 - Understanding the relations between BIM implementation and other areas of construction activities/processes in particular the impacts of BIM on work delivery (3)
 - Develop Molina's STC as a working model to help analyse the BIM implementation process in the case studies (4)

The exploratory study will construct narratives build around exemplars and critical instances, and the flexibility of the interview formats will lend itself for contextual exploration as it enables alternative line of inquiry to be pursued (McEvoy & Richards, 2006). Some questions that are explored with participants include: what needs drive the implementation, what conflicts arise in the process, what the main constraints are in the organisation, how solutions are developed, what difficulties are encountered in managing the process and how they are resolved. Wheeldon (2010) considers that, with the principles of abductive research, construction of some kind of framework or theory about the phenomenon under analysis is necessary to perceive and understand that phenomenon. From this perspective, the outcome of the exploratory interviews is used as a framework, not only to develop the analytical structure of the case studies, but also to trace back the meaningfulness of the subsequent STS literature and the theoretical frameworks.

4.7.1.2 Selection of the Participating Organisations for the Exploratory Studies

In the case of the selection of organisations for the purpose of the exploratory research it was decided to engage stratified sampling techniques rather than statistical techniques in selecting the population. It was decided to stratify the selection of construction organisations based on; 1) geographical location, 2) the nature of the work they are engaged in, with regards to BIM projects, and 3) demonstrable evidence that the organisation is in the process of (or has already) implemented BIM within the organisation. For reasons associated with limitations on resources it was decided to select the organisations from those whose offices or projects are based around the Midlands and South of England. Also, it was decided to limit the selection to twelve construction organisations.

The participant organisations had different expertise in BIM including BIM implementation successes and oversights experiences. The interviewees from the participating organisations held

various professional roles in their respective organisations. They included, group level directors, middle managers (e.g., BIM managers/coordinators) and operational site-based managerial staff (e.g., site engineers) and other professionals such as architects, quantity surveyors, MEP and structural engineers (see Appendix 2). One industry consultant for Bentley (i.e., BIM software vendor) was included to provide a breadth of perspective and because he was a chairman of a group that emphasised integration of technology into construction practice. Typically, interviews with respondents were open and candid.

Exploratory interview was first secured with the Chairman of mobile technology centre of excellence (COMIT: Construction Mobile IT), who was also a member of the government BIM task group. The interview was secured through one of the supervisors of this thesis whom have collaborated with the Chairman on several fronts, mostly related to human resource management research. The initial strategy was to use the 'snowballing' method to find BIM-enabled construction organisations to participate in the research. This is done by asking the interviewees whom they can recommend that fall under the highlighted criteria. Upon the interview with the Chairman of COMIT, he recommended that members from the associated could be sampled for the exploratory study as the association is actively promoting the use of construction related technologies to it members. COMIT is a centre of excellence for the implementation of technology in the UK construction industry. It started as a two-year research and development project in September, 2005 part-funded by the Department of Trade and Industry. Predominantly led by Arup, in partnership with BSRIA and Loughborough University, the project brings together representatives from construction, technology, research and dissemination organisations to form the COMIT Community. There are over 40 construction stakeholder members of the group. The director of COMIT recommended some 12 active companies on the COMIT membership database that he suggested would fall into the categories elaborated.

In November 2011, University College London (UCL), in collaboration with COMIT, organised the 'delivering the value of BIM' seminar at UCL. The recommended organisations presented various ways BIM tools and concepts were being applied in their respective organisations. Invitations were sent to ten of the organisations and seven were willing to participate in the study. Access to five additional BIM-enabled organisations was also secured bringing the total number of participant organisations to twelve. Overall, sixteen construction professionals were interviewed from all the participating organisations. Table 4.3 presents an overview of the participant organisations and their representative that was interviewed for the research.

Table 4.1 Participants of the exploratory studies

	Participant (Pseudonym)	Work Title	Experience	Gender	Company ref.	Organisation Type
1	Ga-B	BIM Coordinator	16year structural and civil engineering	Male	BCO1	Multidiscipline Consulting Engineering Firm
2	Na-I	BIM Development Leader	8years BIM and CAD Design	Male	BCO2	Design/BIM Consultancy Firm
3	Pe-B	Director	Over 30 years in architectural practice	Male	BCO2	Design/BIM Consultancy Firm
4	Ma-B	Group BIM Manager	21years Wider AEC knowledge	Male	BCO3	Contractor Organisation
5	Ti-E	Group Innovation and Knowledge Manager	Over 20years in innovation and best practice solutions	Male	BCO3	Contractor Organisation
6	Ha-O	Graduate Estimator	Over 4years quantity surveying	Male	BCO3	Contractor Organisation
7	Ia-S	Design and Project Manager	23years building design and facilities management	Male	BCO4	Architecture Practice
8	Ma-M	Senior Quantity Surveyor	12 years construction projects	Male	BCO5	Cost Management Consultancy Firm
9	Ia-M	Industry Consultant	17years construction and infrastructure consultancy	Male	BCO6	Software Developers for the AEC Sector
10	Ma-S	UK Head of BIM	Over 25years civil/structural design management	Male	BCO7	Contractor Organisation
11	St-B	Director	Over 18years in architecture and innovative healthcare design	Male	BCO8	Architecture Practice
12	Ph-L	Head of BIM(M)	Over 37years in design and construction management	Male	BCO9	Civil and building
13	Do-B	Group Director	39 years architectural design	Male	BCO10	Infrastructure & building management
14	Va-V	Design Engineer	5 years design engineering	Male	BCO10	Infrastructure & building management
15	Ni-B	Director	22years Geodetic engineering	Male	BCO11	Geomatics and 3D Laser scanning to BIM
16	Ro-D	Technical Advisor	6years BIM and CAD design	Male	BCO12	Specialist Contractors

The data collection involved semi structured interviews, and BIM documentations. Interviews lasted thirty minutes to one and a half hours, with the average interview lasting one hour. Interviews were audiotaped and transcribed. To enable triangulation and reveal contradictions, the interview transcripts and the BIM documents were integrated into a research database and analysed.

4.7.1.3 Data Analysis Strategy for the Exploratory Findings

Data analysis and interpretations are required to bring order and understanding; nevertheless, this is difficult to achieve because it requires creativity, discipline and a systematic approach (Taylor-Powell & Renner, 2003). According to Robson (2011), there is no single set of steps to rigorously conduct qualitative data analysis. There are different types of qualitative data analysis proposed in literature. This study adopts qualitative content analysis strategy (Taylor-Powell & Renner, 2003) to analyse the data from the exploratory findings. Taylor-Powell & Renner (2003) provided six steps for qualitative content analysis, including: 1) data transcribing; 2) reading and rereading; 3) condensing and indexing 4) creating categories 5) sorting relationships and connections between categories; and, 6) data interpretations. These steps are discussed as follows:

- The data transcribing is the process whereby all digital records relating to the research are transcribed verbatim into a text format and stored in a database.
- The data is organised by reading and rereading the texts to identify themes and subcategories. These themes or indexes are assigned with abbreviated codes during the reading process.
- Condensing the data includes the concept of reducing while still preserving the core of the text within its context (Coffey & Atkinson, 1996). Indexing allows descriptive labels to be assigned to the condensed data. Indexing is also refers variously as codes, themes or incidents (e.g., Taylor-Powell & Renner, 2003). The indexing can be done using emerging codes or predetermined codes (Creswell, 1994). If the data analysis is reliant on priori themes backed by existing theories, then predetermined indexes are used, otherwise, emerging indexes would be created by choosing words or key phrases from the texts.
- The categories creation is a process of abstracting or aggregating condensed data and grouping together under higher order headings (Barrosso, 1997; Burnard, 1991). The categories represent a group of content that shares a commonality (Krippendorff, 1980) and it captures verbatim in its immediate context. This is a common feature of content analysis. The various categories are grouped under their matching indexes, which often

include a number of sub-categories at varying levels of abstraction (Graneheim & Lundman, 2004).

- Once categories have been created and descriptive labels assigned to the categories and subcategories, the next stage is a process of sorting relationships and connection between categories. It provides a way of linking the underlying meanings together in categories. Baxter (1991) defines the relationship sorting process as threading across categories of meanings that recur in domain after domain. The connections and relationships in the data categories could help explain why some events occur, by identifying causes and effects and sequence of events across categories.
- Interpreting the data is a process of reflection and discussion of the linked categories and subcategories, and reflective dialogues with extant literature to explain the findings (Graneheim & Lundman, 2004). This helps to attach meaning and significance to the analysis. Quotes from the informants that illustrate meanings of the categories, combined with extant literature supports are used to discuss the categories and explain the findings.

The decision was taken to analyse the exploratory data manually following the content analysis process as discussed above. This approach provided guidance from unstructured data to the generation of codes, categories of key phrases, then finally to the theoretical interpretations of the phenomena under investigation. Taylor-Powell & Renner (2003) indicated that coding and indexing transcripts can be by manual means or by using analysis software tools. Manual coding can be done when the volume of data is handy, but unwieldy volume of data may require software tools for quick and accurate indexing and categorising.

Following the qualitative content analysis strategy, the audio data were transcribed verbatim and stored in a folder along with other text documents obtained from the participants. The text documents were read through several times to obtain a sense of the whole. Then the texts about participants' experiences and practices of implementing BIM were extracted and brought together into one database. The abstracted texts were condensed into words-in-contexts and labelled with codes. The various codes were compared based on similarities and differences and sorted into categories and subcategories, which constitute the crux of the content analysis. As this iterative process continues, the interconnections between the indexed data categories and their generality emerged and were further explored by engaging with the scholarly literature. These linkages were explored as sociotechnical antecedents in BIM-enabled construction organisations. The indexes were created from emerging codes from informants and predetermined codes as informed by the STS literature review (Creswell, 2004). For instance, the four main sociotechnical components offered by the LSM (presented in section 3.4.4.5) were

used as lexicon to explore the related STS challenges associated with BIM implementation in the participating organisations. The results of the exploratory studies are analysed in chapter five of the thesis. The findings from the exploratory investigation provide the basis for the selection of appropriate STS framework to aid in the analysis of the subsequent case studies research design.

4.7.2 Case Study Design

In order to develop a detailed understanding of BIM implementation in action, in-depth, case studies of BM implementation approaches were undertaken in three BIM-enabled construction organisations. The level and units of analysis is explained, followed by a description of the processes used in selecting the case study organisations, data collection, validation standard to ensure the trustworthiness of the case study design, and data analysis. Finally, ethical considerations relevant to the case study are discussed.

4.7.2.1 Level and Units of Analysis

Sociotechnical systems research often deals with inter-level interactions such as micro (individual level), meso (organisational or institutional level) and macro (regional, national or international level) (e.g., Valerdi & Davidz, 2009; Knorr-Cetina & Cicourel, 1981). Social research also defines four common levels of analysis: individuals, groups, organisations and environments (e.g., Valerdi & Davidz, 2009). The interest of this research is on a sociotechnical systems analysis of BIM implementation in construction organisation, and therefore this research focuses on the inter-level interaction of individuals in construction organisations. The primary level of interest in any inter-level interactions is important to consider, when choosing the constructs upon which to focus and when designing research tools. This is especially so in the construction context, because, construction organisations are focused on relations between in-house expertise and external stakeholders with references to each other in their efforts to assemble the world. The level of analysis thus, stresses the interdependence, and acknowledges the roles of inter-organisational network in the success of the BIM implementation process (Knorr-Cetina & Cicourel, 1981).

The units of analysis are sources of data that support the levels of analysis (Yin, 2011; Baxter & Jack, 2008). These sources may include individuals, roles, social artefacts, process models or relationships (Martin & Davidz, 2007; Valerdi & Davidz, 2009). Relevant unit of analysis for this study include individuals and their experiences and perceptions of organisational objectives, strategies and practices. Such data can be collected both directly from organisational members through interviews, or through observation and primary documentation. To facilitate triangulation and comparison across case studies, it is important to define units of analysis that

are comparable across organisations and contexts (Valerdi & Davidz, 2009; Knorr-Cetina & Cicourel, 1981).

4.7.2.2 Selection of Case Study Organisations

For this study, a multiple case studies method is adopted. The reason for adopting the multiple case study design is to add confidence to the emerging theories. Herriott & Firesstone (1983) assert that the evidence from multiple cases is often considered more persuasive, and the overall study is thus regarded as being more robust. Deciding on the number of cases deemed necessary or sufficient for multiple case study research, Yin (2011) contends that greater certainty lies with larger number of cases for theoretical replication purposes (more cases selected on the basis of predicting contrasting results). However, if the issues at hand do not demand detailed study for undue degree of certainty due to an underlying priori themes backed by existing theories, then the selection of two or three multiple cases for *literal replication* (similar conditions/criteria are used to guide the selection of cases in order to predict similar results) could be warranted. Prior to conducting the case studies for this research, exploratory interviews with BIM experts were conducted to help strengthen the initial theoretical framework and to augment the case study data collection and analysis.

Thus following the replication strategy proposed by Yin (2011) the research design for this study involves selecting three case studies for literal replications, allowing the generalisation of the first findings to the two other cases on the basis of a match to the underlying theory and not to the larger ‘universe’ (i.e., the AEC sector). This decision is congruous to Yin’s (2009, p.59) assertion that “*the simplest multiple-case design would be the selection of two or more cases that are believed to be literal replications, such as a set of cases with exemplar outcomes in relation to some evaluation questions [semi-structured interviews] or objectives.*”

As with the case of the exploratory study, three main reasons are used to guide the selection of the three case study organisations. It was decided to stratify the selection of the organisations based on; 1) geographical location, 2) the nature of the work they are engaged in, with regards to BIM projects, and 3) demonstrable evidence that the organisation is in the process of (or has already) implemented BIM within the organisation. For reasons associated with limitations of resources and time it was decided to select the organisations from those whose offices or projects are based around the Midlands and South of England.

Getting access to case organisations proved to be very difficult. Two main reasons could be attributed to the difficulty in securing the access. These include; 1) issues with confidentiality/commercial sensitivity, and 2) current work overload.

Despite the assurance from the researcher that adherence to strict ethical procedures would be followed, some of the organisations turned down the invitation to participate in the research citing confidential reasons. Some of the organisations also had the perception that their participation in the research work could expose their strategies thereby jeopardising their competitive edge with regards to BIM implementation. A few potential case study organisations also declined the invitation to participate in the research, mentioning their current workload as the main reason for their unwillingness to participate.

Nevertheless, the researcher secured access to three organisations that initially participated in the exploratory study and also satisfied the selection criteria elaborated earlier. They include 1) a large civil and building contractor, 2) a small-size specialist contractor and 3) a large specialist firm, focussing mainly on the zero carbon market. These organisations were willing to take part in the research mainly because they were interested to know the final outcomes of the research findings. As BIM-enabled organisations, their personnel in management or executive-level roles (e.g., BIM managers/coordinators, architects/designers, engineers, cost consultants, project managers and directors) are more likely to have BIM implementation success and oversight experiences. The researcher established close contact with the professionals of these organisations, especially those working on BIM projects and/or BIM implementation strategies in order to create and maintain their interests on the research. Also, the organisations were given the assurance by the researcher that, the outcomes of the study would be shared with them upon completion of the study and also, a confidential protocol would strictly be upheld throughout the research process.

4.7.2.3 Data Collection

Three data collection techniques were adopted. Participants observation and documents analysis were adopted to complement the data collected from semi-structured interviews, and also, to provide stronger substantiation of the phenomenon under investigation (Eisenhardt, 1989).

Participant Observation: As Bryman & Bell (2003, p.178) write on the practice of observation in research, "the aim is to record in as much detail as possible the behaviour of participants with the aim of developing a narrative account of that behaviour." The observation affords a unique access of events/behaviour in the work place of participants to be captured. Adler (1995) advised that observation is fundamentally naturalistic in essence; it occurs in the natural context of the occurrence, among the actors who would normally be participating in the interaction, and follows the natural stream of everyday life. It also allows the capture of data which would not otherwise be recorded by semi-structured interviews alone. The strategy to be used for data collection from observation relies on incidents (Bryman & Bell, 2003, p.181). This involves

recording significant incidents and the results that follow from it. Observations are carried out during site visits made by the researcher and in the offices of the informants. Observations are centred on the roles of the informants and oriented by recording their activities that relate to BIM. Following up on processes of BIM implementation contributes to the understanding of what work details and needs must be anticipated and thus foreseen by the implementation strategy.

Document Analysis: The inclusion of documentary data provides an opportunity to both expand the empirical depth and robustness of the research. Reed-Scott (1999) emphasised that integrity of documents or “texts” should not be taken for granted. "The textual approach is based on the assumption that texts have the interpretations of their creators embedded in them (Knorr-Cetina, 1981). A second assumption is that meaning is actually "inter-textual" (Culler, 1976): a given text is constructed from, and acquires meaning through, its embeddedness in a multiplicity of discourses. The intrinsic properties of embedded interpretations of the authors of texts are used to provide substantiation and clarification of data elicited from interview and observational methods. As texts, sources of documentary data allow the researcher to interpret the meaning of events and to generate understanding of both the document and the event as contextually mediated (Gephart, 1993). The analysis of documents in this research involves the examination of all relevant printed or softcopies of company information such as BIM implementation strategy, company profile, organisational structure, mission statement and company brochures. Key issues emerging from documents analysis will be integrated with the observations and interviews data.

Semi-structured Interviews: This research is predicated on the collection of rich qualitative data. For this reason, semi-structured interview approach is selected as one of the appropriate methods for generating the necessary quality of data required. Semi-structured interview is appropriate as it affords a good level of flexibility needed in generating in-depth qualitative data (Bryman & Bell, 2003). It allows greater flexibility for the researcher to probe themes, events or phenomenon where more depth or explanation is needed than would otherwise be afforded by more structured collection methods such as questionnaire survey. A semi-structured interview is more suitable than structured or unstructured ones. As BIM is an emergent phenomenon, and manifests in a complex social setting, a fully open interview may yield a large amount of data which is irrelevant or unimportant to the understanding of the BIM implementation process. Also, as it is not yet clear which ‘variables’ are important and should be put to test in the study of BIM, structured interviews may not be appropriate at this stage.

Interview guide is prepared for the three case study organisations. It is designed for the interviewees within the case organisations (see table 4.4). The interview guide is divided into

three parts. These are 1) the context or background information about the organisation 2) the organisation's BIM initiatives and 3) the organisations relations with intra- and inter-level BIM constituents. The key variables used in the interviews are grounded in the theoretical insights from STS analytical frameworks (e.g., Molina, 1998; Cherns, 1987; Mumford, 1985).

Table 4.2 Themes for the semi-structured interviews

<i>Key themes</i>	<i>Examples of variables</i>
Part 1 Context	
Background information of organisation	<ul style="list-style-type: none"> • Organisational information • Technology and growth strategy • Organisation objectives
Part 2 BIM Initiatives	
1. Initiatives (e.g., motivation, vision and action)	<ul style="list-style-type: none"> • Vision • Motivation • Prime drivers of BIM initiative • Resources: needed and available • Actions: including inter-level alliance and persuasion
2. Make-up (components) of BIM (innovation assemblage)	<ul style="list-style-type: none"> • Technology / technical artefacts • Different actors • Tasks / emerging roles and responsibilities • Structure / Organisational reconfiguration
3. BIM implementation plan / strategy (Perceptions of what is required for the BIM implementation process)	<ul style="list-style-type: none"> • Targets: aim and objectives • Means of achieving targets <ul style="list-style-type: none"> - Access to resources - Constituency building and networking - Technological / choice of vendor and collaboration - Other aspects of development and competitive advantage - Streamlining BIM competency and maximising benefits
4. BIM governance (perceptions of how things actually manifest)	<ul style="list-style-type: none"> • Governance: formal and informal <ul style="list-style-type: none"> - Individual perceptions / personal circumstances - Organisational circumstances
5. Appraisals of BIM (perceptions of any weaknesses/problems and strengths with regards to implementation realities)	<ul style="list-style-type: none"> • Successes and oversights experiences <ul style="list-style-type: none"> - Building depth of actors' knowledge and relations - Process transformation/alignment to BIM concept - Strengthening/increasing technical capabilities - Strengthening the governance of the BIM initiative
Part 3 Inter-organisational sociotechnical BIM constituencies	
<ul style="list-style-type: none"> • Understanding of strategic aims BIM stakeholder organisations / construction professionals may have at inter-organisational level (micro-meso macro strategies) • Reflections on inter-organisational strategies and relationships 	
1. Networking at the project level (project stakeholders relationships and project BIM implementation strategies)	<ul style="list-style-type: none"> • Nature of links and role • Any agglomeration benefits • Any barriers to synergies/collaboration • Organisation to project BIM implementation plan
2. Choice of BIM vendor (technological institutions)	<ul style="list-style-type: none"> • Nature of links and role • Any agglomeration benefits • Any barriers to synergies/collaboration • Any knowledge sharing or technology transfer
3. Network supporting organisations (R&D institutions, policy)	<ul style="list-style-type: none"> • Nature of links and role • Any agglomeration benefits

mandates)

- Any barriers to synergies/collaboration
 - Government's policy mandates and impacts
 - Any knowledge sharing or technology transfer
-

4.7.2.4 Data Analysis Strategy for the Case Study Findings

In sociotechnical research, McLeod & Doolin (2012); Horton et al. (2005); Kling & Lamb (1999); Orlikowski (2010); Kim & Kaplan (2006); Avgerou (2003), among others, have described and/or used a range of complementary strategies for analysing IS data. Examples of these analytical techniques include: 'temporal bracketing' as a way of organising the description of a sequence of events to enable analytical treatment of overlapping or mutually influencing phenomena (e.g. Langley & Truax, 1994); 'visual mapping', in which graphical representations facilitate the summarising of large amounts of data, the depiction of time, and the simultaneous presentation of multiple dimensions or parallel processes (e.g. Lyytinen & Newman, 2008; Newman & Robey, 1992; Madsen et al., 2006); 'alternative templates', where the explanatory capacity of several different interpretations of the same events are assessed (e.g. Newman & Noble, 1990); 'grounded theory', in which a theoretical understanding of a phenomenon is derived from process data using a structured approach outlined by Glaser & Strauss (1967) (e.g. Urquhart, 2001); 'quantification', where detailed process data is systematically reduced to quantitative data that can be analysed statistically (e.g. Van de Ven & Poole, 1990); and the content analysis technique, where information is coded into pre-defined categories to inform analysis, has seen a widespread use in innovation study (Beretta & Bozzolan, 2004; Lombard, 2002; Guthrie et al., 2004). Sociotechnical systems researchers however, do not advocate the use of any particular qualitative or quantitative strategy, arguing instead that the choice should be driven by the research objectives, the kind of data available, imagination, and the desired level of accuracy, simplicity and generality (Newman & Robey, 1992).

Following the precedent set by other sociotechnical studies, the analysis and interpretation of the in-depth case studies has followed the qualitative content analysis technique described in section 4.7.1.3. The details of the case studies findings are discussed in chapter six.

The data from the cases took the following form:

- Interview transcripts
- Notes of project / site meetings
- Observational notes
- Background information of case organisations
- Background information of organisations' BIM projects

- Materials (e.g., BIM strategy documents) collected from case organisations

Strauss & Corbin (1998) proposed a 'microscopic' technique, which calls for thorough scanning of the empirical data, looking for events that relate to the phenomenon under investigation. The documents were read through several times to obtain profound understanding and a sense of the whole. The Nvivo9 qualitative software was used to augment the data condensing process. The raw texts from the field were imported into the Nvivo to be condensed into their immediate contexts. The key words in context were compared based on their similarities and differences and indexed into categories and sub-categories. A process of reflection and discussion in the underlying meanings of the tentative categories and cross-categories, augmented by extant literature was then presented.

4.7.3 Quality Criteria and Validation Issues

The use of case study research design is well established across the various disciplines of the social sciences (Hartley, 2004). Nevertheless, it is not without limitation or criticism. For instance, Simon (1969) argues that, the method of the case study depends upon the wit, common-sense, and imagination of the researcher doing the case study and makes up his procedure as he goes along, because he purposefully refuses to work within any set categories or classifications. Walsham (1993) however recognises that the validity of the understanding derived from a research study relies on its plausibility and clarity of the logical reasoning underpinning its argument. Most types of social research assert claims to fulfil certain quality criteria for measuring and collecting data (Kohlbacher, 2006). The criteria for judging the quality of research designs is needed in both quantitative (Garver & Mentzer, 1999; Mentzer et al., 1999) and qualitative studies (Ellram & Edis, 1996; Golicic et al., 2002; Halldorsson & Aastrup, 2003).

Qualitative research differs from the quantitative tradition in its fundamental assumptions and inferences, thus, each approach tends to be governed by different quality criteria (Graneheim & Lundman, 2004). In the positivist research paradigm, reliability, external validity, internal validity and construct validity have widely been used to evaluate the quality of research (Maxwell, 1992; Morse et al., 2002). Schwandt et al., (2007) concepts of credibility, dependability, confirmability and transferability have extensively been used to judge the soundness of qualitative research (e.g., Patton, 2005; Denzin & Lincoln, 2008). This approach represents an objective and logical step to ensure that the research process and findings are credible to both the one involved in the research and those that may review it at a later date. To ensure trustworthiness of this research, the concepts of credibility, confirmability, dependability, and transferability are built into the research design as discussed below:

4.7.3.1 Credibility

Credibility refers to the “adequate representation of the constructions of the social world under study” (Bradley, 1993, p.436). Many researchers argue that the most important criterion for judging a qualitative study is its credibility. The concept of credibility is related to the idea of construct validity as used in quantitative designs, uncovered by evidence that the construct being studied is based on interpretations and predictions of relevant theoretical models (i.e., a predicted pattern matches an actual pattern). The use of a rich and multiple sources of evidence increases credibility within naturalistic enquiry. In this study therefore, data triangulation was devised, comprising interviews from multiple sources and different perspective, document analysis and observations, to build this depth. Credibility is also a question of how to judge the similarities within and differences between categories and opinions. There are various opinions about the appropriateness of seeking agreement. Sandelowski (1986) argues that, since multiple realities exist that are dependent on subjective interpretations, participants’ recognition of, and agreement with the findings can also be an aspect of credibility. This also serves a purpose of validation.

4.7.3.2 Confirmability

Confirmability refers to “the extent to which the characteristics of the data, as posited by the researcher, can be confirmed by others who read or review the research results” (Bradley, 1993, p.437). Its main objective is to maintain objectivity (neutrality) and the control of researcher bias. Confirmability can be enhanced by peer review consensus on the findings, interpretations and recommendations of the research.

4.7.3.3 Dependability

Dependability is akin to the concept of reliability in quantitative research paradigms. In this case, the qualitative researcher gathers evidence to support the claim that similar findings would be obtained if the study were repeated. Qualitative researchers however argue that given the ever-changing social world and perceptual shifts, outcomes of a study, even if repeated in the same context with the same participants would yield new results (Patton, 2005). Nevertheless, the researcher is responsible for providing data sets and descriptions that are rich enough so that other researchers are able to make judgments about the findings’ transferability to different settings or contexts. Dependability is determined by checking the consistency of the study processes. This is enhanced by the coherence of internal processes (Bradley, 1993). Another technique for achieving transferability is suggested by Schwandt et al., (2007). By indexing a coding system that links to the relevant data sources, external auditors would be able to follow the investigation process to demonstrate the dependability of the work.

4.7.3.4 Transferability

Transferability refers to evidence supporting the generalization of findings to other contexts across different participants, situations, and so forth (Slevin & Sines, 2000). This is akin to the notion of external validity used by quantitative researchers. Transferability is enhanced by detailed descriptions, as is typical in qualitative research, which enable judgments about a “fit” within other contexts (Lincoln & Guba, 1985). Comparisons across cases (cross-case comparisons) that yield similar findings also increase transferability. At the theoretical level, transferability can be achieved by evidence of theoretical transference; that is, the same ideas apply more widely and are shown to be applicable in other similar contexts.

In qualitative research, trustworthiness of interpretations deals with establishing arguments for the most probable interpretations. This is because, the findings of a naturalistic inquiry are embedded in the context within which the data was gathered and analysed. It is therefore not possible to infer categorically the degree to which the outcome will replicate in a different situation and the same results expected. Nevertheless, this work present thick description of the represented case organisations in order to give readers sufficient knowledge to judge what degree of transfer is plausible in different contexts.

4.7.4 Ethical Considerations and Access

An overriding concern in conducting fieldwork and subsequent data analysis is to treat participants with respect and integrity at all times. Commenting on the issue of ethics in research, Cohen & Manion (1994, p.359) averred:

“... a matter of principled sensitivity to the rights of others. Being ethical limits the choices we can make in the pursuit of truth. Ethics say that while truth is good, respect for human dignity is better, even if, in the extreme case, the respect of human nature leaves one ignorant of human nature.”

The following are potential ethical issues of this study using Patton’s (2002) ethical issues checklist as a guide (p.408): Explaining purpose; informed consent; confidentiality; and advice.

4.7.4.1 Explaining Purpose

Prior to the start of the case studies, an accompanying letter outlining the research project was sent to the respondents. At this point, participants were told about the purpose of the research, the nature of their involvement, what measures would be taken to protect their rights as participants – including protection of their identity, and the option to withdraw at any stage.

4.7.4.2 Informed Consent

An appropriate consent form was developed according to the guideline of Loughborough University. Participants were given an information sheet to read detailing this information. All participants were informed of their rights and asked to read and sign the informed consent form in accordance with the University's requirements. In doing so, they acknowledge that they understand what is entailed by their participation and agree to have various activities recorded for research purposes.

4.7.4.3 Confidentiality

Researchers have an obligation to uphold the dignity of the participants and to ensure that confidentiality is upheld and that no quotation is attributable to the respondent without prior consent. An undertaking of confidentiality was given to each respondent before the interview began and the purpose of the recording of the interview explained. None of the respondents declined to have the interview recorded.

4.7.4.4 Advice

The two supervisors for this research were considered the researcher's confidants and counsellors on issues of ethics during the study.

4.8 Summary

This chapter has presented the research design and methodology for the research. The chapter highlighted the philosophical foundation of the research and the choices made with regards to research approach and methods of enquiry. The research stages, data collection protocols and analysis strategies were then presented in the research design section. The study follows an abductive research approach, which stresses the importance of analysing multiple and interconnected levels of contexts in research design. This approach expands understanding of both theory and the empirical phenomenon under investigation by calling for parallel and successive analytical review of theoretical insights and the emerging data. A two-stage research approach was employed. The findings of the exploratory studies augmented the analytical framework development and thus, informed the design and analysis of the main case studies. Such a multidimensional construct is critical in abductive research for breaking the more linear view on relations between empirical data and theory development. The next chapter discusses the exploratory findings and the subsequent STS analytical framework development.

CHAPTER FIVE

5 EXPLORATORY FINDINGS AND SUBSEQUENT DEVELOPMENT OF AN STS ANALYTICAL FRAMEWORK FOR ANALYSING BIM IMPLEMENTATION PROCESSES

5.1 Introduction

The previous chapter has made the case for the underlying premise of the research to have interpretivist worldview. Reflecting the desire for the empirical data to be underpinned by organisational participants' interpretations, thick descriptions, and saturated by contextual and practice-based overtones. A case was also made for a qualitative enquiry comprising exploratory investigation of BIM-enabled construction organisations which feeds into a subsequent and more detailed case studies research design.

Having presented the data collection and analysis aspects of the study in the previous chapter, this chapter presents the results of the exploratory studies and the subsequent development of the framework for analysing BIM implementation. The findings of the exploratory studies, coupled with the review of the sociotechnical systems theoretical perspectives presented in chapter 3 will help formulate an appropriate STS analytical model for the analysis of the BIM implementation processes in the case study organisations. This chapter thus addresses the fifth objective of this research which was to propose an STS analytical framework that can support construction organisations with their BIM uptake.

5.2 Results of the Exploratory Study

The exploratory study presents BIM strategies as practiced in some selected construction organisations. The goal is to identify the main drivers, successes and oversight experiences during the evaluation, selection and use of the various BIM technological artefacts and the concomitant innovation processes at the participating organisations. 16 different construction practitioners, representing 12 number BIM-enabled construction organisations (BCOs) participated in the exploratory study. Table 4.3 presents details of the participants. The BCOs were targeted based on demonstrable evidence that they have implemented BIM in their respective organisations, and are able to manage a BIM project. Seven of the organisations are classed as large construction firms with an average annual turnover of £557 million and 80 years of average construction experience. The remaining five are small to medium construction firms with an average of 36 years of construction business experience and the highest annual turnover is in the region of £30million. All the participating firms are BIM-enabled. Thus, the interviews and the documents collected are all related to their BIM delivery approaches including oversights

and outcomes. Table 5.1 encapsulates the more detailed summary of interview findings that follow.

Data collection for this study relied on semi-structured interviews focusing directly on the topic. Documents were also collected from the participating organisations to corroborate and augment the evidence collected through the interviews. The documents examined included BIM implementation strategy documents to ascertain the content of and strategies that the BIM implementation processes entailed. Also, records of the organisations' BIM projects were analysed to see the manifestation of the implementation strategies and the real issues emerging from the implementation processes. The data collected were analysed by indexing the responses and collating those common to the objective of the study for a qualitative content interpretations (see subsection 4.7.1.3). The content of the analysis emerges from reading the interviews and the documents, and indexing them by the issues that were identified to be most important to the respondents. The analysis is underpinned by the interrelated sociotechnical systems design principles that give joint consideration of the work system components. The outcome will highlight issues requiring particular attention in the design process and inform the design for the potential framework for analysing BIM implementation in the case study organisations.

The analysis is structured into seven sections. Firstly, the drivers of BIM implementation is presented in section 5.2.1. Secondly, the development of BIM implementation plan is discussed in section 5.2.2. Thirdly, the criteria used for selecting BIM tools and supporting systems artefacts are presented in section 5.2.3. Forth, the management of the organisational change processes are discussed in section 5.3.4. This is followed by section 5.3.5 which discusses BIM project delivery processes and the emerging roles of the BIM team members are presented in section 5.3.6. Also, a sociotechnical systems perspective to challenges associated with BIM implementation are highlighted in section 5.3.7. The section concludes by summarising the key findings of the exploratory studies and the implications for the framework development.

Table 5.1 Summary of exploratory study's results for 12 no BIM-enabled construction organisations (BCO) in the UK

Background Information							
Name	BCO-1	BCO-2	BCO-3	BCO-4	BCO-5	BCO-6	
1 Business type	Engineering Consultancy	Design/BIM consultancy	Construction/ infrastructure	Project management	Cost management	BIM vendor	
2 Size ^a	Small	Small	Large	Small	Large	Large	
3 Annual turnover	>£30million	>£7million	>£930million	Not known	>£116million	>£300million	
4 workforce	>500	>100	>4,700	<20	>1,300	>3,000	
5 Scope of operation	Multi-national	National	National	National	Multi-national	Multi-national	
6 Years in business	37	60	>150	10	66	29	
BIM Implementation Initiative							
7 Years of BIM experience	7	10	5	3	5	3-5	
8 Drivers for BIM	Future work security, Alleviate silo mentality, Condense project timeline	Efficiency, Added value, reliable project information	Competitive advantage, clients' driven, Value adding	Concerned that BIM has been hyped, whilst vendors are profiting	Clients' demands, eliminate unbudgeted change and optimise performance	Help address sustainable design, and maximise return on investment	
9 Implementation plan	Yes (bespoke BEP)	Yes	Yes	No (Per clients requirement)	Yes	Yes	
10 Strategy for implementation	BIM committee developed strategy from training needs to tools selection	BIM development leaders led the transition	Technical support from external BIM consultant on first BIM project	Conferences and seminars on BIM processes and self-thought on the use of the BIM applications	Internal committee assessed BIM feasibility, financial implications and developed plan for uptake	Promote Bentley products for the AEC market thus assess market needs via engagement with users	
11 Choice of BIM application	Initially Revit, now per project requirement	Revit and Vasari for swift models creation	Bentley for complex infrastructure and Revit for building modelling	No particular preference	CATO enterprise and Autodesk QTO	Bentley products	
Key drivers for implementation success or failure							
12	People related (internal processes and inter-organisational), nature of available technologies	Training needs, technical challenges (different products performances)	Technical (interoperability), People (mindset change), process (liaising the tools with the workflow)	Process issues (expensive training schemes), and technical / license issues (expensive running cost)	People and technical: Expensive products and training schemes, but no clear evidence on positive return on investment	No alliance amongst vendors hence existing products lack interoperability; limiting BIM capabilities	

^aNote – Small to medium-size enterprises (SMEs) have been defined within this study as companies employing less than 250 people and have a turnover of less than £50million per annum: large organisations are those that employ over 250 people and have a turnover above £50million per annum (e.g., BIS 2011).

Summary of exploratory study's results for 12no BIM-enabled construction organisations (BCO) in the UK (Cont'd)

Background Information							
Name	BCO-7	BCO-8	BCO-9	BCO-10	BCO-11	BCO-12	
1 Business type	Civil and building contractor	Architectural design	Civil and building contractor	Infrastructure building and design/ management	Geomatic engineering and 3D laser scanning to BIM	Specialist contractor	
2 Size	Large	Small	Large	Large	Small	Large	
3 Annual turnover	>£1.1billion	Not known	>£1billion	>£350million	Not known	> £102 million	
4 Workforce	>4,000	>50	>2,800	>5,000	<50	>600	
5 Scope of operation	Multi-national	National	Multi-national	Multi-national	National	Multi-national	
6 Years in business	>10	45	>150	145	30	> 10	
BIM Implementation Initiatives							
7 Years of BIM experience	5	4	3-5	8	5	>5	
8 Drivers for BIM	Efficiency saving, clients as the main drivers	Predictability “mirror image of the virtual in real time”	Efficiency driven, adding value to construction process	Competitive advantage, Clients driven	Maximise productivity, new corporate identify, potential for growth	Value adding via greater predictability, It will become the way of working	
9 Implementation plan	Yes (Bespoke BEP)	Yes	Yes	Yes	Yes	Yes	
10 Strategy for implementation	Technical department formulates strategy including the process and selections of BIM applications	BIM feasibility plan developed and directors approved	Internal BIM team works alongside external BIM consultants for training and advice	External consultants (Excitech) provides technical training and support services	Internal BIM process has been developed as guideline for use by all engineers	BIM champion identified and trained. Now over a dozen members meet every 4weeks to review and discuss BIM progress	
11 Choice of BIM application	Bespoke BIM platforms	Autodesk license and used mainly Revit architecture	License agreement with Autodesk	A deal with Autodesk for a global network license agreement for use in over 70 countries	Laser scan to BIM. 3D GIS systems	Autodesk Revit used to develop models	
Key drivers for implementation success or failure							
12	Process (developing industry best practice to suit BIM workflow), Technical (lack of interoperability)	People and process (BIM is driving radical change processes), clarity of training and IT infrastructure setup	Technical (interoperability), People (mindset change), process (liaising the tools with the workflow)	People (buy-in and financial support), process (work configuration) and technology (tools selection)	Knowledge development, problems with existing BIM applications, overall cost of training, and process configuration	Appropriate BIM platform consistent with users' roles. Easy to learn and easy to use products	

5.2.1 Drivers of BIM Implementation

The analysis showed that the motivation for BIM uptake varies from one organisation to the other. The responses of the interviewees pointed to BIM drivers such as: the UK government 2016 BIM-compliant procurement strategy; efficiency; competitive advantage; it befits contemporary (complex and dynamic) market demand, and capitalising on evolving technological capabilities. Table 5.2 summarises the analysis of the BIM implementation drivers emerging from the exploratory data. It provides a critical starting point which has to be developed further by the implementing organisations to establish a meaningful and comprehensive plan. This is generally consistent with the strategic management view by Hussey (1998), that the critical starting point of innovation trends are the drivers and vision, values and strategies of the implementing organisation.

Table 5.2 Summary of drivers for BIM implementation

Drivers for BIM implementation	Sample quotes on BIM implementation drivers
Collaborative relationship	BIM is not about architects or for that matter any other discipline taking on all the other roles. It is more about individual disciplines upgrading their status and adapting new technologies and new processes and ways of working that provide greater opportunities for all project disciplines to integrate and work together [BCO2 – NaI] We like to think that our adoption of BIM over the few years has continued this tradition of integrated design” [BCO1 – GaB].
Efficiency driven	We wanted to alter our corporate identity which involved significant changes to our company services as well as the means of service delivery.... Now it [BIM] has revolutionised our business process and made the way we work much more productive [BCO11 – NiB] There is a long heritage of innovation within our practice. By embracing advances in technology and an ethos for integrated working, we continue to pursue our aim of delivering excellence through our people, our service and our architecture [BCO2 – NaI]
Forecast	We understand that BIM is going to be the way that the building industry works, end of story [BCO9 – PhL]
Trends and turbulence	Matching the pace of global business and managing challenging market conditions requires us to achieve a seemingly disparate set of goals; decrease costs, realise efficiencies, improve communication, condense project timelines and maximise resources. I have no doubt that the adoption of BIM solutions will be instrumental in helping us succeed and reach that goal [BCO1 – GaB]
Government drive	BIM is still relatively new to highways infrastructure, however, that’s about to change due to tighter Government legislation. Companies that can successfully use BIM technology and demonstrate its effectiveness should be in a better position to win more work. By 2016 all publicly funded projects will have to be BIM compliant and it will feature heavily in procurement marking. Therefore, if we can demonstrate, through a live project, how it works then it should score well in future tendering [BCO3 – TiE]. ..We’ve got to (implement BIM), because by 2016 we’ve got to work out our own BIM strategy. We have got this memo from Paul Morrell saying you will do BIM

Competitive advantage	<p>otherwise there is no government job for you [BCO6 – IaM].</p> <p>We are looking to be competitive and that’s really important. The globe is becoming a lot smaller in terms of being able to transact business across anywhere in the world, so we are looking for ways to make our business efficient, cost effective and therefore being able to compete in the global market and that’s vitally important for us, as global brand-and that means more receptive to technological change [BCO10 – DoB].</p>
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For one organisation, the change is driven by the need to diversify and restructure the business activities, resulting in a launch of new corporate identity which coincides with the firm’s 25th anniversary. As a result the company diversified to incorporate BIM platforms and upgraded its computer workstations to matchup with the BIM tools, and streamlined its business processes in order to “*maximise productivity, broaden the potential for growth*” and meet demand for its services.

Some interviewees were of the view that, the earlier generation CAD era of working has been unable to keep up with the changing demands of a sector which stresses greater certainty in the three-level triangle of cost, quality and time whilst recognising increasing levels of complexity in the information to be delivered. Consequently, the capabilities in the emerging BIM tools are providing new capabilities for the early BIM implementers which have not been possible in the past. For instance, a multinational construction consultancy firm relies on latest innovative technologies and processes to enable dispersed teams to work collaboratively, wherever they are, to respond to business anywhere in the world, ultimately, making the company more competitive and cost effective. “...we acknowledged that for us to benefit from the global market, it was important to combat the silo mentality that is very common in a business of this size and nature” [GaB – BCO1].

The enthusiasm that drives the implementation of BIM has partly been influenced by the UK government recent announcement to make BIM obligatory on all public procurement projects by 2016. Commenting on this, one respondent emphasised that: “*We’ve got to (implement BIM) because at least that’s what the government is campaigning for...we are also saying to our supply chain-by 2016, if you don’t do BIM you won’t have a job*” [BCO9 – PhL].

In addition to the general consensus of the government influence on the AEC sector’s BIM enthusiasm, each knowledge boundary of the sector, such as architects, engineers, clients, and contractors also have their unique drive for BIM; and it is often related to their work practices. Thus, a senior quantity surveyor working for a major cost consultancy firm elaborated that BIM

offers them the option for a well-informed whole life cost analysis rather quickly as compared to the conventional format. “... *It [BIM take-off software] has a direct efficiency benefit, an example is the speed for which quantities can be taken off from a BIM model compared to the traditional approach*” (BCO5 – MaM). Another respondent with a project management background said they have been drawn to BIM because of its potential to “*reduce the time spent by the cost guys to get quantities from a model-helping to make ample time available for other things such as the application of value engineering*” [BCO7 – MaS]. An architect also said the real opportunity in BIM for their organisation is “*the power of virtualisation*”, and how the mirror image of the virtual world interfaces with the actual project in real time [BCO8 StB]. From the project management perspective, the virtual construction and coordination prior to the actual construction, is a big plus for BIM implementation; “*what we do is build the facility in a virtual environment, find out the mistakes, coordinate it and remove the clashes, we can now put a timeline on the virtual model - the timeline allows us to demonstrate the construction process in the model, we can fly through it, walk around it so everyone can understand how it is going to look like*” [BCO9 – PhL].

Even though the respondents rightfully identified the drivers for BIM implementation, that alone is not enough for leveraging the benefits of BIM to the implementing organisation. Knowing why it is important to implement BIM will help organisations to develop implementation plans and also understand the requirements and expectations that accompany the implementation. However, the CIC Research (2012) have emphasised that the decision to implement BIM must be based on resources, competency and anticipated value to all the parties involved. It has also been suggested that if the industry is to move forward with BIM implementation, firms must focus on perfecting what they can deliver (Jernigan, 2008). This means reaching for the straight forward targets of the available processes and products that can instantly add value to organisations. What is problematic, however, is for organisations to develop competences that can ultimately become the selling point for the organisation. A director of a large consulting firm for instance, said: “*...if you’re not going out there to put yourself in a good light, you’re not effectively selling yourself. So if you’re not selling yourself, you’re not winning the work to get your positive return-on-investment on BIM*” [BCO10 – DoB].

5.2.2 BIM Implementation Plans

In order to develop a BIM-enabled working environment, all the respondents agreed that, the business requirements need to be clearly elicited and implementation plans developed. It was drawn from a narrative given by an interviewee that BIM implementation should not be treated as an *ad hoc activity*. The more grounded the plan is in relation to a company's strategic goal, the more successful the implementation is likely to be. One interviewee for instance stated that:

“You need to have a vision of what you do. If you try to implement BIM without a vision you are actually not going to get there really ... it is more of if we are going to do it, this is the reason and an appropriate implementation plan lay out to the company to say this is what we need to do” [BCO1 – GaB].

There is no consensus on a common set of criteria for the plan. Several recurrent organisational-specific strategies influence the BIM implementation plans. These plans intuitively lead towards the same fundamental principles of collaborative working that enable construction project partners to work together. These documents guide through the development of people and processes, mobilising existing technologies, team working and access to a common data environment (CDE).

Basically highlight plans on how organisations should approach their wide-scope organisational or project-level BIM. Further, the BIM plans alone cannot make construction organisation become BIM-enabled. The plan highlights the expected changes, but more importantly, it calls for support, buy-in and collaboration amongst the construction workforce in order to realise the associated changes as underlined in the BIM plans. Table 5.3 highlight some of the common changes addressed in the BIM implementation plans. In essence, successful BIM implementation is possible but it does require expertise, planning, and proper selection of BIM tools.

Table 5.3 Key changes captured in BIM implementation plans

Key changes addressed in plan	Sample quote supporting the highlighted changes
Technology change (system selection criteria) <ul style="list-style-type: none"> • Hardware (workstation and network) • Software (BIM and systems selections) 	"...BIM is an overhaul of the whole process; new hardware, new software, new possibilities [...] it is a game changer if you are doing it properly" [BCO7 – MaS].
Organisational process change <ul style="list-style-type: none"> • Workflows • Professional roles • Training and support • Organisational structure 	"...it's actually quite a complicated process because for the first time in the building industry the entire development process has been affected [...] the existing process is fragmented; silos of architects, builders, and dead data. BIM process is joining everybody up and that's the major difference [BCO9 – PhL].
Project-level process change <ul style="list-style-type: none"> • Project deliverable (BIM project rollout) • Professional roles (supply chain involvement) • Team structure (work relationships) 	"When you start going into those documents, it shows you the process at the start of the project [...] concerning deliverables, who is modelling the pipework and so on [...] That information is also shown in what we called project BIM execution plan [GaB - BCO1].

5.2.3 Criteria for Selecting BIM Tools and Supporting Artefacts

A marketplace competing and complementary BIM products exist thus having a selection criterion to guide a decision making is important. All the respondents indicated some criteria that guide in the choices they make with regards to the appropriate BIM tools and their associated set of products. These criteria are broad but they are categorised under three main subsections including 1) cost implications; 2) capabilities of the vendor's products and supporting computer systems. These are captured in table 5.4 and are discussed under the following subsections.

Table 5.4 Factors influencing the selection of BIM tools and supporting artefacts

Determining factors	Sample quotes for factors influencing the choice of BIM tools and artefacts
Cost implications <ul style="list-style-type: none"> • Upfront software cost • Supporting systems cost • License maintenance fee • Training costs • Operational cost 	"Their products carry a sense of getting at a reasonable cost" [BCO9 – PhL] "We started to use Revit, well, sort of...three or four years ago and it was a slow uptake and it was hard trying to get it implemented. You know the cost and everything associated with it" [BCO1 – GaB] "...another important aspect is to look at the cost of the proposed choice in terms of IT infrastructure upgrade, BIM software, staff training needs and so on" [BCO2 – NaI].
Capabilities of vendors' products <ul style="list-style-type: none"> • Available technical support • Market present • Compatible with IFC interface 	"You cannot just buy anything and expect it to work well for you and it is not a silver bullet because there is not only one technology out there" [BCO7 – MaS] "we were aware that several BIM technologies may offer

<ul style="list-style-type: none"> • Interface with other BIM tools • Fit for purpose • Level of adoption • Strong online present and support • Constant cycle of versions improvement 	<p>equal or greater value.....but ultimately selected Revit in 2005 as our preferred solution on the basis of its functionality, stability, technical support and level of industry adoption” [BCO2 – NaI].</p>
<p>Appropriate supporting systems</p> <ul style="list-style-type: none"> • Workstation • Operating system • Network access • BIM server domain • Cloud-based repositories 	<p>“Certain pieces of the BIM software are located in the central server. Users can temporarily download them, do their work in a remote location and then the information goes back to central folder as soon as they logoff” [BCO9 – PhL].</p> <p>“My 18months old laptop had 32bits OS and 3RAM which was ok then for my CAD. But I understand civil 3D or Revit MEP for instance requires bigger spec than that-it shows how things are quickly changing” [BCO1 – GaB].</p>

5.2.3.1 Cost Implications

Considering the inevitable costs involved in purchasing new systems, retraining staff, and the resources needed in developing new organisational protocols, there seemed to be a lot of trepidation from a section of the participants regarding the knock-on effect after investing in BIM. From the responses, the small-size organisations with less investment budget seem to be affected by the investment cost than the large-size organisations.

As the large number of construction organisations are SME, the core implication of this is that, majority of the AEC sector organisations might not afford to make necessary investment in BIM unless and until the associated costs are perceived to be reasonable and affordable by them. Some respondents also indicated that due to the financial implication involved in BIM uptake, most organisations may need the assurance that it is worth committing any resources to it in terms of payback period and return on investment (ROI). The organisations that have made the necessary investments in BIM believe that it can create value on the appropriate projects and it can also generate benefits to the BIM organisation: *“it does create return on investment in terms of the kinds of contracts that we can now do.”* Thus the significant costs associated with the transition result in productivity benefits, which otherwise would not be realised in the conventional structure of the construction industry. For some, even the ability to produce consistent drawings from a model, and create coordination drawing which leads to clash detection and resolution, make the transition to BIM worthwhile.

5.2.3.2 Capabilities of BIM Products-range

Typically, each BIM platform is biased towards a particular task in the AEC work domain. The wide range of BIM tools provide discipline-specific functionalities, such as architecture, MEP, civil, structures, costs, planning, energy simulation and cloud-based repository systems. When each specialist user has the leeway to choose from, or gets expert advice in deciding from the competing product ranges, this may enable a blend of the best-breed product solutions at the project level.

There are a wide range of criteria that the BIM users mentioned that they use to judge a particular BIM application. These include: the ability of the application to manage large or very detailed project information; its ability to interface with, or compatibility to other BIM tools; the sophistication of their object libraries to design complex geometries. The BIM tools are also judged by the ease with which users can create models; the ease of updating objects; ease of use; their ability to handle large numbers of model objects and in their ability to support collaboration. From the discussions with respondents, it became evident that, the capability of a BIM tool to import and export models using an appropriate industry exchange standard such as IFC is considered mandatory for any BIM tool to have. This entails the ability of the system to address the operational issues of the organisation for which it was selected. This condition is also supported by Cherns' (1993) notion of 'compatibility'; where the selected system must be expected to be compatible with the organisation's technical and operational objectives.

Nevertheless, with the current capabilities of the available BIM applications, it is difficult to judge based on these criteria because, these products keep changing in terms of capabilities and functionalities with each new released version, which often occur annually. It may therefore be hasty to stick to a particular product without regular assessment of the available product ranges. This suggests that, a vendor who has a good reputation in the marketplace, and is able to respond to practical interrogations and has a strong online presence with a view of providing technical assistance for user as and when needed, will be a preferred choice for BIM users.

5.2.4 Managing the Organisational Change Processes

In addition to selecting the appropriate BIM applications, and the concomitant technological workstation configuration, it was also acknowledged that organisations have to do things differently in order to ensure implementation success. A whole range of organisational

procedures were discussed. These are grouped under three main themes, including: 1) top management support; 2) bottom-up involvement; 3) training and support; and 4) development of BIM champions.

5.2.4.1 Top Management Support and Operational-Level Buy-In

In terms of management participation and contributions to the BIM implementation process, it became increasingly evident that the resources needed for the period of change are as a result of strategic decision made at the top level of the organisation. Accordingly, top managers needed to understand what BIM could offer to their business in terms of efficient ways of reinventing baseline profits on projects to get more on returns. According to a BIM manager, decision making managers do not just buy into *fanciful* technologies, “*they don’t want to know anything about that, they only want to know what that means to the business and how it is going to affect the business*” (BCO9 – PhL). This suggests that, for the top management, the underlying tendencies of BIM is about efficiency, being commercially viable, and other aspects that allow people to work in order to make profit to the business. Top management support is a positive signal that funds would be made available to advance the BIM implementation process, and this implies that, those at the “*shop-floor level can have the tools, the pieces of software, and the support they need*” to do their work (BCO10 - DoB). A BIM coordinator also emphasised on this by inferring that without top-level support BIM cannot get off-the-ground.

However, it is not top management support alone that can ensure successful uptake of innovation. Challenger et al. (2011) have asserted that it is highly unlikely for individual or group to understand all the component parts when considering innovative systems’ development, adaptation and use. Therefore complementary range of knowledge, resources, procedures and expertise should contribute to systems design and implementation. To obtain meaningful buy-in for innovative processes, Lewis et al. (2010) have pointed to the need for consensus building among parties. They also posit that achievement of consensus building does not call for sales blitz to members, but instead comes from low-profile meetings that stress equal participation. Thus, the ideal situation may be for management decision to be made in close consultation with operational-level workforce, those that actually use the BIM applications. People at top-management level need to know what BIM can offer and the benefits it will bring to their organisation in order to be able to make strategic decisions regarding financial commitments. Also, the people at the “*shop-floor*” need the knowledge and the tools in order to effectively

execute their work. Literature has also confirmed that end-user participation in, and ownership of, systems design and implementation is critical for implementation success (e.g. Clegg & Walsh, 2004; Mumford, 2006).

5.2.4.2 Training and Support of End Users

Training and education is considered as being the underlying drive for BIM implementation success, with one interviewee even asserting that “*training is the leading indicator of a successful transition to BIM.*” This is because the BIM practices and the available tools used for execution are relatively nascent, thus, the implementing organisations undoubtedly have to upgrade their existing professional workforces’ knowledge status to encompass BIM in order to be able to successfully execute BIM projects. The responses from the interviews pointed to two main training strategies that lead to the development of BIM competent workforces. Some rely on external BIM consultants to provide them with all their training needs; and 2) others have in-house BIM training plan, which comprise organising seminars and BIM workshops for staff, and developing BIM champions amongst the workforce to drive the process. The responses of the interviews imply that, BIM solutions keep developing in parallel with evolving technologies, which are “*constantly (often annually) upgraded.*”

The implication of this is that, BIM-enabled actors must position themselves on constant loop of learning to act decisively towards the common goal of their work context, creating the condition for present, as well as future success, taking into consideration the fluidity of current technologies as they continue to develop in content and in form. The notion of double-loop learning approach where the latest versions of BIM tools can effectively be used to avoid the repeat of any on-going deficiencies in work practice requires not only training, but also, support, encouragement, and on the job-learning, or learning-by-doing, that matches up with the latest available BIM applications. This is consistence with Korkmaz et al. (2012) assertion that innovation is more likely to be adopted in the intended manner if actors have skills to master the innovation, have incentives to implement, and are beneficiaries of managements’ efforts to remove structural and procedural obstacles to implementation.

5.2.4.3 BIM Champions

The analysis showed that, organisations are keen on developing *technology-savvy* BIM champions to drive the implementation process from the bottom-up. It was felt that BIM

champions play critical roles in bolstering organisation's BIM implementation effort from downstream or "*shop-floor*' level where people actually create the models." A director narrated that most companies have potential BIM champions, "*they are the ones, where it is almost like hobby wanting to learn more, wanting to use the latest technologies.*" When they are noticed, their passion and enthusiasm can spark interest at the grassroots level, spreading across a wider context, "*what you're trying to achieve is to take their passion and enthusiasm, add the technology to it, get some organisation standard, to form 'this is the way that we actually want to work'*" [BCO10 - DoB]. The BIM champions may be required to develop some skills such as 3D knowledge of BIM, and component-based design or experience with the use of BIM software to apply to the business operations. This may advance the organisations' BIM-competency level in areas such as design coordination, project planning, energy analysis, modelling and visualisation, etcetera.

5.2.5 BIM Project Delivery Process

From the responses, it was evident that the de facto implementation process of BIM occurs at two levels; the organisation level and the project level. Thus, there is the organisation-level BIM implementation strategy and there is also the project BIM strategy. From the organisation perspective, BIM strategy documents contain the organisation's BIM competence-building, encompassing appropriate technical competencies, procedures and knowledge workforce, which ultimately leads to BIM project delivery. From the project perspective, careful consideration is given to the project BIM execution plan (BEP) which is co-developed by the multidiscipline project team (the BEP is developed on a project-by-project basis as each project is often unique). The latter thus represent project specific BIM strategy whilst the former defines generic organisation's BIM implementation strategy. For the project level BIM delivery, criteria may vary in emphasis according to the characteristics of the project. The BEP actually defines the way the BIM project will be delivered.

From the responses, the project level BIM strategy can be categorised under five broad headings, comprising: 1) early involvement of the supply chain; 2) development of BIM project protocol and plan; 3) define each supply chain BIM deliverables; 4) clarify the compatible BIM software platforms for use; and 5) contractual relationships.

5.2.5.1 Early Involvement of Project Supply Chain

The responses indicated that one of the most striking benefits of the BIM work process is the close working relationships and greater co-ordination among the project team at an early stage of the project cycle. The early involvement of the project team members thus provides a stimulus to collaborate, and a platform to have expertise advice about how project information will be created and what object geometries will be coordinated in the model prior to the start of site construction.

5.2.5.2 BIM Project Protocol and Plan

The plan provides information on how the project teams intend to deliver the agreed level of BIM and the protocol elaborates on the shared responsibilities; *who is responsible for doing what*. A BIM development leader alerted that organisation should not underrate the necessity for a conscientious planning and adherence to protocols during the appropriation process of BIM on a BIM-enabled project. A well-prepared BIM Execution Plan and protocol is a prerequisite to establishing the *expected outcome from the BIMs file sharing formats, levels of detail, and coordinated models*. The BIM protocol and plan, when agreed upon by the project supply chain it can then become addendum to the contract.

5.2.5.3 Supply Chain Teams' BIM Deliverables

A decision amongst the model creators have to be reached regarding the detail of model information that is to be created. BIM deliverables thus outlines the responsibilities and matching capabilities of the project teams in terms of the BIM delivery. According to the responses of the interviewees, the project team have to dedicate some time in defining roles and responsibilities at the outset, because BIM deliverables are not explicit in any of the current contract forms. However, the AIA (2008) have defined the concept of Levels of Detail (LOD) described through a sliding scale of LOD 100 – 500 (Bedrick, 2008). In essence, the levels can be summaries as follows: LOD 100: Conceptual; LOD 200: Approximate geometry; LOD 300: Precise geometry; LOD 400: Fabrication; and LOD 500: As-built. This is important because it can help define the level of BIM deliverable per each BIM stakeholder.

5.2.5.4 Compatible BIM Software Platforms

Coordination of different project information and federated models is very important at the project-level. However, there are wide ranging complementary and competing BIM tool in the marketplace. As the various supply chain members select their preferred BIM tools to help them do their works, there are two main rules that can guide this process. The project team may have to decide whether the selected applications are required to provide proprietary interface or they are supposed to be open platform so they can be integrated by the use of industry-neutral IFC format. There are different rules that guide each decision. With the proprietary interface, all the supply chain members' BIM tools have to be sourced from the same BIM vendor to ensure that they all have the same native file formats for coordination purposes. When the selected BIM applications are open, each of the applications will have to comply with the IFC rules to enable coordination. The level 2 of the government BIM strategy requires the application to be integrated on the basis of proprietary interface while the level 3 calls for the use of open BIM platforms.

5.2.5.5 Contractual Relationships

From the analysis of the responses, it emerged that contractual and legal considerations are needed on several fronts to augment the rollout of BIM across project organisations. Although there was a general agreement on the need for appropriate contract language to foster the open sharing of BIM information, there was no consensus on whether currently, there is any well-developed standard to regulate BIM uptake. Some argue that currently, the UK does not have a BIM specific contract and thus, lags behind other countries that have developed BIM contract forms such as the integrated project delivery (IPD) and ConsensusDOC which are very popular in the United States. Some also acknowledged the steady progress being made in the UK. For example, currently, there are some existing collaborative standards and emerging BIM protocols in the UK, for instance, the Construction Industry Council (CIC) has recently developed BIM protocol and defined the role of a BIM Manager who takes charge of the overall BIM process. Also, the AEC (UK) BIM standards and the BS1192 provide some collaborative processes and protocols to guide work relationship among BIM project teams. Nevertheless, more is needed to be done in terms of developing collaborative contractual frameworks for use in delivering BIM projects in the UK.

5.2.6 Emerging Roles of the BIM Team Members

This section looks into the professionals' pre-BIM experiences in relations to their new roles as a result of BIM uptake. The section is divided into two parts: 1) pre-BIM experiences and 2) current BIM practices. This section thus addresses part of the fourth research objective in relation to the assessment of the changing roles and responsibilities of the BIM-enabled construction professionals.

5.2.6.1 Pre-BIM Experiences

As BIM is relatively nascent, all the participants have indeed worked in the traditional setup for a long time. The conventional construction environment was described to involve PDF data flow, information sharing via email, coordination in a 2D environment, hard copy mark-ups for drawing changes, and unstructured handover of as-built documents to clients with paper-based operations and maintenance manuals. The norm of the construction delivery lifecycle was described as fragmented and sequential 'throw-back-the-wall' workflow. A BIM coordinator described how they have transitioned from a "*silo style of working; which is, I will do my bit, and then throw it over the wall to the next person who will probably catch half of it...*" Evbuomwan & Anumba (1998) in their study reported similar results about construction practice, emphasising that, in the conventional practice, the predominant workflows at the various construction phases (i.e., design, construction and operation) follow sequential progression, where each phase starts only when the previous one is completed. This fragmented process has been termed *over-the-wall silo*" style of working and is illustrated in figure 5.1.

Some of the main issues associated with the conventional project delivery process include: fragmentation of the different participants in the construction project, leading to misconceptions and misunderstandings; fragmentation of design and construction data, leading to design clashes, omissions and errors; occurrence of late and costly design changes and unnecessary liability claims and; lack of communication of design rationale and intent, leading to design confusion and wasted effort (e.g., Anumba et al. 2002; Evbuomwan & Anumba 1998). However, BIM necessitates a more reformed and improved processes to garner the benefits offered by the latest construction technological product solutions.

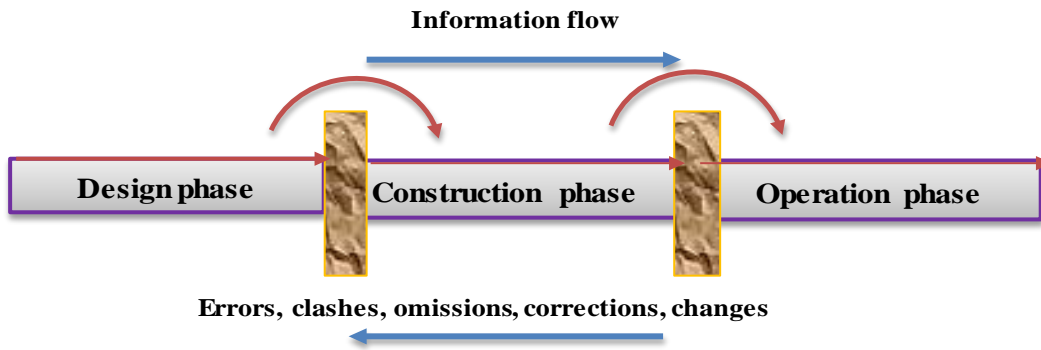


Figure 5.1 Fragmented, (over-the-wall) construction workflow

5.2.6.2 Current BIM Practices

The responses from the interviewees have characterised the transition to BIM as a “*paradigm shift from drawing on 2D media to modelling.*” Others see it variously as “*a game changer*”, “*a wholesale change*” or “*an overhaul of the paper-centric predecessor process.*” The current BIM practice runs counter to the fragmented and sequential work processes. The notion of BIM is to create reliable, accessible, and easily exchangeable building information for the project team who needs it throughout the lifecycle of a building. This places greater emphasis on the purposes for which the project information can be used, as and when needed. Figure 5.2 depicts a BIM environment in which parties use different BIM software tools best suited to a particular task, but are able to reliably exchange model information with every other party through a common information exchange protocol. Such a notion of BIM enables the project teams to develop a mutual understanding of intended results from the client’s briefing stages through the design to construction and then, to the operation and maintenance phase of the facility.

The transition from the over-the-wall working relationship to BIM also demands the supply chain members to substantially alter their roles and responsibilities. The entire project team: owner, architect, engineers, consultants, contractors, and specialist contractors must build a formidable team structure in order to optimise the efficiencies embedded in the federated BIM applications.

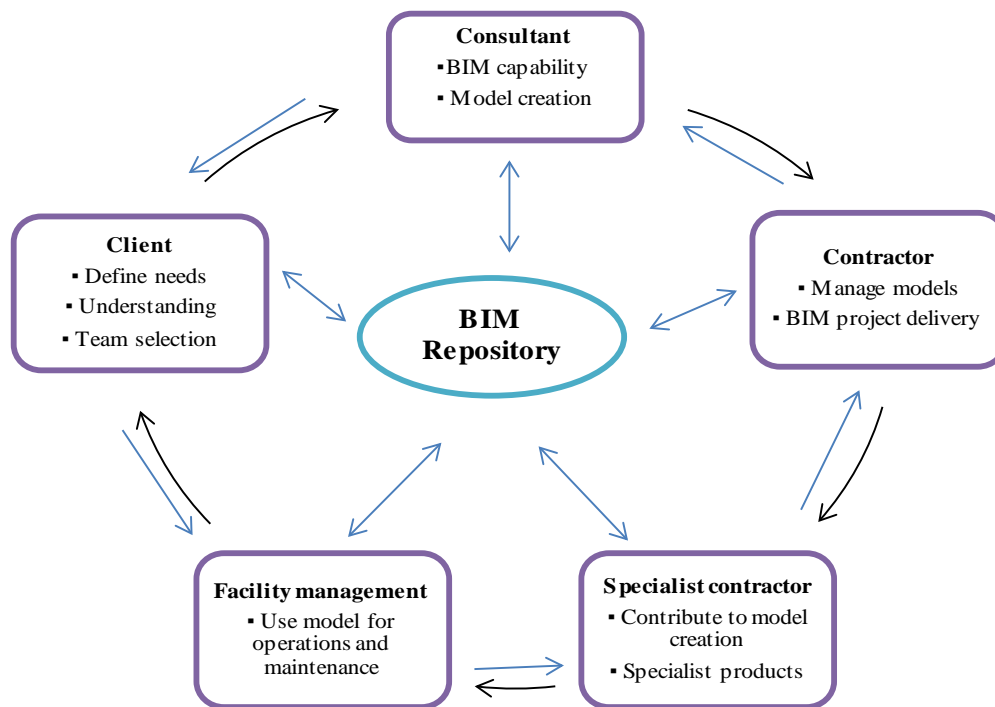


Figure 5.2 Role of BIM users in project team integration (Adapted from Anumba 1996)

Client's roles definition: It was emphasised by the respondents that, clients have important role to play in the BIM delivery process. They have the arduous tasks of selecting the project team, the type of BIM procurement, delivery arrangement and the overall specification. Thus, in a BIM-enabled working environment, clients are expected to become educated in the ways of BIM so they can mobilise resources and collaborate with the project team to define, design, and develop BIM deliverables for the project. Educated clients can better leverage the expertise and know-how of their BIM-enabled supply chain, from design to construction to address the complexity of design requirement, cost reliability and management, quality of product, asset management, or whatever the business needs might demand so that the project team can mobilise BIM tools to fulfil those needs. Owner-requested changes ultimately impact design quality, construction cost and schedule of the 2D-based method of working. This often happens because clients (or owners) are usually not able to interpret the conventional 2D design information hence, they frequently are not certain of the design outcomes until construction begins (Hardin, 2009). It is therefore argued that, clients that are unfamiliar with BIM and its potential uses may not adequately engage the design team in assessing the project's subtle goals regarding function, cost, and time-to-delivery.

Consultants' roles definition: From the interviewees' general acknowledgement of consultants' roles in the BIM process the responsibility of understanding the project requirement from the outset is a critical success factor for a BIM project delivery. The consultants also have to deliberate on, and collaborate with each other in the creation of federated models which are fit for the client's purposes and facilitate efficient work delivery. The parametric integrity of the model and every bit of the model's intelligence thus, have to serve two purposes; first, by building a collaborative relationship among the project team by virtue of creating coordinated model to enhance the efficient project delivery; and second, by providing a purposeful model to the client upon handover, for the management of the facility.

Contractors' roles definition: The main role of the contractor is to mobilise the various facets of model information and coordinate them into a coherent whole. A respondent emphasised that during the design phase, engineers and architects usually *juggle models between each other* without any proper checking; at the construction phase therefore, the contractor should be able to collate all the design models, MEP, and structural information, and export them into one coordinating BIM platform for further analysis *"to make sure they actually fit."* That was perhaps why Eastman et al. (2011) explained that the contractor may need to have a BIM coordinator, *someone who would be able to use different BIM application tools such as Solibri or Naviswork to address issues* such as coordination between BIM platforms, and manage communication between the model owners, and the model users. The contractor is also expected to have the capability to manage all the project information from the different BIM platforms, with coordination tools that include features for checking physical clashes, construction planning and sequencing, energy analysis, and change resolutions. However, from the responses, it was emphasised that; *"when you've got many different disciplines to manage on a project, it can be a tough challenge and many things can easily go wrong"* (BCO9 – PhL). Due to the challenges involved in coordinating disparate model information, it might be helpful if the contractor can lead regular BIM meetings; possibly weekly or fortnightly, depending on the project size, (e.g., Eastman et al., 2011) that include the design team to do *"a robust set of integration"* and also, to address any emerging coordination issues.

Subcontractors' roles definition: Getting specialists involved in the early design phase is considered necessary and important without their inputs, the information (e.g., schedules, cost, base objects etc.) in the federated models cannot be considered accurate. This underscores the significance of effective planning right from the early stages of BIM project delivery. The

findings however, show that most of the specialist contractors are not particularly eager to invest in BIM. This may be attributed, in part, to the fact that most of the specialist construction firms are small and medium enterprises (SMEs) and thus, do not have the initial capital investment required during the implementation process. Nevertheless, being part of the project delivery team, the contributions of the specialist construction firms are as important as the other project team members. Collectively therefore, the rest of the BIM project team members have the obligation to provide some support for those struggling to develop their BIM competences. This can be achieved, in part, by: 1) highlighting the benefits of BIM to the non-BIM project organisations that do not deem it imperative to develop their BIM competence; 2) clarifying the approaches of, and expectations from the BIM delivery processes; and 3) the ramifications for not being able to deliver BIM have to be emphasised to those who are not willing to develop their BIM competency.

On the whole, the responses from the exploratory study have provided some understanding of how BIM uptake affects the roles of the BIM-enabled construction professionals. An important theme that ran through the analysis of the interviews was that BIM-supported work processes emphasises the need for early and continual collaboration of the project team, including the client, designer, contractor and the specialist trades. This is to provide accurate model information from the outset thereby avoiding design coordination conflict. Under the conventional construction delivery process, there has been an issue of inadequate, or late involvement of all the relevant parties, and this often results in the misrepresentation of collective project needs and values, and lost opportunities to innovate and create value for the facility owners and project stakeholders (Kamara & Anumba, 2001). One of the main trends of BIM is to overcome such a shortfall in the construction process. The collaborative roles of the BIM-enabled construction stakeholders are indicated in figure 5.3.

The findings are generally consistent with the views of Eastman et al. (2011) as well as Suerman (2009) who claimed that there is bound to be wholesale changes to work roles of construction professionals to adapt to BIM. This is because, transition to BIM is not a natural advancement from CAD – it involves a paradigm shift from drawing on two-dimensional media to modelling, which is akin to actual construction in a virtual environment. Thus it requires new set of skills, new ways of thinking and new approaches to intellection.

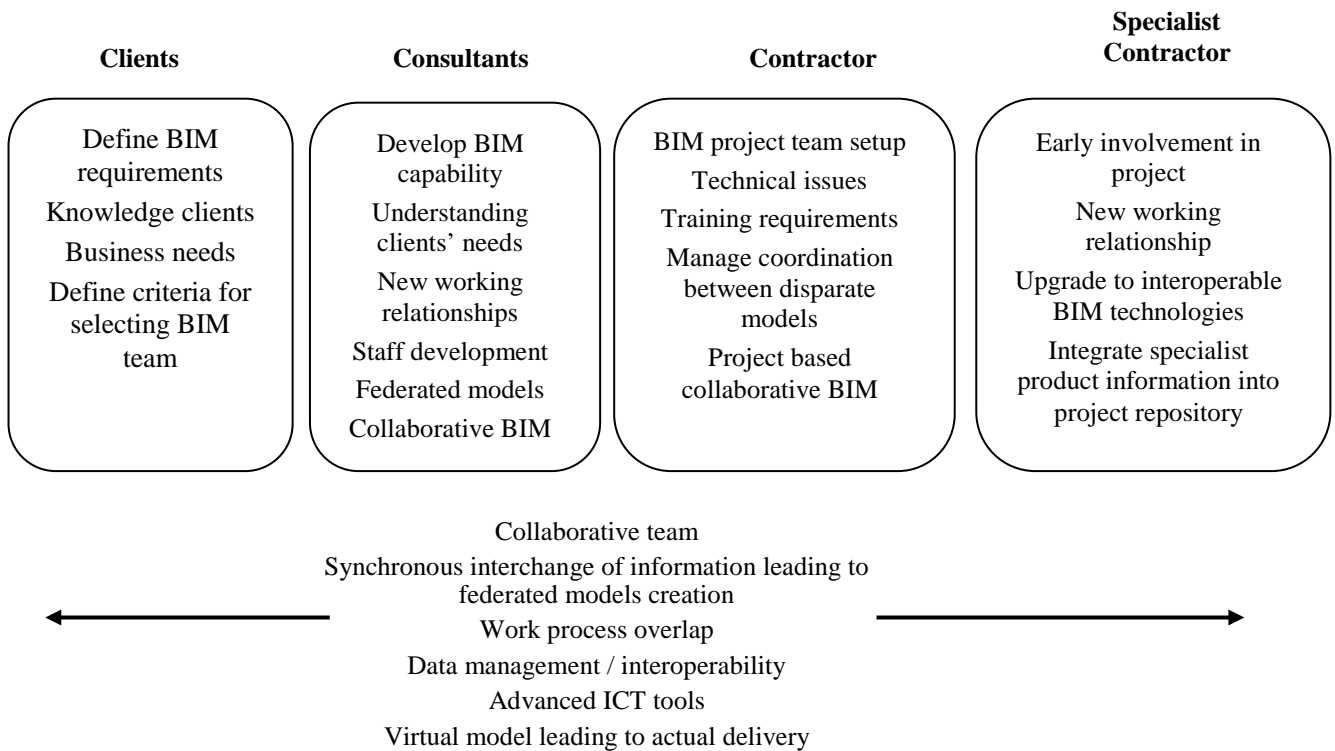


Figure 5.3 Roles of construction stakeholders on a BIM project

5.2.7 Sociotechnical Systems Perspectives to Challenges Associated with BIM Implementation

The analysis from the findings has shown that BIM implementation demands a complete break with the status quo, by requiring wholesale disruption of existing business practices, processes, contractual relationships and even individual habits in order to optimise the opportunity afforded by BIM. This finding reinforced the results by Erdogan et al., (2013) which have identified that introduction of new collaborative technologies in collaborative environments, initiates new ways of working which need to be well managed in order to achieve the full benefits expected from the changes. From the lenses of STS and multilevel perspective, this section attempt to highlight some of the main concerns associated with the available BIM applications and the supporting technologies and also the challenges associated with the work system redesign as a result of introducing BIM. The responses from the interviewees have implicitly shown that BIM implementation is influenced by phenomena at different levels or across levels. Rousseau (1985)

underscores that organisations' relationships intrinsically possess multilevel or cross-level characteristics.

Multilevel researchers recognise the relationship among variables at different levels of analysis and it has been commonly conceptualised as a nested hierarchies that constitutes the micro, meso, and macro levels (e.g. Lundvall, 1988). In the case of this study, the micro level represents the core BIM-enabled organisation. The meso level abstraction represents the work configuration at the inter-organisational or project level. It provides a platform to integrate multiple BIM platforms and diverse professional knowledge and ideas towards a common project goal. It is the level where threats to BIM deployment from the artefacts' functional behaviours and human agents' knowledge and cooperation are acknowledged. The macro level represents a changing landscape that provide gradient for innovation trajectories in the micro and the meso contexts. It covers the plethora of the different organisations that, in one way or the other, influence the design, stabilisation and closure of technological solutions in the micro context.

At the macro context, there is the advent of many different ideas and BIM platforms some of which work better than others. There is therefore a great deal of trialling taking place with these applications at both the micro and the meso levels. This is allowing construction organisations to test different business practices and workflows, to gain better insights from their experiences, and modify their approach in a continuous cycle of innovation. The challenges associated with the implementation particularly draw attention to the issues of the main sociotechnical components comprising the actors, structure, technology and tasks. Solutions to the BIM implementation challenges lies in identifying and mitigating the issues that typically hinder the alignment of the interrelated components of the STS.

There were some technical issues that impact on the implementation process. Currently, the popular BIM platforms in the marketplace, such as Revit, Bentley, ArchiCAD, Tekla and Vectorworks, are not able to directly exchange model information without losing some of the model's data. The parametric integrity in the model is also deactivated when the model objects are transferred to or from different vendor platforms. A respondent acknowledged that, this problem will not go away sooner because it is driven by the commercial interests amongst the various competitive BIM vendors in the marketplace. When the vendors maintain a proprietary range of products rather than interoperable, open product ranges, BIM users may be compelled to select one vendor amongst the lots rather than choosing different and more suitable range of

products from the broader marketplace. This situation is unfavourable to the construction practitioners; however, it is commercially viable to the vendor market. As such, the leading vendors such as Autodesk and Bentley have captured enough market shares, therefore, they may not on their own volition, make their applications interoperable to the wider BIM market, because that might negatively impact on their market share. As one respondent indicated; *“exactly what is in it for them-they have the market, why do they need to share it with their competitors.”*

These compatibility issues can however, be addressed by relying on vendor products that are compatible to international open model exchange format such as the IFC. The motivation for developing the IFC is to ensure easy and reliable exchange of data between BIM applications that comply with the IFC native objects’ rules. Nevertheless, it emerged from the findings that the current IFC formats, do not adequately support the management and tracking of changes to models from different BIM platforms. For instance, a BIM coordinator who very much relies on the IFC to interoperate/coordinate different models acknowledges that, some data is often lost when transferred with the aid of the IFC. Eastman et al. (2011) have also raised similar concern that the development of industry-neutral open-model exchange format such as IFC has been relatively slower compared to the pace by which the commercial vendors such as Autodesk or Bentley develop their BIM software applications. This weakens the IFC as a non-consistent model exchange platform, and often, the ‘model intelligence plus some information is lost’ during the exchange. Eastman et al. (2011) further warned that, until the interoperability gap is closed, the issue of “non-conforming” data interchange may remain unresolved.

As the BIM applications evolve to become increasingly more sophisticated, they place greater demand on the supporting work stations. The BIM vendors often recommend the minimum system specifications for their product portfolio. When users opt for the recommended computer specifications, they often find it very difficult to develop detailed models on the workstation. As the level-of-detail (LOD) of a model increases, the speed of the workstation begins to significantly reduce in proportion. The ideal workstation specification, encompassing hardware, operating system, graphics and processor may have to be consciously higher than the minimum spec recommended by the vendors. This ensures that the BIM platform can gain speed, efficiency and productivity to meet the demanding user requirements.

Moving beyond the technical and structural to the ‘human’ level, the transition to BIM is perceived to be a paradigm shift for all construction professionals, because it demands the user-groups to acquire new set of skills, new ways of thinking and new approaches to abstraction and then, learning and managing those skills in a continuous cycle. As the technological solutions continue to evolve, it bestows on the users to develop new skill and knowledge. The change in the BIM product range creates a knowledge gap among the BIM users, this knowledge gap can however, be ultimately addressed by providing learning opportunities and management support for every affected person. The regular cycle of change in BIM applications, upgrades and new products’ releases imply that construction practitioners that habitually use BIM applications may have to revert into “double-loop” learning trend, in order to be able to capture, retain and apply each improvement in the latest BIM platforms.

Other concerns are the associated cost and the loss of productivity during the implementation process. The financial investment associated with integrating BIM and the ongoing operational expenses are considered by many, especially the small and medium construction firms as very significant. *“It’s such a heavy investment so we need to be realistic that there’s no point throwing a lot of money at it”* [BCO5 – MaM]. Also, the BIM users that go through the training during the initial phases of implementation often remain less productive as they progress along a learning curve and accustom to the BIM applications. On the whole, it impacts on the organisation’s production capabilities and thus, steps have to be taken to reduce the consequences. This calls for a feasible plan for a phased replacement of the company’s existing CAD stations with the BIM workstations in order to reduce work disruption to the barest minimum.

On a more macro context, the benefits of BIM are best be realised if there is a concerted efforts to spur the implementation forward by addressing some of the common incipient challenges. Because building is accomplished by a broad network of people and organisations that collaborate towards a common project goal, the impact that collective measures will have cannot be denied. For instance, one BIM development manager explained that: *“a major shift in improvement would not occur until the industry as a whole adopt, rather than being led by some few lonely BIM users.”* With few exceptions, the lack of design and construction partners working in the same BIM ways stifles opportunities for them to improve their design and coordinate their work with other project organisations. Also, while many independent institutions, from different interest groups such as construction organisations, government institutions, BIM

authoring vendor groups, academic institutions, and BIM consultant groups, have a stake in the success of the BIM initiative, it does not come across from the analysis of an industry-wide consensus on processes or technology suites most suitable for BIM implementation. The concerns that emerged from the exploratory enquiry are expounded in table 5.5.

There are aspects of the innovation issues that the industry must address collectively, for example: by transforming the open standards into a robust and reliable set of model exchange format; by developing and disseminating best practices that eventually can become routine operating procedures or practices; by establishing academic research efforts and research-publishing tradition, centred around BIM and related technologies that can help disseminate knowledge quickly and widely; by developing, or at least, aligning the existing contract forms to incorporate BIM practices; and also, by streamlining the wider BIM vendor market to develop products that meet the future aspirations of the AEC industry sector as a whole.

Table 5.5 Sociotechnical insights to potential constraints and concerns associated with BIM implementation

STS attributes	Challenges to BIM implementation	Probable solutions to implementation challenges	Respondents' Viewpoints	Level of abstraction
Technical	Due to commercial interests, BIM applications lack the ability to directly exchange accurate/complete model information with other competitors' BIM products	Selected BIM platforms must be compliant to open model exchange formats such as IFC Encourage the development of interoperable BIM technologies and networking products featuring symbiotic relationships	Our biggest problem is what I call open-BIM problem [...] the engineering drawings were done with micro-station and we could not access them with our TEKLA system and that caused major problems (BCO3 – MaB).	All levels
	The IFC formats are not able to port model from different BIM platforms without losing some of the model information.	Users need to be informed about the development cycle of the IFC as each latest version sees some improvement relative to the previous versions Industry-wide support for interoperable toolkits' developers	“when I export my model with the IFC, in all likelihood, I will lose a lot of information [...] Although they say you can basically exchange information with IFC on these different software – that’s fine, but they don’t really talk about the level of information that you lose when you do that (BCO1 – GaB).	Macro
	BIM applications tend to run slow on typical recommended computer workstations.	The ideal workstation selected to run BIM applications may have to have higher specification range than the minimum approved recommendation. This is to ensure speed, efficiency and productivity gains for the BIM user	“[...] if you want to run Revit civil 3D, which is also a big package, you are better-off with a high-end computer...” (BCO9 – PhL).	Micro and meso
	Wide ranges of products quality, price-range, functionality and usefulness of BIM products are available in the marketplace, making it difficult to select appropriate BIM suite	Define selection criteria for the different BIM users to provide industry-wide coherent approach to BIM uptake	“...you say to them [vendors]; your product doesn’t quite work, can you get it fixed? Their usual response would be, yes, but that’s going to be resolved in the latest version (BCO10 – DoB).	Both levels
people	BIM requires technology-savvy knowledge workforce with the ability to learn and apply existing and emerging range of BIM products	Provide opportunity for people to learn and work with BIM tools Encourage BIM users to be acquainted with the evolving market trend of their BIM tools	“...some people embrace it quickly, and yet, others need a bit of coaching to take it through (BCO9 – PhL) “...from the learning point of view, one, we sent our guys on training courses, conferences, etc., two, we brought in Revit experts to work with us, three,	Micro and Meso

	Differential qualities of BIM competencies/applications at the project/inter-organisational level	<p>Users involvement to BIM competency building at the organisational level (micro context)</p> <p>Multidisciplinary inputs to the development of the BEP at the project level (meso context)</p> <p>Without the active engagement of knowledge workers and the support from the top management level, the implementation effort may not yield the required results</p>	<p>we then show them the point clouds and other retrofit aspects which are quite bespoke” [BCO10 – DoB].</p> <p>“...So we produced guidelines in the use of BIM so that everyone who’s at least still coming from the same background or using the same process in the same way can achieve the results that we want to achieve at the end of the day” (BCO10 – DoB).</p>	All levels
Structure	Existing construction arrangement (fragmentation and sequential workflow) permitting a constraint on new BIM practices	Changeover to knowledge-based design and production sector: replacing dependency with interdependency	The existing process is fragmented; silos of architects, builders, and dead data. BIM process is joining everybody up and that’s the major difference (BCO9 – PhL).	All levels
	Lack of industry-wide consensus on approaches to BIM practices			
	Initial cost for BIM uptake (Training and systems upgrades)	Require top-level management support	“From logical and common sense point of view, adopting BIM is completely the right thing to do but financially it has put too much burden on the business” (BCO8 – StB)	Micro
	Operational costs for maintaining BIM licenses	Understand the need to make financial commitment and appreciate the positive return-on-investment for the business		
	Loss of production during the initial stages			
	Lack of common vision across disparate BIM vendors with regards to products development to targeted market	Establishment of common vision and a regulatory framework to streamline development and growth of the vendor market	“...a major shift in improvement would not occur until the industry as a whole adopt, rather than being led by some few lonely BIM users” (BCO2 - NaI).	Macro
	Competitive commercial vendor markets succeeding to greater extent than the collaborative range of BIM products development	Appropriate resources in place to support development and growth of industry-neutral open model exchange formats	“...Its just absolute minefield. If few of them [vendors] are going to control the market, because the rest cannot compete, again, there are issues with that - they’ll end up controlling everyone, and nobody will want that” (BCO1 – GaB).	Macro
Task	There is no consensus among peer	Develop a global understanding of BIM	“It is not plain sailing by any means. At the minute,	All levels

groups on a common understanding to BIM implementation and a prior arrangement of action plans to help attain its benefits/usefulness	usefulness for the various users with specific target actions to attain predefined goals	there are no guidelines that tell people the way to do BIM. A lot of people do not understand it. I hear people say “oh we are at level two already.” But the answer is you’re not. You may think you are but it’s actually quite a complicated process (BCO9 – PhL).	
Lack of common motives and drive for BIM uptake among BIM-enabled organisations	Creation of sector-wide BIM vision and structure Draw on expertise of external BIM consultants and vendor support system during implementation	“...people are just doing a little bit here and a bit here and think they are doing BIM. What people don’t realise is that BIM is a whole philosophy change and not until we get appropriate management structure to fix this, we shouldn’t expect any big changes (BCO10 – DoB).	All levels

When these collective measures are considered, individual construction organisations can then align their internal business practices, workflows, and technology platforms to suit accordingly. A director of a multinational construction management firm emphasised this by saying:

“In your research you’ll come across people who are just doing a little bit here and a little bit there and think they are doing BIM. What people don’t realise is that BIM is a whole philosophy change and not until we get appropriate management structure to fix this, we shouldn’t expect any big changes” (BCO10 – DoB).

Without the consideration of appropriate implementation strategies, the future direction will remain uncertain, and this could render any long term implementation ambitions or capability maturity plans unrealistic.

5.2.8 Summary of the Exploratory Findings and Implications for Developing the STS Analytical Framework

In the pursuit of the wider research aim of analysing the implementation of BIM within construction organisations, this exploratory study was undertaken with the objectives of understanding strategies for and oversight experiences of BIM-enabled construction organisations. It also provided the opportunity to learn the best practice from the users’ perspectives regarding evaluation, selection and use of the various BIM artefacts, as a precursor to the main case studies. The findings of the exploratory inquiry have further emphasised that BIM implementation challenges are sociotechnical in nature pointing for the implementation to acknowledge the evolving nature of technological solutions and the associated change processes in the work context. The study has also shown that successful BIM implementation largely depends on the control measures put in place not only in the immediate work context, but also the project-level influences where the actual work usually manifests. The sources from which the BIM applications are created and the macro contexts where the specifications and the technical supports are derived, also influence successful BIM implementation. The outcomes of BIM implementation, seems to be affected by the interplay of variety of influences from multilevel perspectives. The multilevel mechanism acknowledges and deepens the level of interdependence between inter-organisational project teams and foster norm of unanimity among project work group members as well as their different knowledge capability of BIM tools. The ability to detect and analyse the challenges to BIM implementation through the interactions of the STS components have been

investigated. As a precursor to the main findings, this shows significant promise if combined with the multilevel perspective to develop the appropriate instrument for analysing and evaluating the implementation strategies in the case study organisations.

The findings thus lend support and credence to the development of a framework on how to conceptualise the BIM implementation process to suit construction contexts. As sociotechnical concepts are useful in explaining and designing complex work systems' change processes, the conceptual framework, when developed, could similarly be useful in analysing the concomitant process changes associated with the introduction of BIM solutions in construction contexts. Also, as the findings have demonstrated, the framework will partly draw on multilevel and sociotechnical lenses to verify and evaluate BIM-enabled case organisations. The next step is thus to develop the framework through STS perspectives that will later be used, to evaluate the implications of BIM uptake and the associated change processes in the case study organisations.

5.3 Synthesising the Findings of the Exploratory Study with the STS Analytic Framework

The construction organisations featured in the exploratory study are faced with an array of technological capabilities, their interactivity with a variety of knowledge institutions and the gamut of actors and work processes needing restructuring. One of the interesting findings of the study is the variation in visions which accompany and inform strategies for BIM rollout. Within the intra organisational and inter project level engagements, there is a call for individual technological platforms and organisational arrangements to be coordinated. This is recognised in the analysis hence positioning the analysis at both organisational and project levels BIM strategies. A case was made in Chapter Three that Molina's STC and the related diamond of alignment model is not particularly structured in accordance to the configuration or the arrangement of construction organisations. The exploratory study has, however, provided insights into how to align the construction context with Molina's diamond of alignment. In order to establish an effective BIM-enabled environment, the needs of the target projects' client should act as a driving force, and this, combined with the organisations' commitment to using BIM where different visions and expectations of the BIM processes at both the project and organisation levels are reconciled.

The analysis of the 12 participating organisations shows that different contexts/levels of use produce different innovation assemblage, visions and practices. And in each case, the

challenges encountered stemmed from the STS elements comprising the actors, technology, structure and task (see Table 5.5). Due to these challenges, the individual visions of the organisations and ‘technological promises’ was a long way from the reality. The STS challenges distributed at micro-meso-macro levels illustrate a need to produce a coherent trajectory of STS requirement to meet the diverse demands of the BIM stakeholders during the appropriation process. In order to account for the multiplicity of visions and expectations, the concept of *alignment* is added to Molina’s STC. The concept of *alignment* has been used more generally in literature to describe the process of ‘matching’ or mutual adaptation involving new innovation technologies and user organisations. Leonard-Barton (1988, pp. 252) identifies three critical alignment strategies that augment and facilitate success of an implementation. These are between "the technology and (a) technical requirements, (b) the system through which the technology is delivered to users, or (c) user organisation performance criteria." The exploratory study shows that an alignment with well-established R&D institutions, industry standards, and technological specifications and trends is often an important factor in this dimension.

Another analytical lexicon used in combination with Molina’s STC is the concept of ‘*governance*’ (Williamson 1979). In the literature, Williamson (1979, pp. 239) uses the term “*governance*” to describe the framework within which “transactions are negotiated and executed...” in a similar sense, ‘*governance*’ is used in this study as an analytical lexicon to describe both the written and unwritten rules guiding or influencing behaviours, relations and interactions within and between constituency-building processes. In Molina’s STC framework and the diamond of alignment, Molina described the concepts of ‘constituents’ perceptions and pursuits; ‘the nature of target problems’; and ‘interacting technologies’, these forming the basis of the STC analytical framework. Molina argues for the interrelatedness of these STS components and for the need for their joint consideration. The STC framework is extended with the additional lexicons to help generate a new set of STS model but more specifically organised to fit BIM-enabled construction contexts.

The combination of these two analytical lexicons in concern with the STC diamond of alignment provides a multilevel context for consensus building in order to align and realign social and technical constituents until a successful work system is established. This perspective is well suited for construction context as the BIM implementation processes mutates through different layers of abstractions comprising the organisations, the projects and the facility management levels. The main premise of this approach is that the processes

involved in creating BIM technological capabilities always require the development of dynamic assemblage of technical constituents in terms of artefacts and social constituents in term of contextual influences. Molina defines STC as dynamic ensembles of technical constituents and social constituents which interact and shape each other in the course of the creation, production and diffusion of specific technologies. In the BIM appropriation process, successful outcome cannot be guaranteed as the outcome is largely dependent on the deeper alignment of the social and technical constituency. The next section is concerned with extending the STC and synthesising it with the concepts of *alignment* and *governance* to help analyse the BIM uptake in the selected case study organisations.

5.4 Development of an STS Framework for Analysing BIM Implementation Processes

Following the analysis that highlight emerging issues from the results of the exploratory studies, this section presents a framework for analysing BIM implementation in construction organisations. The framework is proposed in this study to address the key research objective 5 developed in section 1.6. Ultimately, this will address, in part, the aim of the research which was to carry out a sociotechnical systems analysis of BIM implementation in construction organisations.

5.4.1 The Essence of the Framework

In order to understand the issues associated with the processes of BIM implementation, it is necessary to have an empirically validated framework that brings together in a logical manner all the essential aspects of the process. A framework or model maps the territory being investigated (Miles & Huberman, 1994) and facilitates an understanding of the phenomenon of interest. Fellows & Liu (2009) consider a framework as simplified designs for visualising objects, processes, systems or concepts too complex to grasp. While a framework necessarily simplifies the process being modelled, it allows graphical representation of significant elements and helps communicate key ideas and concepts. Fitzgerald (1998) provides a useful justification for using a framework or model to guide the research process and analysis. Fitzgerald (1998) suggests that frameworks or models can be derived from theory or prior research, and then refined or modified in light of empirical findings. In addition, a good framework should be systematic, and easily understood, and should have clear links between elements which are presented, and also, implementable. These guides are followed in developing the framework for this study.

The framework is developed to help facilitate the implementation of BIM in construction organisations and it is informed by the issues related to the findings from the exploratory studies as presented in section 5.2. Overall, the findings of the exploratory studies revealed that construction organisations have numerous strategies for managing the implementation of BIM technological solutions. The innovation product and process development, adaption and appropriation are sociotechnical in nature and are influenced by phenomena at different levels or across levels. Investigating one level, while ignoring the effects of different levels on a phenomenon, may result in inadvertently generalising theory from one level to another (House et al., 1995). However, the importance of integrating sociotechnical systems requirements from different constituents into the implementation process of BIM is often overlooked. Accordingly the exploratory findings supported by STS perspectives have been used to develop a framework of managerial intervention that provides better insights into the BIM implementation processes.

5.4.2 Overview of the BIM Implementation Framework

The framework presents a holistic view of the issues that influence the implementation process of BIM within construction organisations. The requirements for the framework development are in two folds and are informed by the exploratory findings:

- 1) It should support **multilevel analysis**, bridging the micro, meso and macro structures, and thereby implicitly addressing inter-organisational constituents' needs; and
- 2) It should create an inter-organisational **sociotechnical constituents' alignment**

1. Multilevel Perspectives

The development, adaption and appropriation of BIM solutions require inputs from multiple agencies such as AEC organisations, BIM vendor groups, legislative bodies and knowledge institutions. Clearly, the process is influenced by phenomena at different levels. Multilevel researchers recognise the relationship among variables at different levels of analysis. The levels range from micro (individual or organisational) to macro (group or inter-organisational) contexts⁷. The multilevel BIM constituents depict firms actively seeking or developing new knowledge from both internal competences and the macro inter-organisational context. The

⁷ Context is referred here as a particular constituency and its accumulated heritage; e.g., type of organisation, expertise, actors' knowledge, experience and reputation, material artefacts, and other elements such as vision, goals, strategies and perceptions. For each of the constituents, the implementation of collaborative BIM infrastructure must make sense and assist their performance

macro support mainly comes from a wider range of contexts such as the R&D organisations, education systems, and legislative systems. The macro level demonstrates that BIM implementation is impacted by changes from a wider dimension such as the constant (often annually) releases of BIM product versions (i.e., BIM vendors), R&D and education support systems (e.g., Penn State CIC research on BIM implementation guides, & AEC UK BIM Initiative), legislative support frameworks (e.g., BS-1192 BIM protocol, ConsensusDOC, and IPD), and government BIM initiatives (e.g., 2016 BIM level-2 mandate). All these influence the BIM constituency building at a more micro or the project and work system levels in diverse ways. This demonstrates how multilevel variables can interact to predict the outcome of BIM implementation at the micro level of analysis. Accordingly, multilevel issues are of great relevance to this study. Figure 5.4 depicts the constituents that influence the successful implementation of BIM across levels. These constituents form the components of the framework.

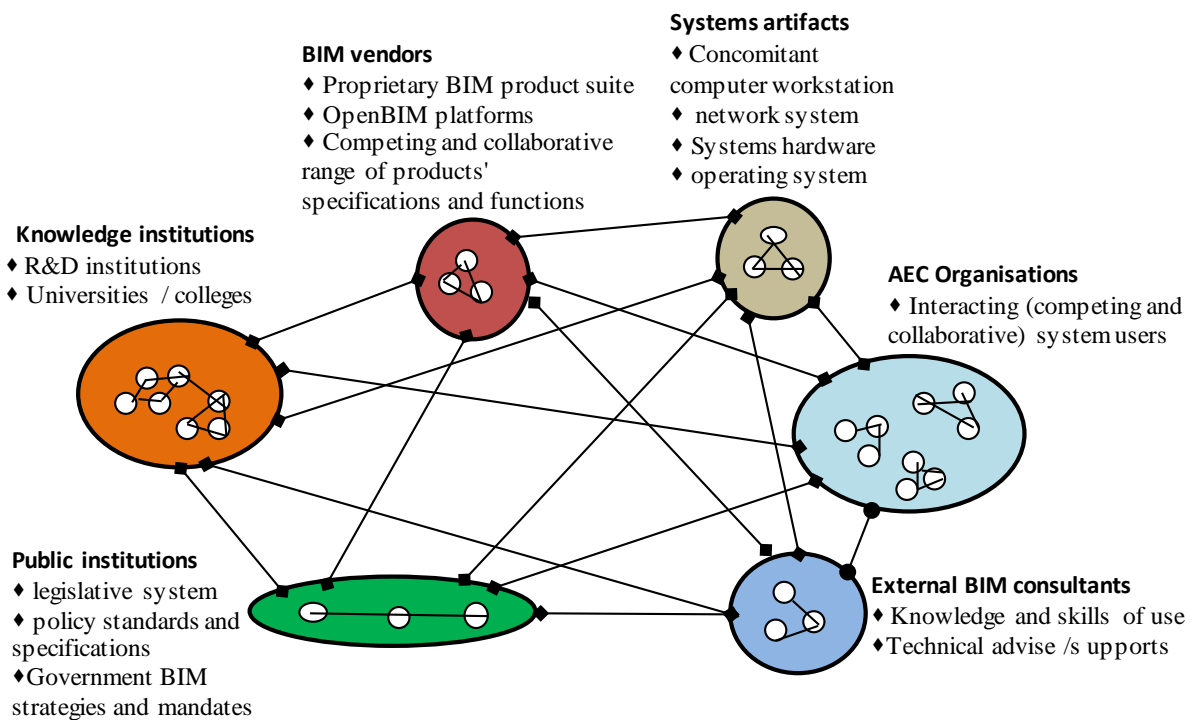


Figure 5.4 Multilevel organisational influences on BIM implementation processes

Figure 5.4 shows that the nature of BIM constituency building process is a multidimensional one as it is influenced by a number of constituents with different governance and rules of engagement. These multilevel constituents form the basis of the BIM implementation framework development.

Clearly, the primary reason for combining STS thinking and the multilevel abstraction to the development of BIM implementation process is to ensure that not only social and technical factors are considered but also, that differing organisational perspectives are acknowledged, appropriate compromises reached and subsequent actions coordinated.

The exploratory studies discussed above and the analyses of the STS theoretical framework discussed in Chapter Three have clearly provided the lens for the analysis of BIM implementation in construction. The exploratory investigation has established a requirement for a multilevel BIM appropriation, arguing that a multilevel perspective has practical and conceptual gains for establishing a consensus among different construction organisations with disparate visions and expectations. Within Molina's Sociotechnical Constituency (STC) that this study proposed (see S

ection 3.2.5) to adopt, this multilevel conceptualisation of BIM appropriation constitutes the "diamond of alignment" required for a successful constituency building in intra and inter-organisational contexts.

2. Sociotechnical Constituents' Alignment (STCA)

Though the framework development is influenced by different STS concepts, a particular attention is however, given to Molina's (1998) STC and the related diamond of alignment as discussed in Chapter Three. This is particularly apt since it combines organisation and technology, centrally features alignment at intra and inter-organisational levels. It also draws attention to the wide ranging constituents whose decisions and influences dictate the manner of technology development, adaption and appropriation. The sociotechnical constituency⁸ defines the ensembles of institutions that interact with each other during the uptake of a particular technological solution. Each sociotechnical constituency is a unique and dynamic fusion of technology constituents (e.g. technologies, expertise, tools, machines and systems) and social constituents (e.g. people, organisations and institutions coupled with their goals, values and governances) stressing the point that no single constituent alone can augment the development, adaption and appropriation of innovation solutions.

The constituencies are built by a conglomerate of active constituents via a process of alignment. Molina & Kinder (1999) argues that no recipe of a successful innovation uptake

⁸ The constituency represents particular groups of institutions being shaped by a common purpose, and the Constituents, (i.e., the actors/people) who are located within a particular constituency shape the constituency purposes.

exists. Rather, the ingredients contributing to alignment can be assembled and analysed. The STC literature uses the concept of alignment to address the activities of constituencies when they are promoting the development and appropriation of technological solution. It therefore describes the compromises, accommodations and social and technical interaction which underlie the constituency building process.

Central to the BIM implementation process is the development of a technological capability to sustain the competitive advantage of the implementing organisation. This is tantamount to the notion of competence development (technological and process solutions). There are four processes for achieving any desired alignment in the constituency building process: 1) governance; 2) targets constituents' perceptions and pursuits; 3) the nature of target problem; and 4) interacting technologies. This is shown in figure 5.5.

Governance: the first alignment process, governance; relates to the roles of the different institutions (multi-level) that shape the constituency building process during the implementation of BIM innovation product and process solutions. The governance processes are likely to differ from each context (e.g., construction organisation governance is likely to be different from the project level governance of BIM uptake) due to different roles, required expertise and different expectations.

Constituents' perceptions and pursuits: the second alignment, perceptions and pursuits; relates to the efforts in determining the relevant constituents in a BIM-enabled constituency. This segment suggest that, firms have to actively and purposely seek supportive knowledge constituents (e.g., external support, R&D institution support, BIM vendor community support, etc) as the need may require, to help close any knowledge gap which may have been caused by the introduction of the new technological solution.

Nature of target problems: the third alignment strategy, nature of target problems; targets the nature of the problem the constituents are mobilised to resolve. The competences embodied in the different institutions, affect whether or not solutions can be garnered to effectively address the 'target problem'.

Interacting technologies: the fourth alignment strategy, interacting technologies; relates to the alignment of different (competing and collaborative) technologies in the constituency. This is much the case of BIM uptake at the intra-organisational or project level where various professionals introduce their preferred BIM applications which may or may not be

compatible with other range of applications. This calls for negotiations and compromises to enable the selected tools to interface with each other.

A proposed framework for analysing BIM implementation, showing the sociotechnical constituents alignment is presented in Figure 5.5. The three layers of the framework represent the micro (organisation), meso (project) and macro (sector of firms) contexts that form the sociotechnical inter-organisational constituency. Successful BIM implementation is as a result of successful alignment between each segment of the model. The framework distinguishes technical (segment I) and social (segment II) constituents as the two key elements that constitute the content of the constituency building. The technical constituents highlight the nature and maturity of the technology, and the social constituents emphasise the different constituents marked by their respective goals and competences.

The social (segment I) represents the constituents that provide functional competencies to the constituency building process. They include R&D institutions, legislative bodies, software vendors and other constituents that feed through the constituency with knowledge and competencies among them are *inter alia* appropriation of BIM platforms, development of implementation strategy, and training and support.

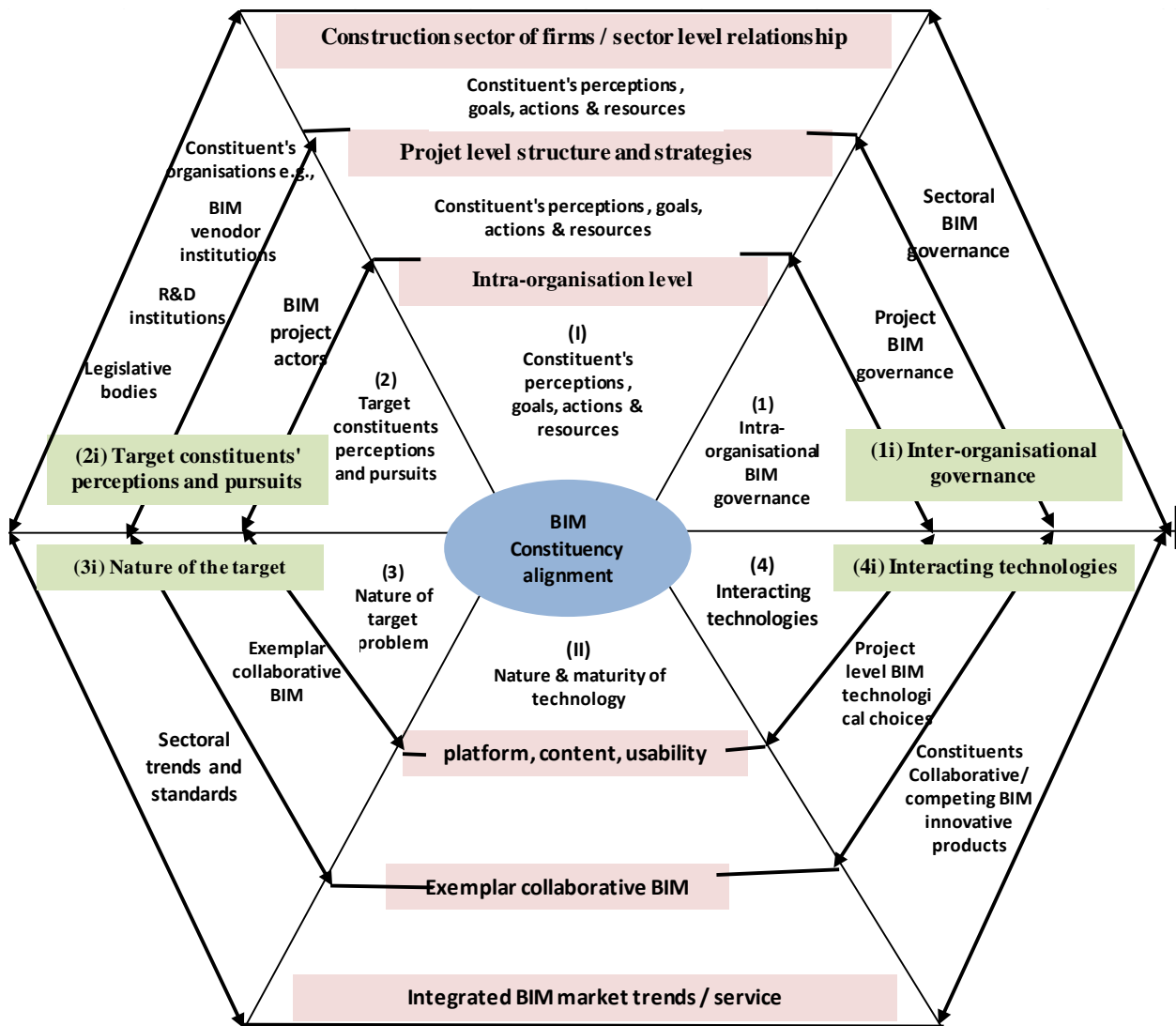


Figure 5.5 Framework for a sociotechnical systems analysis of BIM implementation

The technical (segment II) represents the nature and maturity of BIM tools and other concomitant supporting technological solutions. The two segments shape each other during the course of a BIM uptake by virtue of interactions, thus, necessitating the need to create a sociotechnical alignment amongst the constituents. Segments (1: 1i), (2: 2i), (3: 3i) and (4: 4i) represent the multilevel aspects which are critical to the success or failure of the constituency alignment process. The most effective way of maintaining alignment in the constituency is to comprehensively resolve in an interdependent manner the constituents' goals, perceptions, and actions towards common technological solutions. Accordingly, the implementation effort should not be considered in isolation, but via collaborative efforts amongst the constituents.

Molina's STC as proposed is dynamic, ensuring purposeful activities to yield a desirable and feasible outcome in a constituency. The overarching advantage of this STC approach over the

other STS frameworks for the analysis of BIM implementation include the ability to examine the rollout of BIM in construction organisations, as well as the causal linkages of organisation, project-level and the more macro-constituents' BIM governance. Building on the above theoretical exposition and the discussions in Chapters 2, 3 and 4, the next Chapter presents the empirical analysis of the BIM implementation processes in three selected case study organisations.

5.5 Summary

Advancing towards bridging the gaps in knowledge concerning the implementation of BIM in construction organisations, this chapter has presented the findings of a exploratory study regarding the strategies and oversight experiences of BIM uptake in BIM-enabled construction organisations. Subsequently, the chapter has presented a framework to support organisations with their BIM uptake, which was developed based on the exploratory study findings and the STS literature, and particularly draws on the STC theory. The framework has shown that BIM implementation inherently requires alignment amongst the inter-organisational constituents by compromising on a common purpose, goal, perception and actions of the product and process solutions. In addition to this, there are also a complementary and competing range of BIM tools which have to be integrated during the constituency building process. The framework could be useful for construction organisation in their pursuits towards developing BIM implementation strategy. However, there is a need to evaluate the framework to ascertain its reliability. The framework will be validated by engaging with construction practitioners of the three case study construction organisations. Validating the framework within the main data collection environment will enable the assessment of how suitable the framework is. It will also preserve the context within which the framework is to be applied. The next chapter uses a case study approach to conduct in-depth empirical investigation of BIM implementation processes within the selected BIM-enabled construction organisations.

CHAPTER SIX

6 CASE STUDIES: WITHIN-CASE ANALYSES AND FINDINGS

6.1 Introduction

In chapter four, the case was made for a number of carefully selected case studies to extend and complement the findings of the exploratory studies by relying on the analytical framework developed in chapter five. This chapter presents the results of three multiple case studies using the STS framework as an analytical lens. The three case studies, henceforth, “CS-Alpha”, “CS-Beta” and “CS-Gamma”, are described and analysed in turn. The section that follows presents an overview of the three cases. This is followed by the analysis of the case studies’ results.

6.2 Overview of the Selected Cases

This study adopts a multiple case study research design. Three in-depth case studies are conducted with BIM-enabled construction organisations in the United Kingdom. The reasons for selecting the 3-case study organisations are justified in section 4.7.2.2. The case study organisations are summarised in Table 6.1. The selection of the BIM-enabled case study organisations seeks to access the empirical realities of BIM implementation strategies of three different organisational conditions which are of relevance to the AEC environment. CS-Alpha is a large construction organisation and is among the top 20 UK contractors. CS-Beta is a small-size construction organisation providing comprehensive consultative and technical services in BIM for structural detailing and architectural metal works. And CS-Gamma is firmly rooted in the zero carbon building product market and is well-known for its investments in high performing energy-efficient building envelope solutions and insulation products. One thing they have in common is that they all utilise BIM in the delivery of their products and services.

Table 6.1 Summary of the case study organisations

	CS-Alpha	CS-Beta	CS-Gamma
Nature of Organisation	<ul style="list-style-type: none"> • Civil and Building Contractor • HQ in London, 11 more offices across the UK • Outputs: Design and delivery of physical products 	<ul style="list-style-type: none"> • Structural Engineering Specialist Contractor • Plant in East-Midlands and office in West-Midlands • Output: Design consultants, physical products and services 	<ul style="list-style-type: none"> • Building Products design and Delivery • HQ in West-Midlands, and over 20 offices across the UK • Outputs: Physical products
Scope of operation	<ul style="list-style-type: none"> • Multinational 	<ul style="list-style-type: none"> • National 	<ul style="list-style-type: none"> • Multinational
Size	Large	Small	Large
Years in business	>160	18	>40
Annual Turnover	> £1 billion	<£5 million	> £1 billion
Technology in use	<ul style="list-style-type: none"> • Mix and match best-of-the-breed product solutions 	<ul style="list-style-type: none"> • 10 TEKLA structural licences, 10 AUTOCAD stations, production equipments, e.g., automatic assembly lines and molding equipments 	<ul style="list-style-type: none"> • In-house BIM collaborative tools, and other off-shelve software depending on clients' needs
Data	<ul style="list-style-type: none"> • Semistructured interviews • Review of documents • Participation observation 	<ul style="list-style-type: none"> • Semistructured interviews • Review of documents • Participation observation 	<ul style="list-style-type: none"> • Semistructured interviews • Review of documents • Participation observation
Output	Context-specific analytical solutions of BIM implementation processes		

The three case organisations afforded an opportunity to juxtapose three very different operational approaches – one operating successfully in a large construction organisation, the second, operating in a small organisation and inherently aiming to maintain a competitive market position, whilst the third is a specialist construction organisation maintaining a strong dominance/presence in the energy-conscious UK market. All of them present interesting but different scenarios in that they all have undertaken measures to develop their BIM capabilities to fulfil the overall strategic mission of their respective organisations.

The selection of these organisations was done on the basis of three facets: firstly, all the three organisations are BIM-enabled and have either completed or have an ongoing BIM project to demonstrate their BIM capabilities; secondly, each of the organisation presents a unique contribution in terms of maintaining a particular niche in the AEC market; and thirdly, all the organisations are willing to participate in the research and also, willing to provide sufficient access to the organisation to make the data collection possible.

Although the focus of the case study is concerned with the evaluation of BIM implementation in construction organisations, it is acknowledged that construction organisations are themselves, embedded in a complex network of project organisations (Knox et al., 2007), thus BIM projects could offer eclectic and rich sites for the study of the case organisations. This study therefore focuses on the BIM implementation processes of the selected organisations as the primary level of interest, and the delivery of their relevant BIM projects as the embedded unit of analysis.

6.3 CS-Alpha: Analysis of Results

This section presents the results of the first case study. The analysis of the results is guided by the analytical framework developed in chapter five and consists of seven sections. Firstly, the background of the first case study is presented in section 6.3.1. This section also discusses the organisational objectives and the background of the research participants. Secondly, section 6.3.2 traces the evolution of BIM in the case organisation and discusses the main drivers for their BIM uptake. Thirdly, CS-Alpha's inter-organisational relationships with other sociotechnical constituents at both the project and the macro-levels are presented in section 6.3.3. This is followed by section 6.3.4 which highlights the challenges associated with the delivery of CS-Alpha's BIM project. And the analysis of CS-Alpha concludes by summarising the key findings of the first case study in section 6.3.5.

6.3.1 Background Information of CS-Alpha

CS-Alpha has been a family owned company since 1852. It started as a one-man bricklaying company, with the first contract being the excavation and brick lining for a 12foot deep new well at an agreed contract sum of £1. This was to be the beginning of a business which has experienced growth for over 160 years.

By the beginning of the 1970's the company was carrying out large building contracts and was widely recognised as one of the top 10 privately owned construction companies in the UK. The company structure was rationalised into three main divisions: construction; maintenance; and housing, each with their own regional business units. However, in 1992 when the economy was in recession, it became necessary to streamline the company structure to save on overheads. Thus, the subsidiary companies were amalgamated.

Currently, the group has consolidated its performance structures in the three sectors of construction, housing and maintenance. Each division provides national coverage with locally

based teams. The housing division is established as one of the UK's leading social housing contractors. Likewise, the maintenance division has a steady position as one of the leading building fabric maintenance service provider in the UK. The construction division carries out major contracting works on non-residential projects. Both the housing and the maintenance divisions have forged partnerships with social housing companies and public sector housing authorities respectively and expanded geographically across the country. The group is among the largest privately owned construction, housing and property companies in the UK, employing around 2,800 staff and has a turnover of circa £1 billion.

With regards to technological advancement, the group invested in a R&D innovation team to research into the widespread application of information technology, and issues of modularisation and standardisation of prefabricated components. In 1980 a department was created that dealt in microcomputers and resource training development. This department developed an internal networked information system called "viewdata." Visual display units (VDU) were then installed in all their offices, enabling staff to have access to a wide range of intercompany information. This seemed revolutionary at that time, but as information technology progressed, this system became redundant and was superseded by more flexible intranet connections which were available to staff's personal computers. Today, the company is in the process of transforming the various divisions into BIM-enabled entities, with the capability to deliver BIM project. A central corporate BIM team has been formed to drive this transformation.

6.3.1.1 Organisation Objectives

The goal of the organisation as stated in its BXP (BIM Execution Plan) document is: *"To be the premier contractor for complex design and construction projects, in which meeting challenges through a combination of BIM technology and people and process management sets us apart from our competition."* It is also stated that BIM tools and its integration with the management of information, people and processes will allow the company to have competitive edge in the market by providing clients with the additional and reusable information expected from today's construction technological products.

In an interview, a design manager further explained the management's guiding principles and vision towards its clients:

"We are committed to undertake our activities in a responsible manner and take a leadership role in the built environment. Our vision is to continue to add value to our

clients and our shareholders and build upon our history and reputation by continuing to contribute to society as a whole.” [Ch-K]

Accordingly, this vision has led the company to define four main BIM objectives and a deliverable timeframe to help realise the overall organisational goal. These specific BIM objectives as defined in the company’s BXP (BIM Execution Plan) document are highlighted in Table 6.2.

Table 6.2 CS-Alpha BIM objectives, anticipated outcomes and expected timeframe for achievement

BIM objectives	Actionable objectives	Anticipated outcome	Timeframe
To deliver project in a BIM technology environment where possible	Train all project team members in the appropriate use of BIM applications and push the BIM agenda with each new bid	When all projects are delivered in an information-rich 3D BIM environment	Current and ongoing: 25% target of all projects to use some form of BIM by end of 2012
Reduce construction cost due to clash-free design	Work with design partners and supply chain to use compatible BIM applications thereby creating coordinated model interface	Declare any cost benefits associated with the use of clash resolution tools on BIM projects	Upon completion of coordinated BIM model for a BIM project
To establish further capabilities in construction planning (4D), cost (5D) and facility management (6D) to boost project value/ delivery	Move from 2D based philosophy by adopting the use of BIM compliant applications within the project teams	Increase workflow and productivity by knowledge sharing and use of BIM compliant platforms	Current and ongoing: 25% target of all projects to use some form of BIM by end of 2012
Reduce repeat work for design and construction information by capturing and reusing coordinated design data by all the supply chain	Deliver project on or below the expected time and cost	Achieve economies of scale over the established traditional project delivery route	To be measured upon delivery of BIM project

The overall organisational goal and the specific BIM objectives and the means of measuring its progress show the company’s determination towards adding value to its clients as well as maintaining a reputable role in the BIM project delivery market.

6.3.1.2 Research Participants

This case study was undertaken in 2012 over a 9 month time scale with the CS-Alpha. During this time-scale, the researcher visited the offices and a project-site of CS-Alpha on different occasions to conduct interviews and also, to participate in project meetings as non-

participating observer. The research is predicated on the collection of rich qualitative data. One appropriate method for generating the required data for the study was semi-structured interviews, complemented by participants' observations and documents analysis as discussed previously in section 4.7.2.3. A total of 9 people were interviewed. All the interviews were recorded, transcribed and analysed. Table 6.3 lists the profiles of the personnel from CS-Alpha that participated in the study.

Table 6.3 Description of CS-Alpha personnel that participated in the study

No .	Participants (Pseudonym)	Title	Gender	Years of working experience	Number of interviews
1	Ph-L	Head of BIMM	Male	37years in design and construction management	2
2	Ch-K	Senior Design Manager	Male	22 years in design and project management	2
3	Ch-J	BIMM Manager	Male	7 years Architectural design and BIM application	1
4	Da-W	Senior Services Engineer	Male	10 years in estimating and services engineering	1
5	Sc-D	CAD / BIM Design	Male	4 years in BIM and architectural design	1
6	Ri-D	BIM Coordinator	Male	10 years in BIM and architectural technology	1
7	St-R	Senior Consultant	Male	25 years BIM / CAD Manager	1
8	Ph-M	MEP Engineer	Male	7 years M&E design coordination	1
9	Da-S	Architect / Project coordinator	Male	16 years in architectural design and project management	1

To examine the process of BIM implementation, the researcher spent time in CS-Alpha's East Midland office, where the head of BIMM⁹ and his team are based. The researcher also visited one of the organisation's first major BIM project sites on different occasions between November 2012 and August 2013, observing the project teams and participating in BIM meetings. Cross sections of the major types of BIM meetings, such as BIM review, coordination, clash resolution, and snagging meetings were observed and debriefing notes made to capture observations of interactions and seemingly critical issues that were emerging. The series of non-participating observation were spread out over 9 months spanning from November 2012 to August 2013. In the context of this case it proved particularly useful for gathering rich qualitative insight into the organisation and their BIM strategies. It also provided additional scope and feedback from those already interviewed and crucially, the

⁹ CS-Alpha justified the reason for adding additional 'M' to BIM to represent the 'management' of the BIM protocols.

opportunity to discuss the BIM project with individuals who were not available for a ‘formal’ interview in the case organisation.

Amidst an industry-wide campaign towards BIM, CS-Alpha has been prompted to adjust the organisational workflow to suit the demands of its clients and the trending market conditions. In this sense, it is possible to see how BIM solutions are involved in shaping the operations of CS-Alpha and simultaneously are reshaping the activities of the organisations involved in delivering its featured BIM project. The following sections examined the roles organisational constituents involved in the implementation of BIM at CS-Alpha and the organisational effects following their implementation.

6.3.2 Tracing the Evolution of BIM at CS-Alpha

The origin of BIM at CS-Alpha is embedded in a series of events that paved the way for the decision by the company to invest in the technology and the related organisational change processes. The main event, however, was the rampant enquiries by major clients requiring their projects to be delivered with BIM protocols and technologies. This sentiment towards clients’ demands is echoed by the Head of BIMM at CS-Alpha:

“Client demand is on the increase – clients are in the best position to lead the delivery of new innovations for a project and in this case the introduction of BIM. They require us to define a process they believe would provide benefits for their business.” [Ph-L]

The implementation goes beyond the construction organisations that use BIM to design and manage the construction process. A key benefit for the eventual owners as suggested by the Head of BIM is using BIM information for the ongoing management of the asset. As such, the case study organisation is being compelled by its clients to demonstrate its BIM knowledge by showing:

- Its overall planning for project implementation and success using a BIM process;
- How it can work with supply chain partners to deliver BIM projects;
- How it can manage BIM workflow and processes; and
- How and what information it would pass on to clients to assist in the subsequent management of the facility

Meeting those BIM requirements therefore involved the case organisation to think and operate in a different manner to the firmly-established “normal”; operating a BIM methodology and implementing a BIM environment throughout its supply chain. Nevertheless, there were concerns about how the organisation could recoup the initial investment in the implementation as it is a departure from the established conventional business model of the organisation. In addition to the relationship between meeting clients’ BIM requirement and attaining positive return on investment is the problem of developing wide-scale BIM capability across the entire offices of CS-Alpha. It was recognised earlier on that, with the decision to embrace BIM, technical support, new challenges and organisational responses are likely to emerge. The institutionalised structure of the established status quo is likely to be destabilised by BIM workflow, thereby calling for assistance from technical experts and management supports.

Hence, a corporate central BIM team was created and tasked to oversee the development of profitable and feasible methods for creating the organisation’s BIM capability and phasing-in such capacity across all projects. Within the organisation, BIM was seen as a technological innovative solution to improving construction project delivery while at the same time allowing the organisation to eliminate unnecessary waste and to offer cost savings to clients. Again, the demand by major clients, and the evolving technological solutions were cited as significant drivers for implementing BIM in the organisation.

6.3.3 Mapping the Inter-Organisational Sociotechnical Constituents’ Relationships at CS-Alpha

This section begins to trace the relationships between the inter-organisational constituents that are connected with the BIM technological platforms featured in CS-Alpha. A variety of institutions implicitly or explicitly influence the BIM project delivery processes. As revealed by the exploratory findings BIM utilisation process is influenced by a sociotechnical constituency alignment (STCA) because the nature of the alignment is a multidimensional one, depicting the influences of multilevel perspectives. As discussed in section 5.3.2 the STCA draws attention to the wide ranging constituents, whose causal alignment influences the manner of technology uptake, stressing the point that no single constituent alone can augment the development, adaption and appropriation of innovation solutions.

The mobilisation of different inter-organisational constituents for the fulfilment of the project objectives call for the case study organisation to have some strategies for aligning the various

BIM applications and the multiple interest groups. The analysis of BIM implementation processes in CS-Alpha is categorised under two main areas: 1) intra-organisation level BIM alignment strategy; and 2) multi-level BIM alignment strategy. Each strategy is discussed and is illustrated by extracts of responses from the interviews and the causality between the two is discussed in the sections that follow.

6.3.3.1 BIM Appropriation in CS-Alpha: Intra-Organisation Level BIM Alignment Strategy

The analysis of the organisation-level BIM alignment strategy in CS-Alpha has been categorised and discussed below under 5 main areas, including: *Formation of a central corporate BIM team; engagement of external BIM consultants for technical advice and support; development of a knowledgeable BIM workforce via training and support; selection of BIM technological platforms and upgrades of supporting computer workstations; and development of organisation-wide generic BIM implementation protocol and guide.*

1. Formation of a central corporate BIM team: Recognising that BIM implementation is a catalyst for corporate business process change, a BIM implementation strategy team was formed in CS-Alpha to provide a direction and a strategy to govern the implementation. The team consists of a whole mix of membership and headed by a BIM manager who was in the organisation for 9 years as the head of design management, until 2012 when he took on his new role. Prior to his new role, he was responsible for managing the preconstruction design processes. The head of BIM(M) explained his role and the reason for adding an extra ‘M’ to BIM to be known as BIMM in the organisation:

“With BIM(M) becoming the single most dramatic change to the UK building industry, I was transferred within the [CS-Alpha] group to lead a small team of experts. Together we engage with other private organisations to promote the most efficient processes and technologies to deliver BIM(M) within the company. The extra M refers to our management of the BIM process. We also give support to the eight local offices to deliver this modern method of working.” [Ph-L]

Some professionals have been trained within the corporate team and have new BIM titles, including a BIMM project manager, BIMM technical lead, and BIMM coordinator. These individuals provide technical support across the project teams located in various parts of the

UK. The corporate BIM team consist of other members across different hierarchies of the organisation. They are situated within one office space and *inter alia*, they are tasked to:

- Develop an agreed company-wide BIM(M) strategy;
- Develop the BIM implementation plan and protocol that can be followed to successfully deliver BIM projects throughout the business on a national scale;
- Provide organisation-wide support on how to utilise new and emerging BIM product suites to provide efficiencies in the process of BIM project delivery; and
- Ensuing gradual and continuous BIM(M) implementation until it becomes the standard of project delivery across the wider business

2. Engagement of an external BIM consultant for technical advice and support: BIMtech (a pseudonym) worked alongside the case organisation’s central corporate BIM team to develop an organisation-specific BIM procedure. BIMtech is a consultancy firm based in the UK that has expertise in IT systems supply and implementation, training and support in BIM and other related construction IT solutions in design, construction and assets management. It also has technical accreditation from some of the IT solution providers such as Microsoft, HP, ARCHIBUS and Autodesk. CS-Alpha solicited the services of BIMtech to support the BIM team with training to enhance their BIM capabilities and overall knowledge alongside assisting them in developing an organisational-wide BIM strategy. The central corporate BIM team was established to develop and roll out a standard BIM methodology across the company. Overall, BIMtech helped fine-tune the CS-Alpha’s central BIM team’s understanding of the significant changes BIM required from a traditional 2D environment. BIMtech were also tasked to provide technical assistance in the selection and installation of new software and hardware to fulfil the organisation’s BIM requirements. BIMtech were well-positioned to configure the organisation hardware and software having first-hand knowledge of the organisation’s requirements from the outset.

3. Development of knowledgeable BIM workforce via training and support: It was noted that, before fully committing to the BIM process, there should be a change in “people’s attitudes” and introduction of new knowledge concerning the use of the selected BIM technological application. Training is considered as being one of the underlying drivers for successful BIM implementation, thus, CS-Alpha’s strategy is to ensure that all staff making decisions relating to BIM, or involved in the operational side of the BIM processes, are appropriately trained. According to the head of BIM(M):

“People are at the forefront of everything we do, with all those involved in and affected by the new processes, thus we are working to engage with people where possible in the process, delivering training and support to reflect the values that underpin what we do.” [Ph-L]

Senior management commitment is clearly needed to provide financial support for the establishment of organisation BIM vision and implementation strategy. This was clearly seen at CS-Alpha, by virtue of having a team of experts to develop the organisation’s BIM strategy. It was also obvious from the interviews with the corporate BIM team that, high level leadership from a central location alone is not necessarily translated into actions on the ground. Both the centralised BIM experts and the local project teams needed to work together to develop a clearly prioritised work plan to implement the vision throughout the organisation. This called for a knowledgeable workforce from the operational side to have specific skills such as 3D knowledge of BIM, component-based design and analysis, or experience with the use of BIM software. These could enable them to drive the implementation process from the bottom-up. Thus, an important strategy that has been adopted for counter implementation resistance is appointing BIM development champions across each of the office locations. They have been empowered to drive the implementation process and also, to address concerns or issues raised by the local workforce pertaining to the BIM agenda. Explaining the duties and the professional backgrounds of the targeted local BIM champions, a BIM manager emphasised that:

“...BIM champions and users are being identified within our local company offices to drive its implementation and raise knowledge at a local level...he will be someone who evolves with the changing technology. He could be an estimator, a planner, or an engineer-that doesn't really matter...but someone who understands the process, knows where to get information, and knows how to find solutions to complex problems. They are the ones, where it is almost like a hobby wanting to learn more, wanting to use the latest technology. What you are trying to achieve is to take their passion and enthusiasm, add the technology to it, and get some organisation standard, to form - this is the way that we actually want to work.” [Ch-J]

In the light of the organisation-wide strategy for BIM implementation, CS-Alpha has developed computer simulation on BIM delivery processes, particularly targeted at the project delivery teams. Through this computer based in-house training programme, which is

assessable in the company's intranet, the organisation's vision for BIM implementation has been communicated to every staff member of the organisation.

The training toolkit is referred to in the organisation as "*BIMM jigsaw*", and it is aimed at providing answers to the questions people may have about BIM. The BIMM jigsaw is broken into eight main themes, and it calls for a complete understanding of each of the themes in order to have an overall grasp of the organisation's comprehensive BIM strategy. The themes of the organisation's BIM training tool comprise:

- the understanding of client needs;
- agreement of BIM protocol;
- 4D programme simulation;
- certainty of cost from the model;
- energy analysis and sustainability issues;
- integration of project supply chain;
- BIMM delivery on site; and,
- As-installed information and ongoing facility management.

The organisation's BIM jigsaw has been presented in Figure 6.1. It was noted also, that an awareness training programme has been established for senior management staff including those that engage in BIM in some way. Also, knowledge sharing workshops are hosted for staff across the company's branches during which the corporate BIM team presents the organisation's BIM strategy along with demonstration of how some case study BIM projects are run. These workshops give the staff a great insight into, and instigate a lively discussion regarding, the use and future of BIM in the organisation.

This is supplemented by the computer-based training delivered to all project team members, to explain how BIM decision processes are made on projects. The core project team members in CS-Alpha consist of a technical manager, a design coordinator, a commercial manager or a quantity surveyor, and a project manager. But now, for a BIM project, an additional role of either a BIM coordinator or a BIM manager has been added. All these different roles are expected to have BIM knowledge in some form.

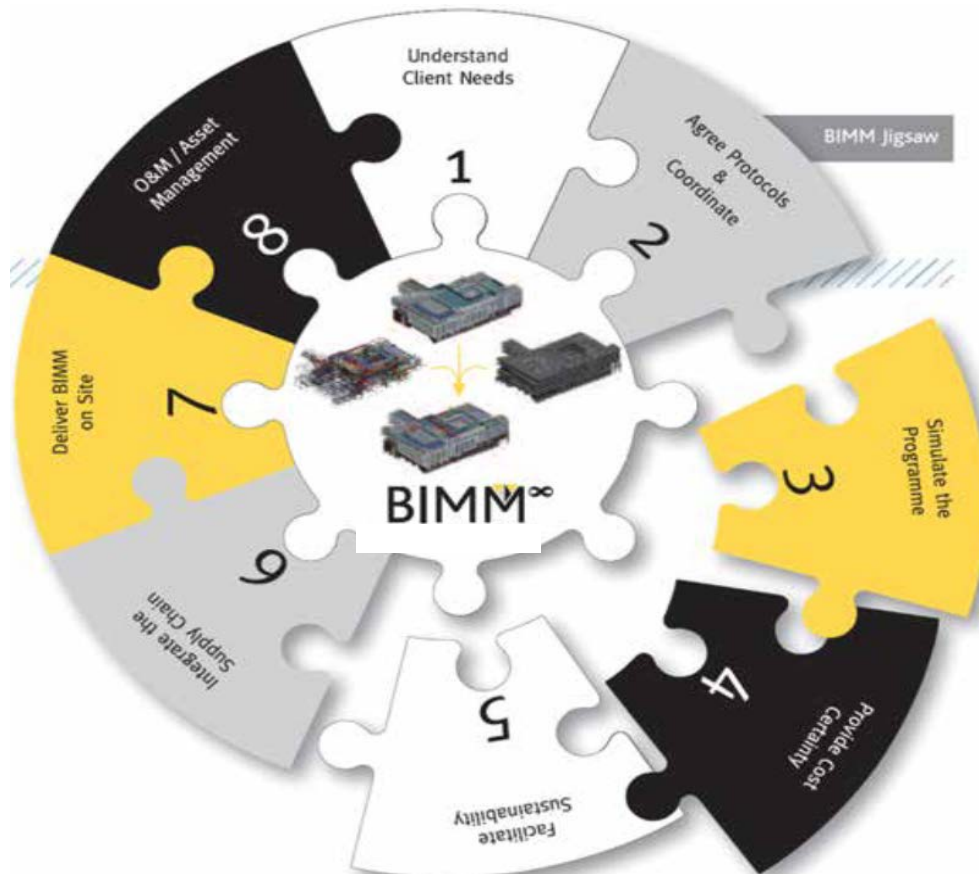


Figure 6.1 CS-Alpha BIM training kit: ‘BIM jigsaw’

The central corporate BIM team is widely considered in CS-Alpha as the in-house BIM resource team that provides technical support and systemic training for staff development. The support is available for all users that need it. Also, the active participation of “local BIM champions” in the BIM support structure provides a strong boost to those at the operational level that struggle to cope with the change uncertainties, complexity of or concerns related to software use, hardware issues, and difficulties related to process change.

4. **Choice of BIM technological platforms and upgrades of supporting computer workstations:** There are various BIM technologies which are favoured platforms by the different construction organisations for delivering BIM projects. The strategy of CS-Alpha with regards to the choice of BIM technology is to adopt the “*open BIM*” approach in order to work with the “*best-of-the-breed*” BIM product solutions to prevent “*risking exclusion from certain BIM projects.*” The open BIM approach is the building SMART initiative where collaborative project teams ‘mix-and-match’ software tools to provide functionality beyond what can be offered by any single BIM platform. This contrasts with the sole use of proprietary tools from one particular vendor, which hinders true data exchange within the

project environment. In the case of mixing and matching different software applications, interoperability, or consistency across the selected tools is very important. Interoperability is achieved via easy and reliable exchange of project data between the different BIM platforms. Table 6.4 captures some of the recommended BIM authoring tools in the company’s BIM execution plan (BXP) document. The reliance on different BIM technological platforms by CS-Alpha for project delivery conforms to a higher level of capability BIM maturity models, however, one of the criteria at this level is that, interoperable data interchange across disciplines should be possible. Therefore, the preferred BIM tools should comply with industry-neutral open standards such as the IFC formats.

All the BIM applications run on computer workstations which run on windows and operating systems compatible with the selected applications. The computers are connected to the CS-Alpha’s LANs via a standard network interface, and per each BIM project, the PCs get connected to WAN for easy access to model repositories, and at the project sites, the connection is per the project setup, but mostly, via Wi-Fi.

Table 6.4 Recommended BIM authoring tools in CS-Alpha BXP document

Model Name	Model content	Example of authoring tools
Architectural model	Full architectural design model	Revit architecture
Structural model	Full structural design model	Revit structure, Tekla structure
MEP model	Full mechanical, electrical and plant design model	Revit MEP, CAD duct,
Coordination model	Full 3D coordination	Navisworks, Tekla BIM sight
Energy model	Energy / low carbon analysis	IES VE
Construction model	Post 3D coordination for use with 4D scheduling Post 3D coordination for use with 5D cost analysis	Synchro QTO
As built model	Full 3D coordination for FM	Navisworks

The conventional CAD drawings are performed on standard desk PCs, normally hosted by some kind of central network server. Some PCs are able to run more sophisticated simulation compared to computers in existence prior to BIM – this is where CS-Alpha sees performance gains from moving away from extant systems towards the use of recommended “top-of-the-range” computer workstations to run BIM applications. The requirement of efficient and viable supporting computer workstations for BIM applications are emphasised by the BIM coordinator:

“... prior to this, my old laptop had 32bits OS and 3gig RAM which is ok for a laptop, but with Revit civil 3D, which is a big package, you’ve got to have 64bits OS and 8gig RAM, so the machine you see here is viable with efficiency.” [Ri-D]

The main reasons for high spec computer platforms for BIM applications may be because, BIM applications contain both 3D geometry objects (required to display virtual reality, rendering and visualisation at the design phase) and additional properties (for analysis of design objects e.g., costs, programming and energy analyses) and their parametric relations (for intelligent linkages and automatic updates) (e.g., Sackey et al., 2013). The number of data types represented in a typical BIM platform is very high, but the same could not be said about the conventional CAD systems, which were, and are still being used mainly for producing two and three dimensional design data.

5. Development of organisation-wide generic BIM implementation protocol and guide:

CS-Alpha’s central corporate BIM team developed a BIM implementation guide, referred to as BXP (BIM Execution Plan) document. It is intended to be used as a support tool by all the local construction project delivery teams across the organisation.

“Our new BIM protocols and execution plans define the required way of working with our project partners in order to deliver projects using BIM and virtual construction (VC) techniques.” [Sc-D]

It has also been indicated in the company’s BXP that, the company’s BIM procedures guide the way for all design consultants and contractors from initial RIBA stages through to construction and building life cycle management to reinforce a collaborative method of working.

The company’s BIM implementation protocol thus provide some guideline on how the workforce can work with other project stakeholders do deliver BIM projects at different phases of the project using collaborative BIM applications. Commenting on this, a BIM coordinator emphasised that:

“[CS-Alpha’s] BIM protocols and execution plans have been thoroughly thought out and documented to give projects the best opportunity to promote collaborative workflows, help deliver coordinated buildings and ultimately deliver well-structured data to clients – the full integration of the supply chain is key to the success of a BIM strategy.” [Ri-D]

A copy of the company's BIM protocol shows a 23-page generic guide showing company-specific BIM procedures and project-level implementation strategy. There are project-specific questions in the project-level BIM strategy, which are required to be answered by BIM-project teams prior to the start of any new BIM-projects. Such questions include, agreed contract type, selected compatible software packages, agreed level of details (LOD), model coordination and analysis plan, and information exchange schedule. The BIM strategy document has been developed as a support tool to assist in delivering a tailored approach to BIM, thereby meeting different project requirements.

6.3.3.2 CS-Alpha: Multi-level BIM Alignment Strategy

The multi-level BIM alignment strategy for CS-Alpha is discussed under six main headings, comprising: *Mobilising BIM solutions on a project; selection of appropriate BIM project constituent members; specifying BIM deliverables and line of management across the inter-organisational units; BIM project contractual strategy; defining BIM applications for use across different constituents' members; and, setting out collaborative BIM work structures.*

1. Mobilising BIM solutions on a project: In 2010, CS-Alpha tendered for a project where the client required the project to be delivered using BIM processes for the benefits they felt it would generate. As part of the tender process, the competing tenderers, including CS-Alpha, were expected to demonstrate their capabilities of delivering a BIM project. Due to the extent of BIM requirement, and the potential value to the project, the central corporate BIM team, working in collaboration with the estimating department, created a proposed BIM model for the building, including a detailed method statement and a programme for developing the model with other supply chain partners. An initial BXP (BIM execution plan) for the project was developed, showing, the key benefits, applications, and ownership of the model information both for the project delivery and subsequent management of the facilities. These include clash resolution at the design phase, energy analysis, schedule and cost information and sequencing and flythrough simulation. Over the whole tender process, CS-Alpha's knowledge and capabilities of the BIM process and the creation of project-specific BIM procedure proved valuable. CS-Alpha won the tender and was expected to take a BIM coordination role in the project and rollout the BIM methodology across the entire project supply chain.

The CS-Alpha's featured BIM project, henceforth, "project Alpha" is a £48million value educational facility for a UK university designed to provide converged facilities for students'

learning zones, PC labs, offices for students union and students services, extension of existing library, upgrade of existing server room, and a media hub of TV, radio, and photographic studios. According to a report from the cost consultant of the project:

“The client has taken the lead, supported by a team who really wanted it to work, and made a firm commitment to adopt BIM from the very start. They’ve taken a long term view with future flexibility of the campus and facilities management very much at the forefront of their thinking.”

With the client’s commitment to BIM implementation on the project in mind, CS-Alpha was required to fulfil the planned design project requirements by leading the tender, design development and the construction processes. The contract required BIM processes within the consultants and the contractor groups for the benefits expected during construction and in the subsequent management of the building.

2. Selection of appropriate BIM project constituent members: As part of the BIM strategy, the selected supply chain, including the architects, the design team and the specialist contractors were expected to be involved in the implementation of relevant processes and collaboration systems and solutions. Hence, care was taken in the selection of qualified supply chain team to participate in the BIM process. This was emphasised by a project coordinator:

“We have engaged with many of our consultants to determine their BIM capability, a full scale appraisal of all consultants has been undertaken with the details being stored on our supply chain database.” [Da-S]

By selecting experienced project consultants, CS-Alpha was able to build a capable design team to develop the coordinated BIM model. The same measure of care was extended in the selection of the specialist contractors; those with skills and have the ability to integrate in a BIM team were particularly targeted. This was confirmed by the head of BIMM:

“Metrics to capture consultant’s performance have been determined so that appointments can be made based on the ability to integrate as well as ability to offer a competitive service. A similar appraisal is underway for our subcontractor supply chain to ascertain their level of knowledge, skills gaps and to determine the amount of support required to integrate them into our BIM approach and on the supply chain database.” [Ph-L]

Due to this selection criterion, it was realised that all the project team members, had their own in-house BIM methodology in place, and so did the project client, who has license for BIW document management systems for managing general project information and information flow. The multiple perspectives of these BIM methodologies meant that the case organisation had the responsibility to unify all parties with a full project-specific BIM procedure to cement a single approach for multiple data interface, reduce risks and increase cost savings throughout the chain.

3. Specifying BIM deliverables and line of management across the inter-organisational units: The contract specified a BIM process for the project including the integration of the supply chain models through the use of open interface BIM applications to achieve interoperability, or easy and reliable exchange of project data and coordination throughout the chain. This required that, the lines of communication and chain of command is structured to support the appropriate functional units throughout the inter-organisational constituents.

The project was procured under design and build contract. Thus, being the lead contractor under this procurement arrangement, CS-Alpha had the responsibility to oversee the design and construction process, hence, having a direct chain of command with the client. Figure 6.2 shows the functional structure of the BIM project organogram. Each of the units underneath the main contractor in Figure 6.2 represents a BIM-related discipline-specific function. These functional roles had been assigned to consultancy firms and specialist contractors who went through the tender selection process and proved themselves capable of performing those roles. The structure of the organogram was then used as the basis to review the models and manage responsibilities, changes, revisions and coordination. One obvious drift from the convention setup is the early involvement of specialist contractors. The project BIM strategy document, which was drafted by the case organisation, with inputs from the other supply chain, states that:

“Sub-contractor information needed to be incorporated in the design model to avoid clashing, hence no need for rework and unnecessary costs during the build process.”

The responsibility then lies with all the functional units to engage with their supply chain during the design development and the coordination processes in order to obtain accurate model information prior to offsite prefabrication and on-site construction. The lines of command across different functional units are hierarchically represented from top to bottom.

Nevertheless, all the functional units are contractually obliged to work in teams to implement the overall project BIM deliverables.

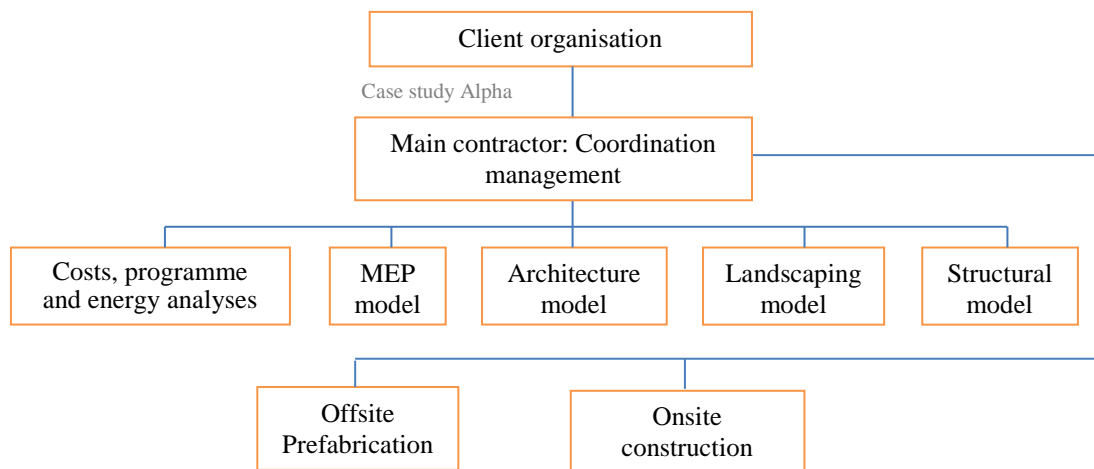


Figure 6.2 Functional structure of the BIM project organogram

4. BIM project contractual strategy: In July 2011, the client entered into a £48 million contract sum agreement with CS-Alpha, as the approved contractor to lead the construction of the facility. It was a 2-years contract and the actual start on site was September 2011, with a scheduled completion date of August 2013. The works comprised a five-floor building, with students learning zones, PC labs, offices for students’ union and students’ services, extension of existing library, upgrade of existing server room, and a media hub of TV, radio, and photographic studios. The coordinated external view of the model is shown in Figure 6.3.

“We have been involved in various types of projects that have used BIM processes; but this project is the largest project to date undertaken using BIM technology, all three main consultants [architect, MEP and structural engineer] use BIM to provide their drawn information while we use Autodesk Navisworks to coordinate and collaborate the project models.” [St-R]

Given the use of the fully coordinated BIM and the required level of details, coupled with the project team’s lack of experience in building a BIM project of such nature, the project quantity surveyor was careful in advising the client of the appropriate contractual arrangements. Ultimately, a design and build contract structure was established, thereby giving the client certainty of cost. Further, the cost consultant to the client stated that, in addition to the more common one-year defect liability period, a further three years be included in the building contract, during which the contractor will be responsible for selective

planned and unplanned maintenance under the client's direction. During this time the client will ensure that the BIM model is maintained to reflect any changes introduced as part of the operational maintenance of the facility.

Commenting on the contract structure, the project architect opined that:

“Contractually design and build is a very traditional contract, but we had a very amended one, ‘off-the-peg’, to incorporate the model creation. In the contract, there are 6 pages of BIM information such as who will be modelling what, what level of detail we will be modelling to, who uses the model, what they use it for. So you know when you open up a model, what you can and cannot do with it.” [Da-S]

Despite the clarifications of and the amendments to the main contract to cater for BIM work processes, the contract drafters were also quick in posing limitations to what the model could and could not be used for. In order not to create contractual fuss from the use of the coordinated model when created and shared, the project team did not consider it as a contract document, however, demonstrating the BIM capabilities of the supply chain was a major requirement for the contract award:

“For how this project is setup, our prime reason for creating the model is to create this contract drawing, and the as-built is the other contract – the model is almost a by-product for creating these contract drawings. So the model didn't have a contract status at this point, it only has for the drawings and the final as built information. So when we issued a model, we were issuing it to say this is RIBA stage E contractor's proposal only. Please don't look at it as a contract document.” [Da-S]

Those who solely rely on the model for other purposes other than the contract drawings and as-built information, without proper checks via the well-established conventional means could therefore not hold anyone else contractually liable for any errors or wrong information generated from the model.



Figure 6.3 External model view of CS-Alpha's featured BIM project

5. Defining BIM applications for use across different constituents' members: To ensure that there were no data exchange and coordination problems during the BIM project delivery process, a critical decision was made to mainly use one vendor product, in that sense the teams are at least, assured that the federated models from one vendor platform will be integrated on the basis of a proprietary interface. This is because, the software companies provide direct links, or proprietary exchanges to their product suites. This interface allows their products family to be supported among each other without relying on the public standard exchange formats such as the IFC.

After one of the coordination meetings, the BIM consultant who helped draft the BIM strategy was asked to clarify the decision to use product suites from one particular vendor. He explained that, their experience on other BIM projects has shown that, problems arise with the use of industry-neutral IFC formats to interchange model information across different BIM platforms:

“...with it [IFC] there is never a 100% translation. We are trialling it on some of our other projects. There are issues of, particularly where model “A” holds specific information, how that comes into model “B” through the IFC if it is not the same parameter set of information.” [Sc-D]

The government strategy for BIM level 3 is to use open BIM platforms which are compatible with the IFC format. This project however, required the entire supply chain to use native Autodesk product suites. This aligns more to the level 2 government's BIM maturity plan, requiring the team to create federated models which are integrated on the basis of proprietary interface.

In deciding on a common BIM platform suitable for the entire supply chain out of the competing range of products in the marketplace, it was an easy decision for the organisation to settle on Autodesk product suites due to a number of reasons: compared to the other vendors, Autodesk has a range of product suites such as landscape, civil, MEP, architecture, coordination, energy, cost and programme analysis tools; majority of the professionals maintain AutoCAD license for their professional work, and it is possible to convert AutoCAD license to Autodesk license, which also comes with the AutoCAD application, making it easier for CAD users to convert to the Autodesk product range; and, Autodesk applications such as Navisworks are able to link and import very well, native CAD files such

as DWF and DWG without the use of industry-neutral IFC formats. The design manager confirmed this by saying:

“It is just that it is [Autodesk] seen as the best product available in the UK at this time. You can also get deals. You have got commercial considerations too. So we managed to negotiate good deals for using their products and they’ve got very good back-up for our service and support. So just on those grounds I think really it was a no brainer.”[Ch-K]

The above reasons were used to justify why the team decided to use the Autodesk range of products to develop and manage the models for the project. Some of the selected Autodesk product ranges that were used on the projects include:

- Buzzsaw: it is a cloud-based electronic collaborative data management system that provides secure access to exchange project information in a dynamic and interactive way by the inter-organisational project constituents;
- BIM 360 field: It is a construction field management system that allows the latest project information to be captured, saved and shared on an interactive cloud-based platform. On this project, it was managed by the client to host the facility management models and used by the project team to update the client with progress information and also to host as-built contractual models;
- Revit architecture: it was used by the lead architect to produce the architectural models;
- Revit MEP: It was used by the MEP consultants to produce design MEP models. The MEP contractor also used it retrospectively to develop a coordinated model to interface with Navisworks after creating production drawings with Cad Duct;
- Revit structure: this was used by the structural engineer to produce the structural design models; and
- Navisworks manager: this was used by the project team at the coordination meetings to integrate the federated models. It also assisted in clash detection and resolution.

Not being an expert to determine if indeed Autodesk has the ‘best-of-breed’ BIM product suite, conscious and deliberate decisions were made by the lead contractor not to strictly force down Autodesk on all the supply chain. And indeed, others prefer different applications. Those that were not using Autodesk product were mandated to at least, use products that were convertible into DWF or DWG native CAD files. This is because, Autodesk Navisworks is

able to import DWF and DWG files, nevertheless, when these CAD files are linked to the Navisworks, it is only the 3D geometry, excluding the associated data that can be accessed.

Some of the non-Autodesk platforms that were used on project-Alpha include:

- Vectorworks: the landscape contractor used Vectorworks landscaping tools to design the external landscape. There was not very much landscapes works as the large portion of the external space was paved, so the contractor was given a dispensation to work with Vectorworks. This application interfaces with Autodesk DWG format;
- CAD duct: the MEP contractor used this application to produce the detailed MEP production models. It is supported by DWG;
- Bentley ProSteel: the structural steel contractor used ProSteel for structural detailing and fabrication. The ProSteel models are compatible with DWG formats;
- Synchro: This software was used to produce 4D construction planning and scheduling/sequencing (time) for the project. It synchronises with DWF format; and
- Causeway BIMmeasure: The BIMmeasure was used by the cost consultant to extract quantities required from the model for cost planning purposes and for managing changes through the coordinated model's evolution. The BIMmeasure interfaces with exported models from Revit via DWF.

Despite the lead contractor's requirements to use Autodesk product suites across the teams to enable proprietary interchange, some of the team members used different applications that were comparatively, better than, or more preferred to Autodesk's alternative. And certainly, it is not all the supply chain members that regard Autodesk products as the 'best-of-breed' solutions. For instance, although Revit MEP was used for creating the design model up to RIBA stage F by the consultant, the MEP contractor refused to use it as its main tool for detailed production drawings because, the current version is not able to create a detailed design to the level that the MEP service engineers or installers will require. Hence, the MEP contractor opted for CAD Duct to develop the production drawing, while they retrospectively used the Revit MEP for coordination purposes. However, all the alternative products were supported by Native CAD file formats such as DWF and DWG, which are able to interface with the Navisworks.

6. Setting-out collaborative BIM work structure: Having worked in the traditional AutoCAD environment for a long time, most of the project participants were rather more familiar with a number of old processes which involved PDF data flow, information sharing

via email, coordination in a 2D environment, hard copy mark-ups for drawing changes, unstructured handover of as-built documents to clients with paper-based operations and maintenance manuals. However, BIM requires a more modified and improved process to garner the benefits offered by the BIM methodology.

The project teams have been setup with some clear rules of engagement. At the internal workstation level, each project participant is expected to use Autodesk BIM applications to enable proprietary interface, otherwise, any other application used must be compatible with native AutoCAD file formats such as DWG and DWF. This is to ensure that each model information uploaded onto the project repository is in a format that Navisworks recognises, and currently, file formats such as Revit (.rvt) and AutoCAD format (.dwg) are convertible into Navisworks cache file (.nwc). The project team uses Navisworks to interrogate and coordinate the federated models into a composite whole. There are three native Navisworks file extensions which were used by the supply chain to coordinate their model information.

These are: 1) Navisworks cache file (.nwc); 2) Navisworks files (.nwf); and, 3) Navisworks document file (.nwd). The project team adopted these files in appending and coordinating their individual models created with different file formats into an integrated model. The use of these file formats in establishing a BIM workflow across the supply chain is presented in Figure 6.4.

Firstly, the NWC file was developed to convert other files into a readable format for Navisworks. Certain file formats cannot be appended directly into Navisworks but must be converted to an NWC file first. The NWC files are cache files containing conversion data only, thus, they contain the relevant data necessary to convert certain files such as Revit (.rvt) and CAD file into the NavisWorks format. By default they are also created automatically whenever you read a CAD file into Navisworks.

Secondly, the NWF files contain links to a number of federated working files (i.e., the architecture, MEP structure and landscaping). Thus, if changes are made to the NWC files by either the architect, MEP coordinator, structural engineer, or the landscape designer, such as moving geometry objects, and adding and/or deleting components to their original 3D data file, Navisworks will look for the linked files when the NWF is opened to re-cache and overwrite the NWC files with the new data.

And thirdly, the NWD file is a highly compressed file containing a complete data set, with all of the geometry and any information created within the Navisworks. This is the format used

by the project team to share progress and as-built information with the model users, the owner, and other external parties, because it does not link the data with the native source files.

Figure 6.4 presents an overview of how the various BIM applications are configured from the individual workstations through the cloud-based repositories to coordination analysis using Navisworks native file formats and passing on the as-installed models to the client. All the federated models in the individual workstations were converted into NWC before importing into the cloud-based Buzzsaw repository. The Buzzsaw contains a folder for the project. The project folder also contains several subfolders for the various disciplines (e.g., architect, MEP engineer, structural engineer, etc.). The team held biweekly coordination review meetings. At the coordination level, the project team used the NWF file as the working file, and it linked directly to the individual subfolders. The information in the coordination model were used for different analyses such as clash detection, cost planning and construction scheduling. Also, from the project repository, the NWD file was used to generate static representation of model information to archive specific milestone events, which were then passed on to the client.

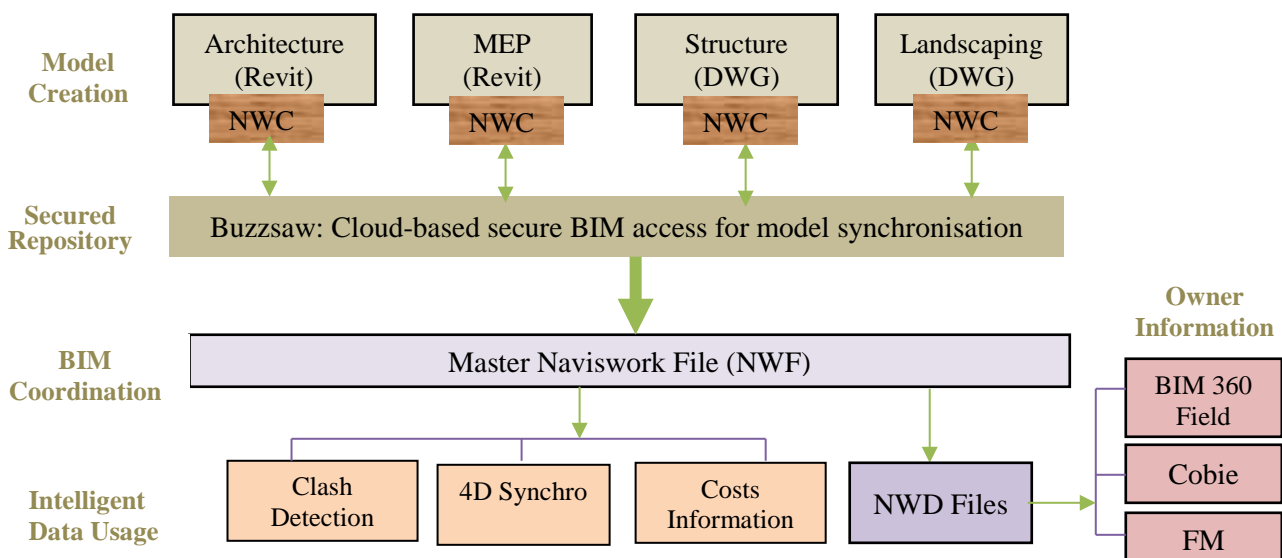


Figure 6.4 CS-Alpha BIM project workflow

Thus, moving beyond the individuals' workstation to the open BIM platform, the project has two different hosting systems, both doing two separate things. The Buzzsaw is managed by the contractor for general exchange of the working models and used by the team to solve the project data collaboration issues (coordination, clash detection and resolution), whilst the BIM 360 field is managed by the client to host the FM models and used to update the client with progress information and O&M data. However, both of them produced a protocol that

ensured that all parties to the project knew where, how and when to upload or access model information, the protocol also ensured that data quality and consistency could be produced throughout the project phases.

6.3.3.3 Summary of sociotechnical constituents' alignment strategy of BIM implementation processes in CS-Alpha

The summary of CS-Alpha's BIM implementation alignment strategy is depicted in Figure 6.5. This illustrates the build-up of CS-Alpha's BIM rollout and it shows the configuration of institutions and mechanisms aimed at nurturing and establishing BIM-enabled work processes across the inter-organisational units. The diamond shows how this build up started and the inter-organisational effort perceived by CS-Alpha as necessary to reach a critical mass and induce a 'virtuous cycle' of BIM work process.

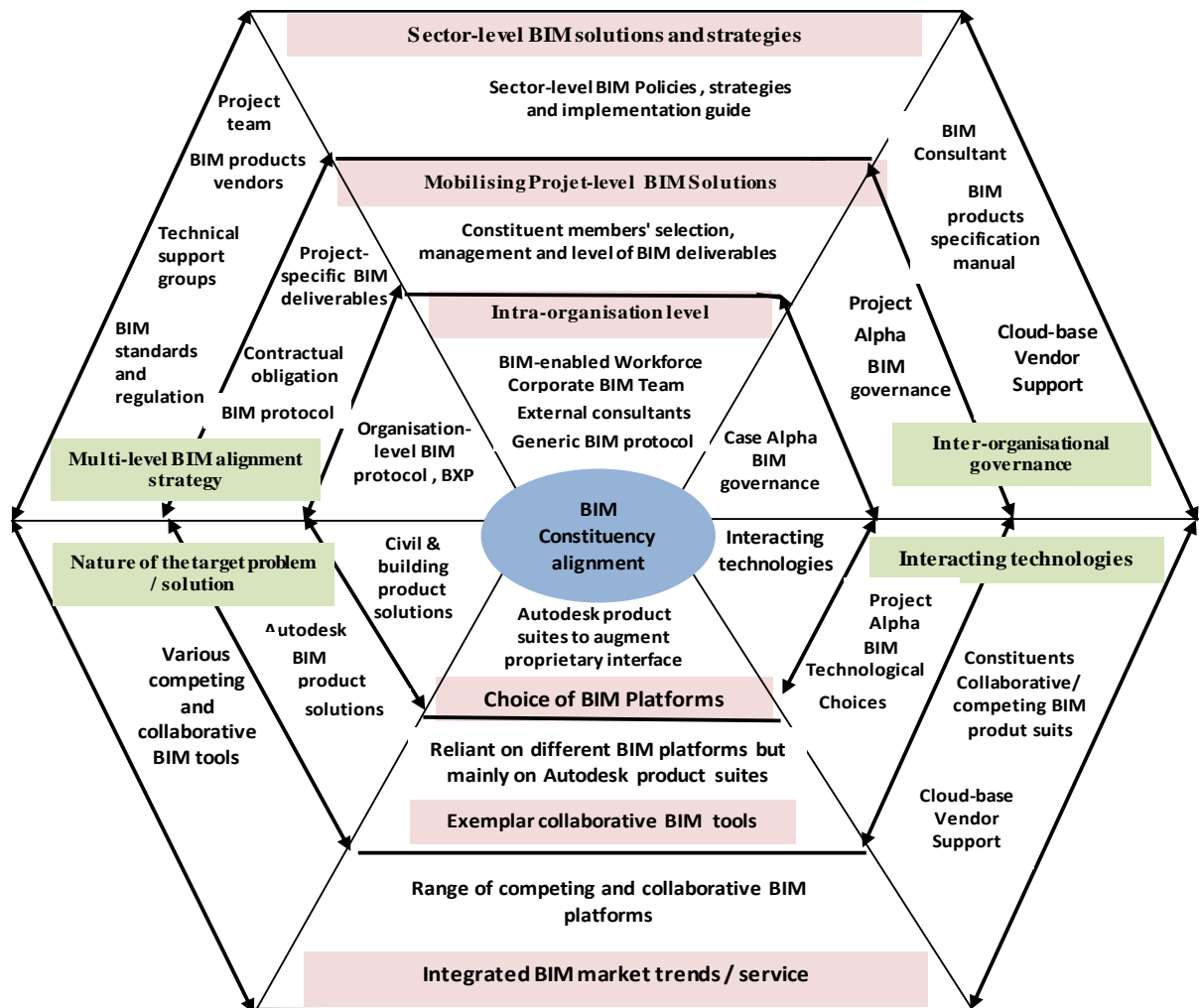


Figure 6.5 Inter-organisational sociotechnical constituents of BIM uptake in CS-Alpha

As CS-Alpha shows, the knowledge relationships among the constituencies are embedded within contractual obligations and defined BIM deliverables among the inter-organisational members. In other words, contractual relationships among the multilevel constituents are the prerequisite of knowledge relationships and deliverables.

Molina (1993) stresses that technological change is a complicated process; it is not only a process of coupling between the technology supply and demand sides, but also a process occurring at ‘multi-levels’ (i.e. artefacts, social constituents, structures). The STC approach highlights that misalignment is in the very nature of the sociotechnical constituency. As a consequence, the diamond captures this ‘problematic’ nature of technological change and introduces inter-organisational governance to counteract any resistance to change and power relations to seek re-alignment of the constituent parts through purposive actions and policy programmes. The implementation strategy is an extremely difficult task in a real life context, it proves to be much more chaotic than when described in theory. The next section highlights the difficulties met by the BIM implementation process after its inception.

6.3.4 Challenges Associated with the BIM Implementation Process

Throughout the process of BIM implementation, there were challenges that were encountered. These are grouped under three main categories: 1) limitations for using single vendor product suites; 2) some supply chain members’ reluctance to embrace BIM; and 3) preparing for unforeseen and impending uncertainties.

The sections that follow discuss each problem and the company’s strategies in overcoming them.

6.3.4.1 Limitations for Using Single Vendor Product Suites

Despite the company’s strategy of using mix-and-match BIM technological platforms to obtain the best-of-the-breed solutions, restrictions were however, placed on all the BIM constituents at the project level to use products from Autodesk. There is a historical context to CS-Alpha’s decision to request for the use of a single vendor product suite for this project. All of their past BIM projects that utilised different applications almost always experienced problems with data interchange and coordination issues because the IFC was not always able to integrate very well with some applications. Nevertheless, out of the 11 number BIM tools that were used on the project, only 6 were from the ‘approved’ vendor and the rest were from different vendor sources. The small size specialist contractors especially could not transition

from their preferred applications to Autodesk, and the relatively large specialist firms such as the MEP contractor, were using their preferred BIM tools to create detailed production drawings whilst using the recommended application, retrospectively in creating another MEP model for coordination purposes. The BIM coordinator emphasised this problem by saying:

“.So [the MEP contractor] did their own model with CADduct and created another model with Revit for coordination and now we have two as-built models running. But by doing this, it is actually putting in extra cost and a delay unto the design coordination team to actually create the coordination model.” [Ri-D]

Aside this problem of using two different BIM applications by one specialist contractor, when the federated models that are created with a different application other than Revit are imported into Navisworks, it is only the 3D geometry that gets exported, but not with the associated data. This also creates a chain of issues such as problems with the automatic extract of quantities and schedules for pricing and planning purposes. In that case, the cost and planning engineers may have to combine both the traditional and BIM approach for their analyses in order to guarantee accurate information.

6.3.4.2 Small-Size Specialist Contractors’ Reluctance to Embrace BIM

One of the main challenges faced is that, specialist firms, that are usually small in size, are not embracing the BIM concept. And this impacts on the extent to which BIM could be implemented on the project, especially, when the specialist firms are expected to play a key role. A coordinator explained that:

“There is a shortage of services contractors who already are up to speed with BIM so you can bring BIM on board and get them working straight away in a 3D environment. At the moment it is very much a struggle trying to persuade them that they need to get on board with BIM and to invest in the technology. Sadly we are not seeing the supply chain investing in BIM in terms of training their people and investing in software.” [Ri-D]

Some of these specialist firms are known to have the ability to provide efficient services on site, but they have not developed their capability to create models because they have not invested in the appropriate BIM tools and training. Some of these specialist firms were given the dispensation to use their conventional tools to create their drawings (fire and security and landscaping), thereby blending the models with some native CAD files. The problem with the

small construction firms is that, they cannot afford to make the level of investment needed to become BIM-enabled. Traditionally, the overhead and profit of construction organisations have long been known to be low, thus, most of the small firms have either limited or no investment budgets compared with the large firms, hence, hindering them in making the required level of investment in BIM.

6.3.4.3 Preparing for Unforeseen and Impending Uncertainties

Though the entire supply chain members were selected *inter alia*, because of their knowledge of the BIM process, a common thread weaving through the interview was that their practical experiences of BIM projects of this nature were very minimal. Anticipating that the supply chain may pose some contractual risks, the client defined its BIM requirements from the outset that the as-built model information would be handed over for the operations and maintenance management of the facility. And subsequently, the client established ‘contractual safeguard’ by transferring any associated risk uncertainties through the contract with the lead contractor. Some of the risks that ultimately emerged, which the supply chain (excluding the client) had to absorb included:

- Cost and time implications for using two BIM applications by some specialists to meet both the project coordination requirement and internal work delivery standard
- Drawbacks caused by some supply chain members not able to implement BIM to the standard set for the project
- Some small works contractors given the dispensation to work with standard CAD thus having a blend of coordinated model and traditional CAD drawings
- Some drawbacks of the Autodesk technological platforms causing some delays. For instance, in some occasions, due to technical hiccups the Navisworks manager seized to perform to expectation, calling for technical assistance from the vendor. These hiccups caused delays, also, the applications run slow when working on a large Navisworks file, additional resources (trained personnel and computer workstation) were therefore needed to breakdown large-size models down into smaller chunks.

The client then opted out of any pain/gain-share arrangement of the supply chain by using design and build as the main contractual arrangement for the project, hence providing certainty of cost regardless of design changes. Unless it was a change to the client’s brief and subsequently supported by an AI (architect’s instruction). Ultimately, the coordinated model was almost considered as a ‘by-product’ for the creation of 1) design drawings and 2) as

installed information. Apart from these two, any other information in the model was not contractually binding.

Like the other traditional contract forms, fixed price lump sum contracts create a conflict of motive between the parties. Measures that allow some sharing of project risks and associated pain/gain are considered as supportive of collaborative relationships. Understandably, the lead contractor (CS-Alpha) also extended the same traditional contract arrangement to the functional units of the supply chain. Added to this was the fact that the defect liability period was negotiated with the contractor for an additional three years period. During this period, the contractor would maintain the information in the virtual reality of the model to ensure it is at par with the augmented reality of the actual facility.

6.3.5 Summary of CS-Alpha

The findings of the first case study conducted at a large BIM-enabled construction organisation referred as CS-Alpha has been presented. First, the evolution of BIM in the organisation is discussed by providing the driving force as well as the commitment and progress being made with regards to their BIM uptake. The driving force towards CS-Alpha's commitment to BIM could be attributed to 'meeting the demand of their clients, and the trending market requirements', 'maintaining a competitive edge' in their niche area amidst an industry-wide advocate towards BIM, and delivery of 'best-value' in the current era using the best available innovation product and process solutions. Following this, the organisation's strategy towards BIM implementation was discussed. Five main strategies that emerged from the analysis were: 1) formation of an in-house BIM team; 2) engagement of an external consultant; 3) training and support of the workforce; 4) selection of BIM platforms and related upgrade of computer workstations; and 5) development of generic implementation protocol and guide. Project-level BIM implementation strategy with the project supply chain were also discussed. Five main project-level strategies emerged: 1) selection of functional constituent members; 2) specifying BIM deliverables and line of command; 3) defining the BIM contractual framework; 4) establishing the preferred BIM platforms for use; and 5) setting out the BIM work structure.

Finally, the discussion moves to present the challenges associated with the BIM implementation process. The challenges encountered include: consequences regarding the restriction for the use of a single BIM product suite; reluctance of small-sized supply chain members to engage with the BIM evolution; and some supply chain members safeguarding

against impeding uncertainties via the contract. Despite the identified problems, the project seemed to have achieved its main objectives in terms of measurable performance. It was completed on schedule, and no major contractual issues were reported. For the lead contractor, the expectation was modest - to successfully deliver an information-rich and complex BIM project for a high profile client, so it can be used to exhibit their capabilities thus, becoming a selling point to attract projects of similar nature. And they seemed to have attained that, not losing sight of the efforts, and resources that went into building the organisation, as well as the project-level BIM strategies.

6.4 CS-Beta: Analysis of Results

This section presents the results of the second case study. Similar to the analysis of CS-Alpha, as presented in the previous section, this section consists of seven subsections. Firstly, the background of the second case study is presented in section 6.4.1. This subdivision also discusses the organisational objectives and the background of the research participants. Secondly, section 6.4.2 traces the evolution of BIM in the case organisation and discusses the main drivers for their BIM uptake. Thirdly, the CS-Beta's inter-organisational relationships with other sociotechnical constituents at both the project and the macro-levels are presented in section 6.4.3. Further, section 6.4.4 discusses the challenges associated with the delivery of CS-Beta's BIM project. And the section concludes by summarising the key findings of the second case study in section 6.4.5.

6.4.1 Background Information of CS-Beta

The second case study organisation was established in 1993 as a specialist CAD drafting company for structural steelwork. Their areas of expertise included, portal framed buildings, mezzanine floors, structural glass balustrades and any design issues related to structural steel buildings. In 2009 it invested in BIM design solutions and rebranded itself as a multidisciplinary practice. Since then, the company has grown into a small multi-disciplinary practice providing not only structural design solutions but also other construction design and prefabrication solutions. The main services that CS-Beta provide to its range of clients now encompass design, consultancy, creation of structural models, and production of fabrication module information and NC (numerically controlled) data to allow accurate manufacture and installation of a variety of projects from structural steelwork to architectural metalwork and staircases.

The company prides itself as being one of the few specialist firms in the UK that provides building information modelling services for structural steelwork and architectural metalwork. Despite being a small construction firm, the company has played a specialist role in high profile construction projects across the UK ever since it enhanced its capability to encompass BIM. Some of these projects and the roles they played include: The Olympic stadium (secondary steelwork); the aquatics centre in the Olympic park (secondary steelwork); Heathrow terminal 5 (internal architectural balustrade); the houses of parliament, Westminster (glass canopy); Westfield shopping centre in Stratford (steel staircases and atrium glass balustrades); Cardiff city football stadium (secondary steelwork) and BBC

redevelopment (architectural and secondary steelwork). The company's average turnover has been 4 million for the past three years and employs fourteen (14) number office-based construction practitioners. Commenting on the company's current status, the managing director emphasised that:

“As key advocates of BIM principles, [CS-Beta] has been involved in many prestigious projects and is having a huge impact on the business. We are growing faster than the capital with both enquiries up and orders up, we continue to grow with the investment in more Tekla stations and now in-house engineers now up to 14 fully employed.” [Da-L]

The statement of the managing director highlights the extent to which the company's investment in BIM protocols has impacted on the business as a whole.

6.4.1.1 Organisational Objectives

The foremost organisational objective of CS-Beta is to deliver “professional’ and ‘personal” construction services to its clients combined with strict adherence to regulations, particularly British Standards and underpinned by “published in-house ethical standards.” The company is steadfast in utilising the latest available supporting technologies to complement its expertise and experiences of the workforce to meet clients’ expectations. In ensuring repeat business with clients, CS-Beta also aimed at setting the pace by delivering value and balancing cost, quality and time accuracy via high quality project management. To ensure the successful delivery of work thereby meeting its objectives, CS-Beta collaborates with its clients and compromises on issues which do not fall short of efficient standards, when the need be in order to provide satisfactory service. This was emphasised by the managing director:

“We work throughout the UK advocating a design team ethos to promote collaboration, cooperation and compromise in our efforts to deliver projects accurately, efficiently and on time.” [Da-L]

By collaborating with clients in order to understand their needs and then use its expertise and available technologies to meet those needs, CS-Beta is able to secure repeat business and also, gets the opportunity to play a role in some of the high profile projects in the UK as is currently the case.

6.4.1.2 Research Participants

The data collection for this case study was conducted in 2012 and lasted for about nine months. In line with the data collection protocols discussed in section 4.7.2.3, the research is centred on the collection of rich qualitative data through the blend of the case organisation's documents analysis, semi-structured interviews and participants' observations. This was achieved within the nine months' span. Altogether, six in-depth interviews were conducted involving the managing director and five professional practitioners of the company. Four out of the six research participants have over 10 years' experience working in their respective professional fields. Meanwhile all the six participants had BIM experience and have been involved in managing the company's BIM projects. Table 6.5 lists the profiles of the personnel from CS-Beta that participated in the study. Considering their backgrounds and experiences, all the responses from the interviewees are considered valuable in portraying a clear picture of the company's BIM strategies and in providing answers to the objectives this case study sets out to achieve. Consequently, it is possible to see from the respondents' perspective how BIM solutions are involved in shaping the operations of the company.

Table 6.5 Description of CS-Beta personnel that participated in the study

No.	Name (pseudonym)	Title	Gender	Years of working experience	Number of interviews
1	Da-L	Managing Director	Male	13years structural steel design and fabrication	1
2	Ne-S	Operations Manager	Male	22years 3D structural steel modelling and fabrication	1
3	Ja-M	Technical Manager	Male	15year structural steel design and CAM	1
4	De-M	Design Engineer	Male	3years CAD/CAM Management	1
5	Da-M	Contracts Manager	Male	35years Commercial and contract management	1
6	Ro-D	Technical Manager	Male	9Year design management	1

Following this brief introduction of CS-Beta and the personnel that contributed to the research, the section continues to present the findings of the second case study. The following section traces the evolution of BIM in CS-Beta.

6.4.2 Tracing the Evolution of BIM at CS-Beta

Structural design and analysis has always been of vital importance in the overall scheme of the construction process. Recent dramatic increases in complex design and the resulting pressure to use more accurate and speedy analytical tools has however significantly raised the profile of the demand from the structural engineering specialists. The existing BIM platforms allow complex modelling of 3D geometrical shapes which are increasingly demanded by the complexity of modern design. As such, both public and private sector clients have influenced the organisation through its BIM journey. This was emphasised by the director:

“It [BIM] is certainly something that contractors have to get on board with, or jeopardise being excluded from some potentially lucrative public sector projects and, like it or not, it really is going to change the way that everyone in the construction industry works.” [Da-L]

The above statement demonstrates that when BIM becomes a requirement of tenders in both the private and public sectors, as it is perceived to be the case, the organisation would be fully conversant to meet the necessary prerequisites. Beyond the influences of project clients, the realities of “modern” projects requires for things to be done differently:

“As a company we were familiar with detailing projects of high complexity but we have seen an increase in the number of jobs where a 3D capability would significantly improve the time required to detail these project requirements.” [Ne-S]

Apart from the recent upsurge of client interest in BIM and collaborative working technologies, the interest in BIM in CS-Beta is partly drawn by the content of the available platforms, some are ‘intelligent’ and contain detailed information such as dimensions, component specifications, carbon content, materials’ performance, manufacturers’ details, supports and maintenance requirements. These information were not available in the conventional CAD platform. Thus developing competency in the BIM applications means that *the efficiency and speed of work is more achievable than ever before.* [Ja-M] This also presents the company with the opportunity to fulfil its technology-led strategy of staying ahead of competitors.

6.4.3 Mapping the Inter-Organisational Sociotechnical Constituents' Relationships at CS-Beta

As shown in the STS analytical framework in chapter 5, the success to a BIM-enabled project delivery process relies on the alignment of the inter-organisational constituents, including the integration of multiple ranges of competing and complementary BIM platforms as well as compromising on common perceptions and pursuits. Also the analysis of the BIM implementation at multiple level of abstraction in CS-Beta is discussed under two main headings: 1) organisation-level BIM alignment strategy; and 2) multilevel BIM alignment strategy. These are discussed in the next section and are illustrated by extracts of responses from the interviews.

6.4.3.1 BIM Appropriation in CS-Beta: Organisation-Level BIM Alignment Strategy

Apart from eliciting the drivers that prompted CS-Beta to develop BIM competence, the development of the organisation's BIM competence was further explored by investigating the implementation strategy. The analysis of the organisation-level BIM alignment strategy in CS-Beta has been categorised under two main components: 1) selection of an appropriate technological platform; and 2) training and support of staff.

1. Selection of an appropriate technological platform: As part of the programme of introducing BIM to its work system, the company evaluated some of the popular BIM software products until deciding on two main platforms. The managing director of the company explained the BIM evaluation process:

“When we decided to adopt BIM in 2005 we underwent an open, comparative selection process to find the software that worked best for us. The things that were vital to us were real world capability, support, interconnectivity, licensing and flexibility. Honestly, there are a couple of them that came out of the evaluation as the software that best meet our needs.” [Da-L]

After a comparison exercise between Revit structure and Tekla, it was recognised that both tools could serve useful purposes in the organisation. Revit structure would be used for 3D 'standard' design solutions because it had a shorter learning curve. And the Tekla would be used in complex bespoke structures and also for producing detailed general arrangement drawings because it provided the functionality needed for steel detailing and automated fabrication. Even though the organisation found Tekla to be relatively expensive compared to

Autodesk, they found Tekla to be quite intuitive and it gave reasonable flexibility for structural detailing and accurate prefabrication information via NC data production.

The organisation and Tekla have signed a flexible licensing agreement. The case study organisation believes that this agreement would help it better serve its clients. The agreement covers technical and maintenance support, and access to the latest versions of Tekla products. This enables the engineers to access the product best suited to their project from a portfolio of Tekla software which are useful for structural design, modelling, viewing, coordination and information sharing, including Tekla structure, Web Viewer and BIMsight. These services form part of the annual licensing fee. The managing director insisted that they had chosen this licensing model as part of a corporate strategy to ensure the organisation is able to support clients' needs even more effectively: *“Our plans demand the harnessing of the best technology available on behalf of our clients.”* [Da-L]

Every BIM software application comes with a minimum computer system requirement, which often turn out to be of higher specification than the average computer capacity. The recommended laptop specification for the current Tekla structure and the BIMsight comprise a 64bits operating system, multi core processor, and a memory of at least 4GB RAM. In order to maintain good performance, the company uses laptops with i7, 8GB RAM and 64-bits. Since there is an annual upgrade of the BIM software, the company has accordingly changed its systems replacement schedule. This was emphasised by the design engineer:

“... instead of doing a 2-yearly computer replacement, now, we replace half of them in a year just in order to use these software, and also, with the BIMsight that also need high spec computers.” [De-M]

This statement clearly indicates that the performance of the BIM software products is inextricably connected to well-configured computer workstations.

2. Training and support of staff: The director of CS-Beta acknowledged that the extent to which the BIM vision is realised depends on the employees' skills and attitudes as it is on leadership and management support. However, a challenge faced by the organisation is that, very often, the employees that join the company do not have the specific skills the business requires. Likewise, there is lack of industry relevant BIM training courses in the conventional academic institutions. To address this challenge, the organisation has developed training structure that provides practical training and college diplomas' qualifications for its staff. Thus the company has developed internal training and management structure to support

employees across the ranks, from apprenticeship, through engineering to senior-level positions. The organisation's employees' training and support structure across the various ranks is shown in Figure 6.6.

The structure provides opportunities for employees to work their way up from apprenticeship level to senior management level. The apprenticeship scheme, according to a contracts manager, *“aims to train, develop and mentor the future structural engineers and detailers of the business by offering them vocational training and hands-on-experience.”*, [Da-M]. The company has forged partnerships with the local college where the apprentices receive some of their trainings. The programme is for three year, and once completed, the apprentices attain two diplomas alongside the practical experience. The qualifications include diploma in engineering construction design and drafting (ECITB level 3) and diploma in operation and maintenance engineering (BTEC level 3). After attaining the necessary qualifications, the employees are then assigned to a project with a skilled engineer as a mentor.

The whole BIM ethos is also incorporated into the company's training and support structure. As discussed previously, vendor supports and systems maintenance are part of the license agreement the organisation and its preferred BIM solution providers negotiated on:

“The added value of the licensing agreement is that consultancy and training included, this ensures that our staff have the competencies to deliver quality services. To complement this, we attend annual trainings and presentations with Tekla on their latest products. We also get all the documentations towards what new features there are and train our staff on them.” [Ro-D]

The above statement indicates that the company relies more on its BIM solution providers to support its workforce with their required training needs, especially with the launch of any new product version.

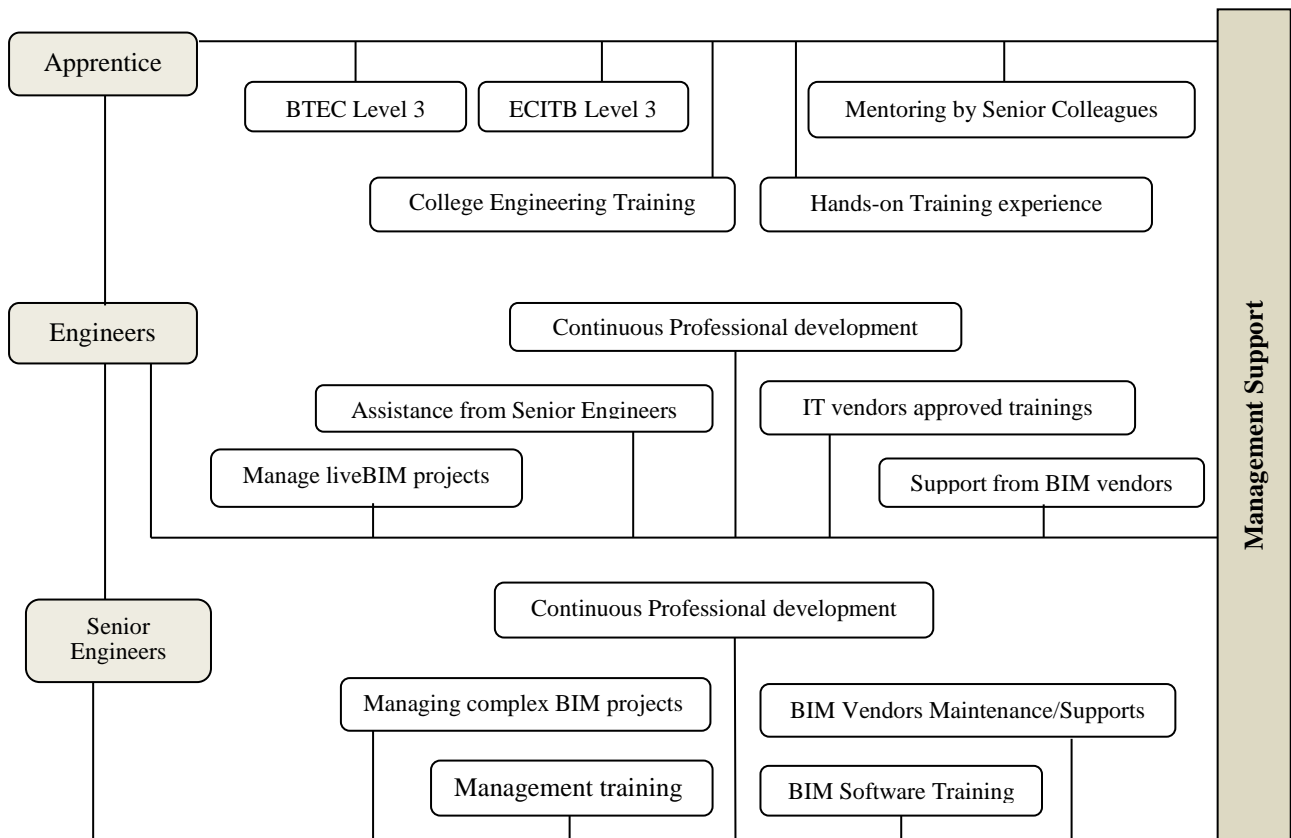


Figure 6.6 Training and management support structure across ranks

The formalised training and support structure is also a setting for performance assessment. According to the managing director, there are ample opportunities for employees to climb up the hierarchy within the company. However, the support structure and the available opportunities also mean that employees are expected to often learn new skills and take more responsibility. This it is considered to be significant for a small firm like the case study Beta.

6.4.3.2 CS-Beta: Multi-Level BIM Alignment Strategy

The multi-level BIM alignment strategy for CS-Beta is discussed under six main headings, these include: *Mobilising BIM solutions on a project; selection of appropriate BIM project constituents; specifying BIM deliverables and line of command across the inter-organisational units; BIM project contractual strategy; defining BIM applications for use across different constituents' members; and setting out collaborative BIM work structures*

1. Mobilising BIM solutions on a project: CS-Beta played a vital role in the construction of a residential building in South London. The company was employed to use a BIM platform to model and prefabricate steel panels that act as enclosures to house 3-number, 9 meter diameter wind turbines located on the rooftop of the building. The overall project scope

involved a 43-storey residential tower rising to 147-metres above ground level, and it provided 310 apartments along with retail units on the ground level. The design of the building targeted an ‘excellent’ rating under the British EcoHomes certificate system. In order to meet this ambitious energy efficiency target, one of the design briefs was to use energy efficient building components for the building whilst generating onsite energy for heating and electricity. The design team thus opted for 3 wind turbines and a combined heat and power plant to meet the energy requirements of the facility.

CS-Beta was contracted to install the structural steel frame, including the design, production and erection of the cladding support brackets for the wind turbines. The design of the model was made, distinctively by the use of a BIM platform with hundreds of unique brackets in the model to support the external cladding system that encloses the turbines. According to the technical manager of CS-Beta, the geometrical shape of the cladding panel was very complex, and it was not possible to design it with the conventional CAD software:

“We could not have been able to complete this project with conventional 2D drafting devices due to the shape of the turbine panels – I don’t see us doing this job without Tekla.” [Ja-M]

The model was created using Tekla BIM application. A screen section of the model is presented in Figure 6.7. The reasons for which the organisation uses Tekla for the creation of the model are in two folds: first, the M&E portion was designed in Tekla up to RIBA stage F prior to the nomination of CS-Beta to further develop the specialist package. Secondly, Tekla is one of two main BIM platforms the organisation has built its BIM capability on, as discussed in section 6.4.3.1.

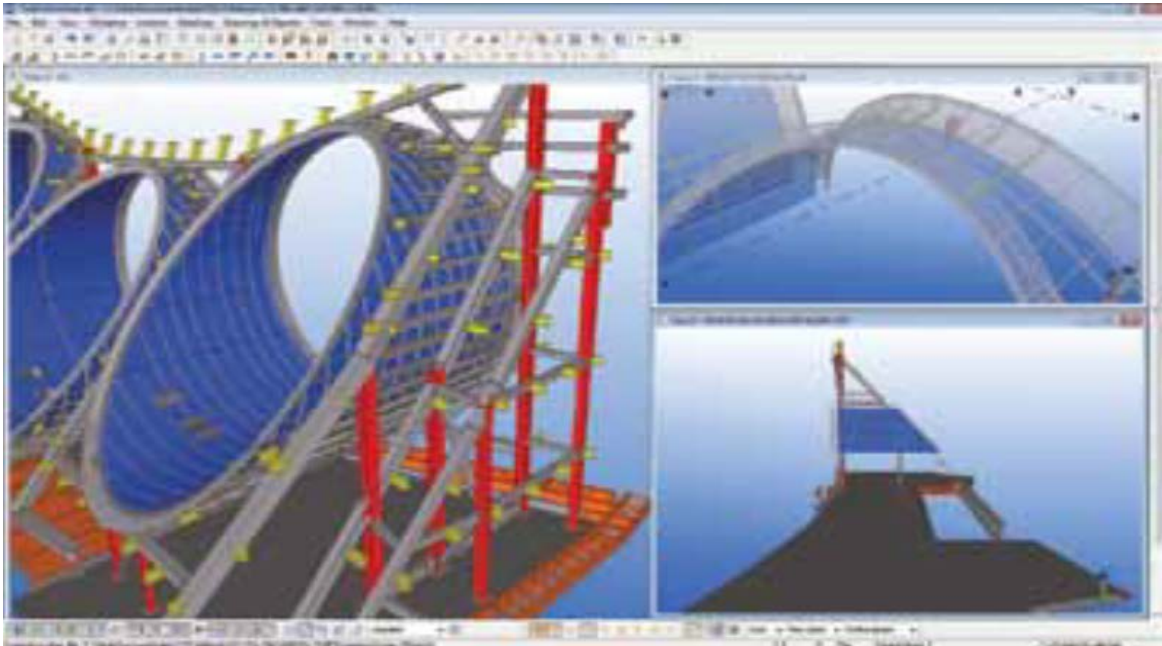


Figure 6.7 Tekla screen image of the wind turbine enclosure panels

The company therefore used its knowledge and expertise in BIM solutions to generate 3D models of the cladding panels as well as worked in collaboration with the design team and the MEP contractor to create a general arrangement (GA) and fabrication details to enable the accurate manufacture and installation of the wind turbine enclosures. The inter-organisational constituents' involvement and the project BIM strategy are discussed next.

2. Selection of appropriate BIM project constituents: CS-Beta was directly employed by the MEP contractor to create the model, and also, to produce GA and fabrication details for the wind turbine enclosures for approval prior to manufacture, installation and commission. The company has worked on some projects in the past with the MEP contractor. There was also a good working relationship among the two companies. The director of CS-Beta however felt that they were successful with the tender because of their competitive advantage in such a niche area of the AEC sector.

“We were selected for this job probably because we were one of the few fabricators that can create these kinds of models and also supervise the fabrication and installation processes.” [Da-L]

Nevertheless, the MEP organisation has a tender mechanism in place which was used as the basis for selecting CS-Beta to design, supply and install, the wind turbine steel panel

enclosures. The MEP contractor has a database of well-standing supply chain members of which CS-Beta was enlisted as a good-standing specialist. Three good-standing specialists were first nominated from the data base, including CS-Beta, to tender for the wind-turbine enclosures. This portion of the works was considered to be a small package, yet complex and technically challenging.

According to the technical manager of CS-Beta, the work presented copious challenges due to the complex elliptical and curving plate work required to produce the final high specification finish. During the tender process however, CS-Beta exhibited the ability to use the latest BIM solution to create a complex model, thereby assisting the fabrication and the installation processes. Also, the organisation exhibited capability in the use of the same BIM platform as the MEP contractor and the engineering design team, this helped in avoiding the use of the open IFC format and the compatibility / interoperability issues associated with the use of competing BIM application from different vendors.

Thus, CS-Beta's ability to use the appropriate BIM platform as an enabler to design, prefabricate and install the complex geometrical enclosures helped them to emerge as the preferred bidders for the works. This illustrates that practitioners relate the capability of BIM application to the actions necessary to deliver good work with relative ease which would be very difficult or impossible to do under the conventional practice.

3. Specifying BIM deliverables and line of management across the inter-organisational units: From the outset, the client communicated its design proposals with the lead architect, prior to the invitation of the other supply chain members. The BIM project delivery began with the clients giving the project participants a description of the project at an orientation meeting held at the design consultant's office. This meeting was attended by the client's representative (a housing developer of London), the chief architect, the project cost consultant and the structural and M&E consultants. The main purpose of the meeting was to discuss the client's request and how BIM could play the vital role of an enabler in assisting the supply chain attain the overarching project goal.

The client's requirements were defined as a 43-storey residential building rising to 147 metres above ground level, with 3-number and 9 metres diameter wind turbine at the top of the building to generate on-site energy to the residents. The building was to be designed to sustainable construction standards and a target of an "excellent" rating under the British EcoHomes Certification System. A set of sub-objectives were also defined to help achieve

the overall project goal. These included: 1) generate profitable income to the client; 2) meet high-end market demand; 3) attract customers; 4) reduce project costs; 5) reduce maintenance cost; and 6) use ‘alternative’ energy efficient materials.

The client’s main contact was the architect, who worked in collaboration with the cost consultant and the consulting engineers to develop the client’s brief for the project. Each of the consulting teams played functional roles in their areas of expertise. The architect led the design process while the MEP and structural engineers led in their respective areas. However, the architect was seen to be leading the rest of the design team, as it was his design information that was used as the basis for developing the services and structural models.

Collectively, a lot of time was spent together by the project team, including the main contractor at the design phase of the project. This was to “*get the design coordination right*”, especially due to the complex nature of the project. The supply chain decided from the outset that, due to the complex nature of the project, it was the best idea to use various BIM applications as enablers for the construction design and coordination process.

The lines of communication and the chains of command amongst the supply chain, as illustrated in Figure 6.8 is structured to reflect the relationships amongst the various functional units. The contractor was fully engaged with both its supply chain and the design team during the design and construction phase of the project. However, CS-Beta took over its part of the work from RIBA stage F design information, to further develop housing panels for the wind turbines. The lines of command and the communication arrangements among the project supply chain are hierarchically arranged on the project organogram as highlighted in figure 6.8.

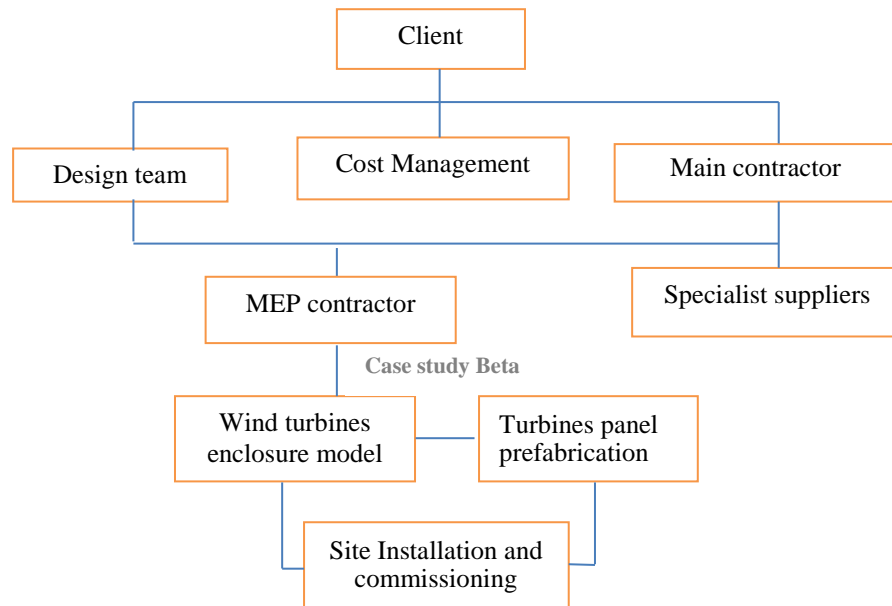


Figure 6.8 Functional structure of project Beta organogram

4. BIM project contractual strategy: The procurement option for this project was design and build. CS-Beta was not on the overall project’s contract scheme with the rest of the key stakeholders, i.e., the client, contractor, architect and the consulting engineers. Nevertheless, there was a contractual relationship down the supply chain between CS-Beta and the MEP contractor, who was also reporting directly to the lead contractor. CS-Beta was directly employed by the MEP contractor thus it was directly communicating with and following the line of command of the MEP contractor.

The featured case study project generates its own power through a series of wind turbines. The wind turbine was part of the MEP contract package. But due to the specialised nature of the steel enclosures for the turbines, that work package was subcontracted to CS-Beta. The specialist contract package for CS-Beta actually comprises 3 wind turbine enclosures. The enclosures for the wind turbines consist of 24 elliptical CHS (circular hollow section) components and 6 curved CH sections. Between these CH sections, there were beams that had been connected to fin-plates to form a “rib cage” for the cladding. It was designed to improve the overall efficiency while preventing wind noise and vibration from the model.

CS-Beta tendered for the job based on the drawing information developed to RIBA stage F by the design team. CS-Beta took the design and structural models created by the consulting engineers and the architect and used them as reference models to create a manufacturing model and a general arrangement (GA) drawing with which to build the panel enclosures. The drawing information and the technical specification document of the wind turbines were

the two main documents that formed the basis of the contract agreement. The tender requirement included the design of a 3D model for the cladding panels as well as to produce general arrangement (GA) and fabrication details to enable the accurate manufacture and installation of the wind turbine enclosure structure.

Figure 6.9 shows the 3D model of the wind turbines enclosed in the steel panels whilst Figure 6.10 shows the site installation of the enclosures on the rooftop of the building. In describing their contractual obligations, the managing director of CS-Beta emphasised that:

“we were contracted to model the steel panel so the contractor could basically see how it fits in and basically work in response to our model. The model was also to resolve any coordination issues between the wind turbine and the air handling units (AHU) and pipework connections as they were both big plants and located on the roof-space.” [Da-L]

The work involved was seen to be far more complex than the initial impression the M&E contractor had, with the modelling of hundreds of unique brackets to support the external cladding system. Also, the work presented some challenges due to the intricate, elliptical and curving plate required to produce the high specification finish to form the “rib-cage” for the wind turbines. The design engineer indicated that, the decision by the design team to implement BIM has had a knock-on effect on the design process because, under the unwritten rule of the established conventional norm, the architect or the engineers would usually show a line around the wind turbine design drawings to represent the enclosure panels. But now, with BIM, the designers are required to produce a 3-D model of the panel, indicating how it actually ought to fit, with all its necessary features. *“They (designers) will need to show it in the model. If it’s not showing in the model, it will look as if you’ve not done your job.” [De-M]*

This shows how the introduction of BIM is countering the issues of providing unclear information (lines and dots) in the design and production drawings which are then used as contracts information.

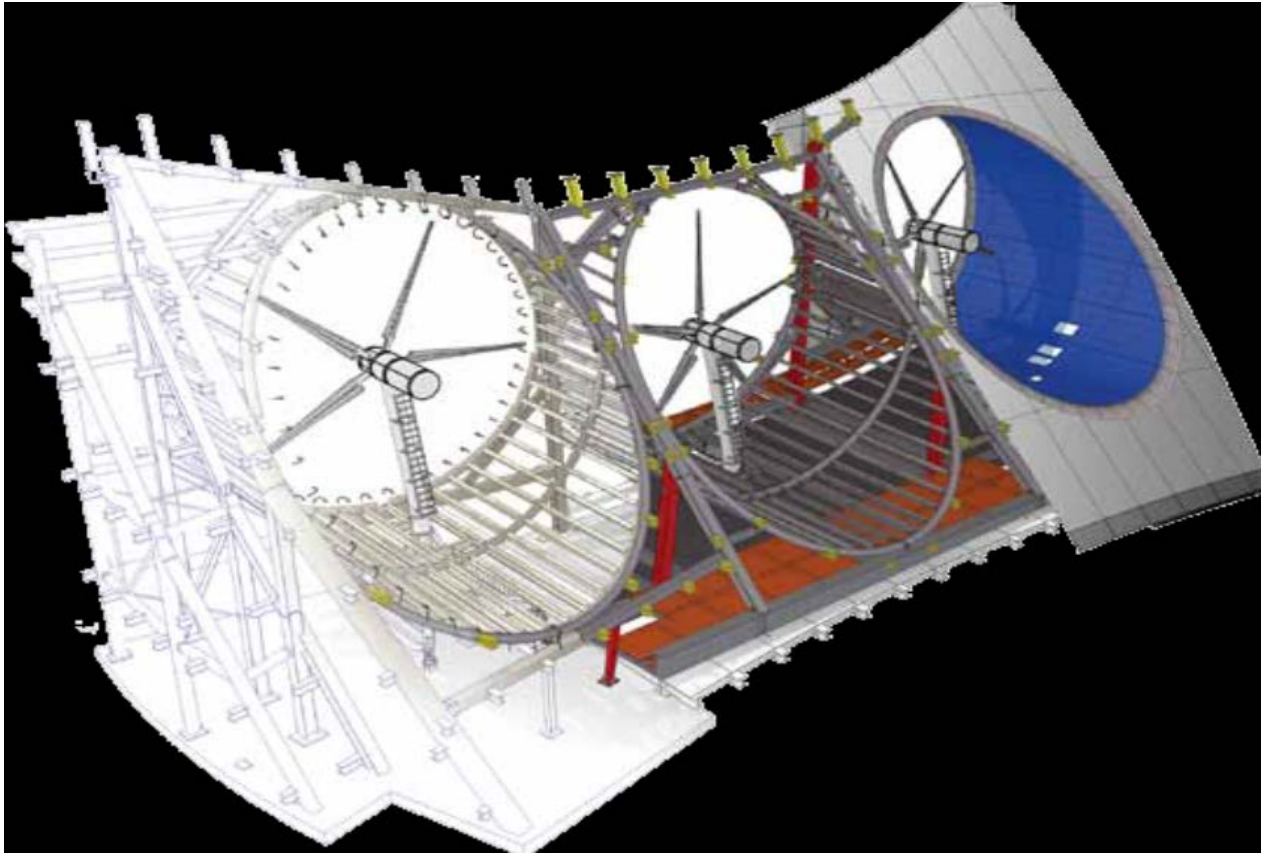


Figure 6.9 Model of the wind turbine



Figure 6.10 Site installation of the wind turbine enclosure panels

5. Defining BIM applications for use across different constituencies: The project integrated wind turbines into the fabric of the building. The 3-number, nine-metre diameter wind turbines are each capable of generating 19kilowatts of renewable energy. The building is clad in high thermal performing façade, and the energy costs per flat was envisioned to be up to 40% less than Britain’s typical housing average. The target emission reduction was used to define the design objectives. According to the managing director of CS-Beta, the building can be “*seen as a new age in thoughtful residential design.*” As a result, the design team decided at the early stages to use BIM solutions as enablers for managing the design and construction process. Thus, the MEP contractor demanded that the successful bidder would be a BIM-capable organisation.

“We had already decided as a business that this project was going to be developed using BIM. One of the first things we needed to put on the table would be a BIM deployment plan which would be needed to agree with the designers and would set up the roadmap for how this project was to be developed.” [Da-L]

This statement indicates that BIM-enabled organisations find it necessary to use BIM on projects they perceive to be complex and may present some challenges under the conventional design and construction process. The main challenge that remained, however, was the selection of an appropriate BIM platform for use by the various project team members.

As a structural engineering organisation, CS-Beta had developed competency in two main BIM applications: Tekla and Revit structure. On this particular project, there were a variety of BIM applications being used by the various teams. Nevertheless, the design model that formed the basis of the tender for CS-Beta was created with Tekla by the design team. Thus, it was an easy decision for CS-Beta to develop the wind turbine enclosure model and the GA drawings with Tekla in order to maintain a proprietary interface with the other Tekla users. Two main Tekla software products were used on this project, each having a different set of functionalities. These include:

- Tekla structure: this was used by CS-Beta, the MEP contractor and the structural design engineer to produce the 3D structural design models and the detailed general arrangement (GA) drawings for the structural works.
- BIMsight: This is a BIM application developed by Tekla for design and construction coordination. It was used on this project by the project supply chain as a web-based

platform to edit, mark-up and communicate and share model changes. At the coordination meetings BIMsight was used as the main platform for interrogating the model. It has a feature for identifying clashes and resolving conflicts during the integration of federated models.

The BIMsight has some functions such as markup tool, clash detection taskbar and the conflict browser. These proved very useful for the team to coordinate and communicate their models. During the design process, models were constantly exchanged between the parties to guarantee that the enclosure panel met the requirements of the complex steel panel geometry whilst ensuring all mechanical plants were well positioned within the confines of the roof-space. The capabilities in the selected tools gave a visualisation to the project stakeholders of holistic design information. There was also a shared cloud-based project folder feature in the BIMsight which provided a centralised access to the project model. After adding a new model or updating an existing one, the BIMsight notified the rest of the team members of the changes.

It was clear from this study that, on a construction site this large, a BIM software solution from one vendor is not enough. Thus while the consulting engineers and the MEP contractor were using Tekla, others were also using a variety of BIM applications such as Revit, CAD Duct, QTO and Synchro. However, Tekla was used to interface with other existing applications. It is an open solution that supports interoperability through IFC and CIS/2 standard formats, and also through proprietary formats such as DWG, AutoCAD DXF and Bentley Systems' DGN. Accordingly, IFC was used as the medium for integrating the open BIM models and for moving the information from one BIM vendor to another. The different parties used the IFC format to import and export the models to the shared environment and then modified and worked on it with their dedicated software solutions.

In theory, it sounds as if it is easy to work in different BIM platforms through the open BIM formats and through proprietary interface, but it is not easy to do in practice. An engineer mentioned some of the barriers they encountered when working with different BIM platforms:

“...so I would say the interoperability between software systems is probably one of the biggest hurdles to get over. Sometimes you get a transfer but you lose something in that transfer or it changes something in that transfer and the result is that you get to spend a lot of time checking it unless you work in the same software system - and that caused us a hell of a problem.” [De-M]

The above phenomenon described some of the frustrations the practitioners encounter with “mix-and-match” BIM solutions. This, to some extent, has made the BIM users struggle to use different BIM platforms on the project, thus presenting a barrier of how BIM tools are effectively utilised.

6. Setting out collaborative BIM working structure: The use of different BIM applications at different phases of the project calls for the supply chain team to cohesively integrate their federated models for coordination and data management purposes. Integrating multidisciplinary information into a single composite model requires multiuser access to the project repository. In order to address any inaccuracies and inconsistencies that will emerge as a result, the BIM team meets bi weekly to perform ‘model audit’.

Figure 6.11 has shown that various practitioners develop their individual BIM models using different BIM application at the design phase, which are then coordinated as a coherent model at the construction phase. From here, rich information, which accompanies the 3D coordinated model and the ability for analyses gained through this information, is generated. Figure 6.11 also shows the complex interdependencies between various technological platforms and knowledge workers that develop the necessary structures for a BIM project to function as intended. As indicated earlier, for BIM to function optimally, it has to overcome the barrier of inter-compatibility with multiple types of vendor applications – requiring industry-neutral standard interface in a format compatible with the BIM applications in use. CS-Beta uses the IFC format which enables the retrieval of information from the BIM repository and the transfer of information back to it without losing data intelligence.

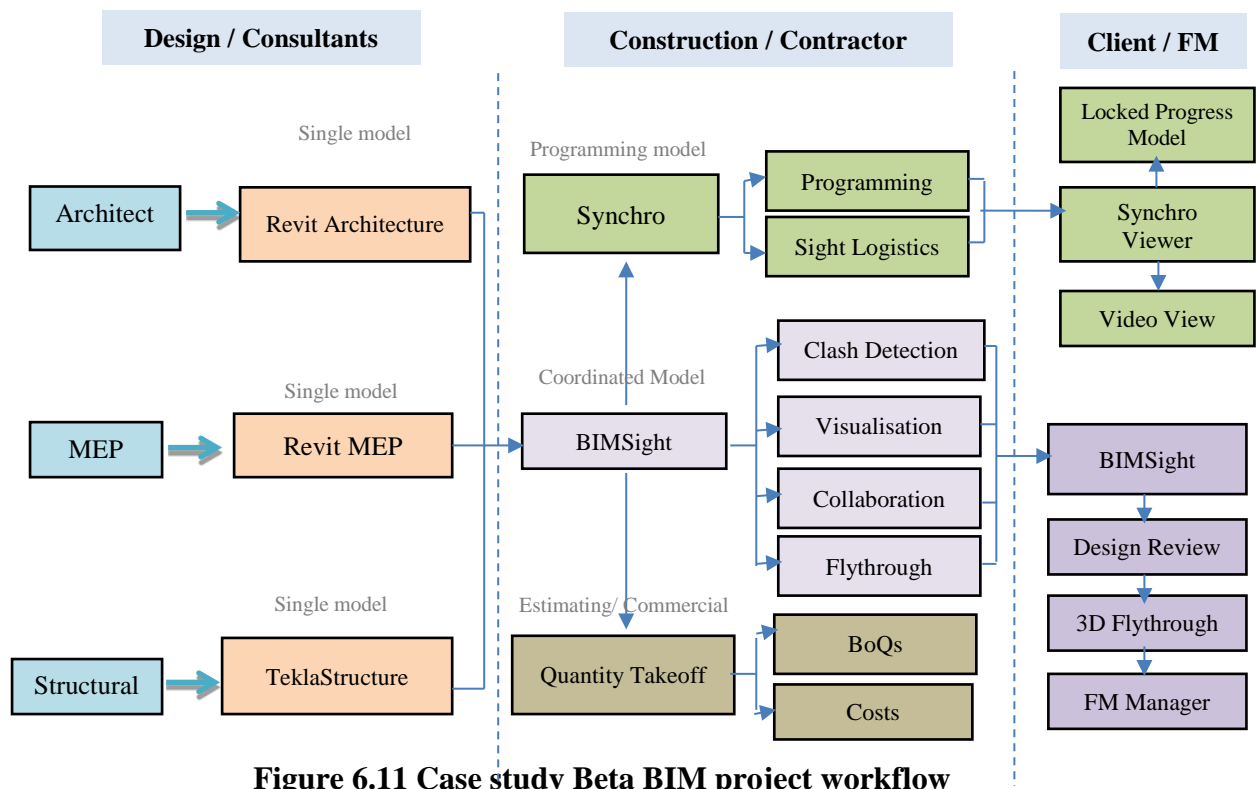


Figure 6.11 Case study Beta BIM project workflow

Figure 6.11 shows the various applications that were used by the functional constituents on the project and maps the linkages between the tools from the design phase through construction coordination and handover of as-installed information. This configuration matches with the government’s advocate of the use of openBIM platforms which are compatible to IFC format. It also reflects, to some extent, capability maturity level-2 which requires the use of the same platforms which are interoperable via proprietary interface.

6.4.3.3 Summary of sociotechnical constituents’ alignment strategy of BIM implementation processes in CS-Beta

Figure 6.12 maps the inter-organisational sociotechnical constituency associated with BIM-rollout within CS-Beta. The evolution of BIM at CS-Beta comes from a prominent internal driver for development and change in the organisation. Moving forward within the case organisation’s BIM aspirations, a BIM plan was established to provide technical rational strategy for the organisation change, and support strategy for staff to be up-to-date with the BIM rollout. Whilst the study has clearly framed a distinct technology in CS-Beta as an object of analysis, the sociotechnical constituency approach (Molina, 1990; Molina, 1993; Molina, 1999) allows a vivid depiction of the ‘ensemble’ active in shaping the changes required. This takes the research beyond cause and effect assertions about the technology

within the confines of the effects the technology has on the organisation. The STC approach presents a setting or environment for capturing a range of technical and social constituencies, including the nature and characteristics of technology and the diversified goals, perceptions and actions of the social actors, all directed towards rolling-out the inscribed functions in the technology. That is to say, the different organisations within the constituency adapt to produce the anticipated effect from the BIM rollout.

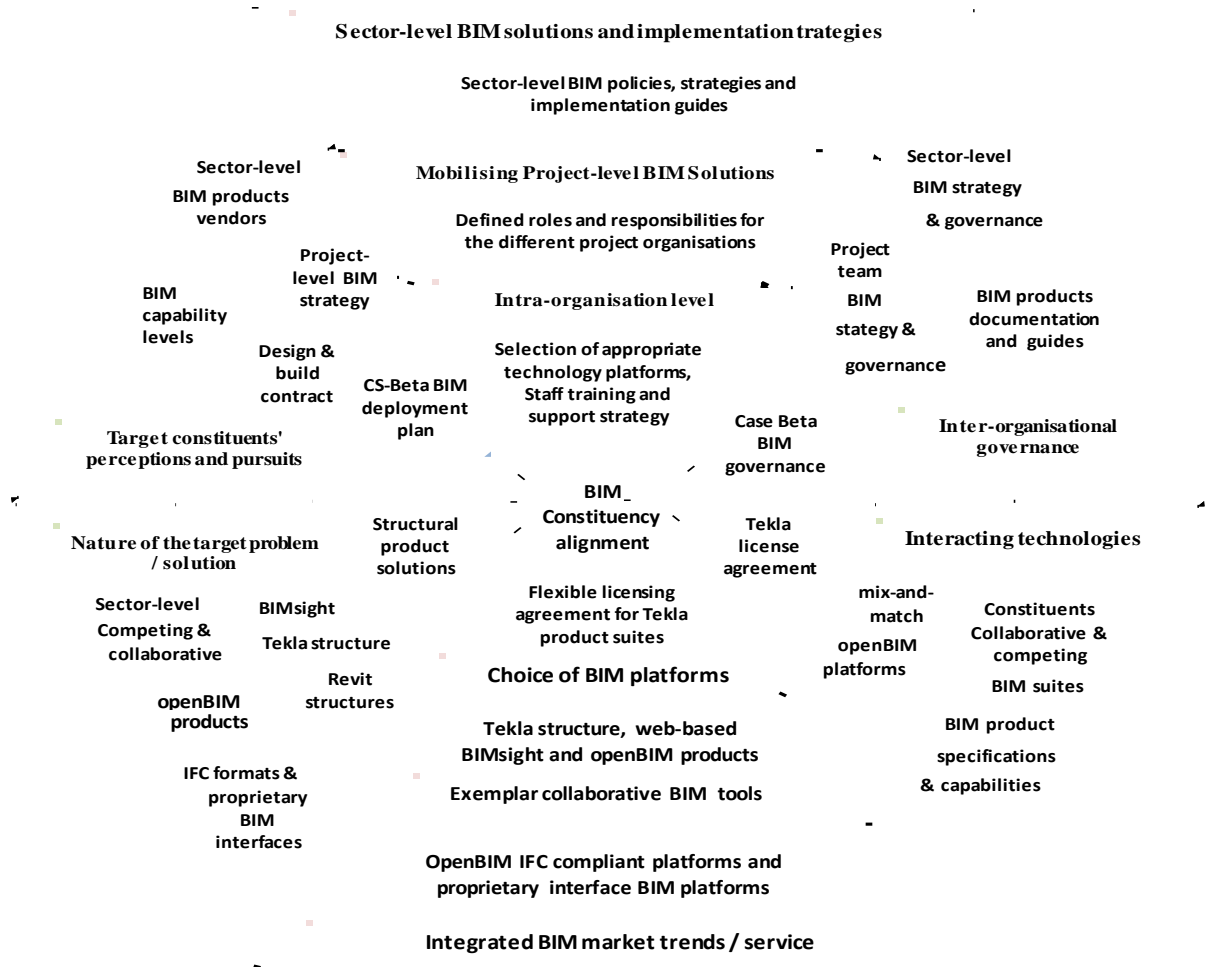


Figure 6.12 Inter-organisational sociotechnical constituents of BIM uptake in CS-Beta

Indeed, as the case study reveals, while the contextual influences in the constituency create a platform for change and enables social discourse, the outcome of BIM deployment is determined inside the constituency through contractual protocols. The contractual protocols help align with the technically rational underpinnings of the technological capabilities among the different organisations, bypassing individual interests and contradictions during their day-to-day work roles. Nevertheless, there are challenges associated with BIM deployment in CS-Beta. The next section discusses some of the challenges encountered.

6.4.4 Challenges Associated with the BIM Implementation Process

There were responses that highlighted unique challenges faced by CS-Beta during the BIM implementation process. The challenges included both organisation level and inter-organisation level issues that impacted directly or indirectly on the BIM project management process. Some of the challenges include: low investment budget due to a small organisational size and productivity loss during the learning curve; not involving key stakeholders of the supply chain in the project design phase; lack of a project-level BIM strategy; and, embedding BIM project on a non-collaborative contractual framework, thus lacking the ‘spirit of mutual trust and cooperation’. These issues are further elaborated below.

6.4.4.1 Relationship between Low Investment Budget and Small Organisational Size

The major concern for CS-Beta was the cost involved in moving from CAD to BIM: “*the biggest struggle for us as a business to move from CAD to BIM has been the level of investment in hardware, software, training and the learning curve. As a small business, the cost involved is very hefty for us.*” [Da-L]. Despite the cost implications, the company is now able to execute projects which would not have been possible with the conventional CAD system, and there has also been an expansion in its business niche.

6.4.4.2 Productivity Loss in the Learning Curve

The loss of productivity in the learning curve of a new BIM solution is also seen to cause challenges on BIM projects. In order to minimise the impact of a drop in productivity, the company’s computer workstations were upgraded with new BIM platforms in phases. The only time there was complete systems upgrade was when the systems users were well acquainted with the new BIM platform.

At the project level, the installation of wind turbines on the rooftop of a 43-storey residential tower was a novel idea. Nevertheless, the associated steel panel enclosures for the turbine seemed simple in concept, yet very complicated in execution. The challenges associated with the complexity of the object geometry were overcome by the use of appropriate structural BIM tools which had the capability of modelling structural units of such complexity.

6.4.4.3 *Difficulty in Engaging the Numerous Supply Chain in the Decision Process*

The contract arrangement did not require the early involvement of the specialist supply chain members, thus, CS-beta was directly employed by the M&E contractor at RIBA stage F, after design completion. This implies that, the specialist ideas and expertise was missing in the design model. Also, CS-Beta was located further down the project organogram structure, thus, the organisation was not participating in the management team meetings and the regular coordination meetings, but it was only represented by its employer (the M&E contractor) during such meetings. Such an arrangement lacks the robust team structure that facilitates communication or fosters a collaborative contractual relationship as advocated in chapter two (section 2.9.2).

There was no clear indication of a project-level BIM strategy (with regards to tools and work processes) to be followed at case study Beta. It was more of intentions in the briefing rather than a developed scheme, but the selection criteria (BIM-enabled organisations) of the key supply chain members, compensated for this potential oversight. The BIM-enabled project stakeholders were therefore able to configure the competitive and collaborative BIM platforms into a well-coordinated BIM working structure.

6.4.5 Summary of CS-Beta

This section has presented the findings of the second case study to further explore practices towards BIM implementation within a small BIM-enabled construction organisation. It presented the background information of the organisation, the driving forces for BIM uptake and the organisational strategy related to BIM technological implementation and the concomitant process change. The project level BIM implementation is also presented, including the structure and the alignment of the sociotechnical constituency during the project delivery process. The evolution of BIM in the organisation is predominantly related to the possibility of “speedy and efficient work delivery”, an upsurge of clients’ interests in BIM, the urge of staying ahead of competitors, and rapid increase in complex design information. Moreover, it was found that the organisation’s BIM implementation strategy relies on two main features; reliance on appropriate technological platforms and provision of training and support for the workforce. The section then presented the findings of the STC alignment process of inter-organisational BIM project members. The STC alignment required for the establishment of common purposes, goals, and compromise on common product and process solutions amongst the BIM-enabled constituency members. Finally, the discussion moved to

present the challenges faced by the organisation in the BIM implementation process. The main challenges were 1) Hefty cost implications; 2) initial productivity loss; 3) Non-collaborative team relationship; 4) late involvement of some specialist supply chain; and, 5) tall hierarchical command structure and communication arrangement. In conclusion, there appear to be many significant challenges related to BIM implementation in construction organisations, which confirms the findings of the exploratory study and that of the first case study. The next section presents the findings of the third case study.

6.5 CS-Gamma: Analysis of Results

This section presents the results of the third case study. Similar to the analysis of CS-Alpha and Beta, this section consists of seven subsections. Firstly, the background of the third case study is presented in section 6.5.1. This subdivision also discusses the organisation's objectives and the background of the research participants. Secondly, section 6.5.2 traces the evolution of BIM in the case organisation and discusses the main drivers for their BIM uptake. Thirdly, CS-Gamma's inter-organisational relationships with other STS constituents at both the project and the macro-levels are traced in section 6.5.3. Further, section 6.5.4 discusses the challenges associated with the delivery of the BIM project. And the section concludes by summarising the key findings of the final case study in section 6.5.5.

6.5.1 Background Information of CS-Gamma

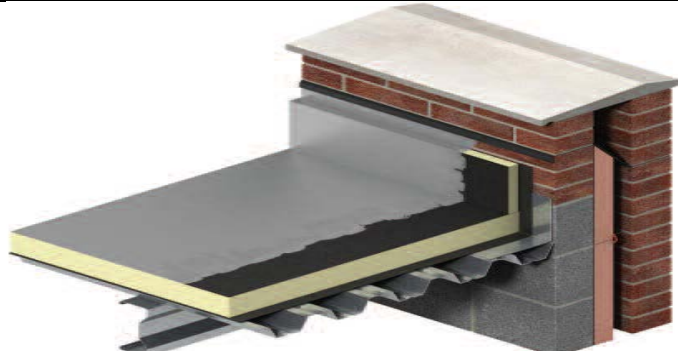
Founded in the early 1970s as a small structural engineering firm, CS-Gamma expanded into providing steel manufacturing solutions, structural sections and insulation materials to the UK and European market. Now it has grown to secure a unique niche in the design, manufacture and construction of environmentally friendly building components for the domestic and commercial property market and has specialised in building low-carbon infrastructure projects from power plants, roads and bridges to housing, schools and hospitals. The company is also well-known for its investments in high performing energy-efficiency building envelope solutions and insulation products. The company's turnover in the 2011 financial year was 1.5billion euros, with employees of circa 4,700.

CS-Gamma has over twenty offices in the UK and is headquartered in Ireland however, the researcher was granted access to the West Midlands office, particularly the design and engineering department. The West Midlands office is composed of five functional departments, that include; design and engineering; commercial; planning (they manage programming and schedule of works); production (overseeing both manufacture and onsite construction); and customer service (sales and service division). These intra-organisational units have different roles to play, but they are all guided by the same goal of fulfilling the overall strategic mission of the organisation, and are served by a common BIM repository.

The main focus of the company is to manufacture a range of building components including flooring, roof and wall insulations, cladding panels, raised access floor systems, ductwork systems, and dry-lining plasterboards and floorboards. Some of these products are described

in Figure 6.13. These products are for building envelope insulations and building services applications.

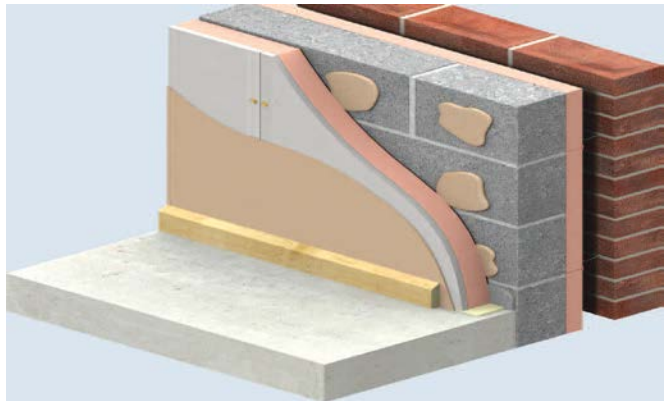
Roof insulation product: waterproofed with fully adhered single-ply, bonded built-up felt, and mastic asphalt. It is suitable for either metal, concrete or timber deck



High Performing Rigid Insulation: This product provides insulation for heavy-duty commercial, industrial, basements and car park decks. It has high compression strength with rigid thermoset insulation.



Internal wall insulation systems: this is a pre-insulated dry-lining system that combines insulation, plasterboard, and vapour control layer. It is directly bonded with gypsum adhesive on internal walls. It can achieve low air leakage rates with BRE Green Guide A+.



Raised access floor system: This system facilitates the delivery of power, data and HVAC, via the underfloor service void, to the point of need



Figure 6.13 Range of building components from CS-Gamma

The company has recently collaborated with the National Building Specification (NBS) to author ten of its insulation product ranges as BIM objects and host them on the National BIM Library (NBR). The National BIM Library hosts a variety of building fabric systems from a whole range of building components manufacturers. The purpose for launching its products as BIM objects in the NBR is to allow its clients (e.g., architects, consulting engineers, contractors and facilities managers) to download these objects and incorporate them into their models. This provides accurate cost information and specification properties to users. These library objects are available in the four major BIM platforms (i.e., ArchiCAD, Bentley, Revit and Vectorwork) and in the IFC format. CS-Gamma's scope of operation in the AEC sector and magnitude of use of BIM tools thus represent a useful reference point that could offer learning opportunities in terms of BIM implementation processes.

6.5.1.1 Organisation Objectives

The main organisational objectives of CS-Gamma is to focus on higher growth in the energy sensitive segment of the building industry, thereby providing modern, low energy building solutions. The company recognises that consumers' perceptions and attitudes towards sustainability issues and the zero carbon market are changing, and these have accelerating implications. With that comes a very evident shift in demand for energy efficient buildings, as explained by a technical manager:

In the coming years, it is likely to see demands for premium and high performance low energy solutions grow as energy standards get tighter. Coupled with high fuel prices and consumer demands for low energy buildings, we will see this sector grow to become the norm.” [Th-R]

For this reason, the company is aiming to be at the forefront of the low energy building drive, hence, focusing attention on low energy building solutions and targeting market areas in the AEC sector where energy conservation is the priority. A published corporate document has also stated the vision of the business:

“To be a global leader in the sustainable business and establish a leading position in providing renewable and affordable best practice solutions for the construction sector.”

To deliver on this ambition, the company invests in research and development in the areas of renewable energy products and the integration of the research recommendations into its

building solution portfolio. Accordingly, this has led the company to ensure that its employees are given adequate training and are fully involved in helping deliver the company's sustainability vision and policy.

The company is also cognisant of working with client organisations, helping them develop their business needs and incorporate a plan to reduce the carbon footprint of their facilities by contributing in three key areas: design creativity (delivering system that pushes the conventional); quality systems (provide high performance solutions tailored to clients' needs); and, affordability (incorporate lean in manufacture and site delivery and also, quick and simple to install).

In order to achieve its sustainability agenda in the provision of low energy building solutions for its clients, CS-Gamma recognises the need to continually engage with innovative construction technologies. Accordingly, the company has committed internal resources to, and emphasis has been placed on, nurturing a continuous flow of new and cutting edge construction technologies as enablers in the most highly efficient design, manufacture and installation possible. BIM is perceived to play a central part in helping meet the company's strategic goals. This was emphasised by a Technical manager when he stated that: "*here at [CS-Gamma], the application of BIM is a key driver behind our philosophy to provide the best service for our clients.*" [Th-R]

6.5.1.2 Research Participants

As discussed previously in section 4.7.2.3 the data collection protocol is grounded on the collection of rich qualitative data within the case organisations by conducting semi-structured interviews, participants' observation and documents analysis. In line with this data collection strategy, the engagement with CS-Gamma continued for nearly eleven months from April 2012 to March 2013.

Observational data including work processes were gathered through field notes. Throughout the observations, the central emphasis was on the sorts of practices that were being performed, how the various intra-organisational units were attempting to transform their practices by incorporating collaborative BIM technologies into the existing practice and what came out of this. Documents collected included BIM implementation strategy, and internal communications, including written policies, procedures, meeting notes and documented BIM case study projects. Overall, eight in-depth interviews, as well as a number of informal interviews lasting between 60 to 120 minutes were conducted with senior and middle

managements. Interview questions were designed to gather information regarding BIM approaches, challenges to BIM implementation, and strategies for improving the implementation. Interviews were tape recorded and later transcribed verbatim and analysed as discussed in section 4.7.2.4. The profiles of the organisation’s personnel who were interviewed for the research are presented in Table 6.6. Additional information was also obtained via informal discussions with technical team members and management staff during the time the researcher spent in the West-midland offices of the company.

Table 6.6 Description of CS-Gamma personnel that participated in the study

No.	Name	Title	Gender	Years of working experience	Number of interviews
1	Ma-J	Head of Design & Engineering	Male	13years design and engineering management	1
2	Th-R	Technical Manager	Male	9years CAD/CAM engineering	1
3	Jo-F	Commercial Director	Male	30years commercial/contract management	1
4	Pa-G	Technical and Sales Manager	Male	9years business development	1
5	Ma-P	Project Manager	Male	10years design and engineering	1
6	Ch-W	Marketing Director	Male	22years B2B strategies and implementation	2
7	Do-W	Technical Manager (Structural engineer)	Male	5years structural design	1
8	Ro-M	Technical Manager	Male	4years business development / solar energy	1

All the eight personnel have different, yet, relevant professional backgrounds and years of experience. One of them is head of the design and engineering department, two of them are directors, and five of them are managers in various capacities. Also, the design and engineering team is based in the Midlands office, where this research was conducted, and they provide technical support including BIM technology deployment to other corporate departments situated in other locations. With such background, any information obtained from the respondents is considered very useful in portraying a clear picture of the company’s BIM implementation processes and consequently, how BIM solutions are mobilised in shaping the operations of the organisation can be deduced from such information.

Following this brief introduction of CS-Gamma and the personnel that contributed to the research, the section continues to present the findings of the third case study. The following section traces the evolution of BIM in CS-Gamma.

6.5.2 Tracing the Evolution of BIM at CS-Gamma

Heralded by CS-Gamma as the future of the construction industry with the potential to change every phase of the construction process, the company recognised the need to quickly replace CAD with BIM as the preferred design and construction management tool. A technical manager opined that not too long ago, companies expected standard minimum proficiency in the use of Microsoft office applications from current and new employees. Likewise, BIM competencies for AEC firms will probably, if not already, be looked at much in the same way, “just as part of doing business”: the company’s position and goal for BIM was explained by a director:

“The company views expertise in BIM processes as an extension of our people’s skill set. Our goal with these roles is to fill a need in developing BIM competencies for our construction professionals in order to maintain a strong market position.” [Ch-W]

The above statement indicates that in order to maintain its market position as a large manufacturer of building components, the organisation identifies the need to evolve with the changing times by maintaining full compatibility with evolving software platforms and its product range and staff competencies.

A technical manager also explained that building components manufacturers have traditionally been producing printed catalogues to help designers, consulting engineers and contractors in their decision-making processes. The introduction of BIM requires manufacturers to raise their game beyond the conventional catalogue-based approach:

“It is no more glossy brochures but delivering the geometry objects into BIM libraries over the web that meets the requirements of BIM users.” [Do-W]

The above phenomenon is influenced by the fact that having readymade model objects that are accurate, up to date and customisable to suit a particular project helps designers and contractors to realise the full potential of BIM through greater efficiencies of time and data coordination. A technical manager also insisted that designers and contractors in BIM-enabled project environments require object geometries (products information) in set formats (e.g., specification, cost information, graphical and warranty information) to help them make

supplier/manufacturer choices, and also to make design and construction decisions, per project requirement. Manufacturers and fabricators of products for the construction sector must therefore take into account the changing needs of their customers who are now demanding product information to be published in new ways.

CS-Gamma acknowledges that the adherence to this new product innovation could become a key differentiator in sales between the non-BIM and the BIM-enabled product manufacturers. This means that well-structured digital information will be needed for all manufactured products as the way forward. Whether the product is displayable in a 3D format (e.g., boilers, tiles, sanitary appliances and partitions) or not, (e.g., paints and wall papers), the technically rich product specification data, when available in a BIM library can be intelligently linked into project models.

The head of the engineering department insisted that the critical aspect of the BIM journey is the use of offsite manufacturing and replication of components for faster, easier and safer site installation. Nevertheless, the BIM agenda in the current situation is driven by technology and design which does not reflect the reality of the construction process. Clearly and significantly, BIM should be seen not just as a design tool, but also, as a tool for the entire construction management process, from design, through manufacturing and construction to handover and operation. A deep understanding of the entire process that transcends technological determinism is essential to deliver the optimal solution. The head of BIM also argues that perhaps, the debate has to widen, out of necessity, to include the other disciplines that are often left behind, such as SME specialist contractors, facilities managers, cost managers, products suppliers and manufacturers. It still remains unclear as to how work and management would be different when working within BIM projects or supplying building components to a BIM project team. Having done its 'homework' and being convinced of what to do as the way forward, the company's management was aware that there were real opportunities for building component manufacturers who invest in BIM to show market leadership and also, relish competitive advantage.

In the current situation, BIM users require generic objects, natives to their preferred BIM platforms, and also object components available in the market and developed by different manufacturers. The product manufacturers wanting to utilise BIM thus have to develop their own libraries of products as complete BIM objects and be made available on the web libraries

to those creating and using models. CS-Gamma therefore sees the incorporation of model objects in a BIM library as the manufacturers' product catalogues of the BIM future.

In early November 2012, the company was recognised by NBS as the first manufacturer to prepare its products as BIM objects for inclusion in the National BIM Library. Currently, a lot of its products have been launched onto the web platform. In order to make its product available to a broader network of users, it was launched as openBIM file formats in the IFC format and also available in the four main BIM platforms including Bentley, ArchiCAD, Vectorworks and Revit Architecture. Each of the objects is embedded with product specification, pricing and warranty information. These innovative solutions help the organisation enhance its position and popularity among BIM-enabled designers and contractors. With an extensive product range, the company is however working toward ensuring the whole product range is available online to wider group of BIM users via BIM libraries for download into different BIM applications. CS-Gamma thus provides a useful perspective of the components' manufacturer and modularisation view of the BIM process and how imperative it is to stay ahead of the competition, and contribute to the upstream supply and installation demand of models' components.

6.5.3 Mapping the Inter-Organisational Sociotechnical Constituents' Relationships in CS-Gamma

Beyond the influential drivers for BIM implementation, the analytical framework developed in Chapter Six has indicated that successful BIM implementation is influenced by a sociotechnical constituency alignment. The nature of the alignment is a multidimensional one, depicting the influences of the primary organisation, the project-level goals and pursuits and the exogenous factors that impact on the work system. The STS analysis in the organisation is discussed under three main themes: 1) organisation-level BIM alignment strategy; 2) multilevel BIM alignment strategy; and 3) mobilisation of BIM solutions on a project. Each theme is discussed and illustrated by extracts of the respondents' statements.

6.5.3.1 BIM Appropriation in CS-Gamma: Organisation-Level BIM Alignment Strategy

BIM utilisation has extensively been discussed in academic literature, there are also a wide range of BIM platforms for use by designers, consulting engineers and construction professionals in the mainstream construction practices such as in the design, analysis and

coordination. A technical manager however believes that, amongst the supply chain, construction product manufacture is one of the areas that best practices have not been fully identified and where the least amount of BIM strategies and R&D have been shown. A need therefore exists for strategies and tools to be developed to support product manufacturers to integrate within the BIM schema.

Training and support structure: CS-Gamma was particularly keen on integrating BIM into existing traditional roles. The company believes that depth of knowledge in the tools alone is not enough. As a technical manager put it, it is more about “*problem solving, working in a team, and a sense of exploration.*” [Th-R]. Those are the qualities expected from the BIM users because the technology keeps evolving and the organisation is “*constantly pushing the envelope.*” Thus, the key to success is the understanding of the construction workflow and processes as well as the proficiency in the use of the software. Not one or the other, but both. A technical manager emphasised this by cautioning that:

“Some BIM experts are great with BIM software but really don’t know how contracts work or cannot read drawings. Let’s get one thing straight; having construction business experience is absolutely essential to being a valuable BIM person.” [Ro-M]

The above comment suggests that expertise in BIM without actual construction work experience is not seen as overly valuable in the organisation. As a manufacturing firm that deals with multiple types of AEC projects, CS-Gamma does not believe in having BIM expertise with “stand alone” experience. The company’s strategic plan is to integrate BIM in engineering roles, project management, commercial management and other production techniques and processes:

“We are working to integrate BIM skills into field engineering, factory production, commercial roles and project engineers.” [Ch-W]

In addition, the company is investing significantly into increasing in-house BIM skills via actively cross training estimators, schedulers, engineers, PMs, and site operatives to be able to deliver BIM in different project situations. The design and engineering department is charged with the responsibility of facilitating the growth of BIM expertise in the company.

HRM strategic role and action plan: It was made emphatic in CS-Gamma that, training alone is not sufficient. The head of the engineering department believes that due to demand-supply deficit of BIM experts there is currently poaching going on among competitors,

calling for the organisation to develop a comprehensive employee retention strategy. Thus getting staffing infrastructure support in place is very critical.

The simple fact is, there is more of a demand for BIM guys than there is a supply so if you treat your guys well, they will be happy where they are and they may not be enticed to leave with probably a 15% salary raise.” [Ma-J]

The above phenomenon calls for the company to review its HR policy with respect to BIM. A technical manager deplored that with the conventional setup, people often stop learning after they start working and the HR departments have a vague approach to managing people. Often when a hire is made for a particular position, the HR managers never review or update the skills and ability of the employee as he matures in the position. However, with BIM, people have to adjust with the times and try to get ahead of the learning curve as the BIM tools evolve and develop as emphasised by a director:

“If you ask CAD managers or a project manager what the company expects from them moving to BIM, do they know how their performance equate with their counterparts in competitive organisations? How about Human Resources issues? Is reference made about staff retention by increasing talent development metrics or some other cocktail of values? [Jo-F]

From the above narrative, clearly, in order to properly develop BIM proficiency and employee retention, especially the best, well trained and experienced ones, Human Resource (HR) actions are preeminent. This presents a base for projecting the importance of HRM within the organisation. Part of the preparation for BIM implementation within CS-Gamma includes awareness and education of employees about BIM and bringing best practice examples into the organisation. Technical competencies, work processes, and BIM tools which the workforce are to grasp in order to engender BIM implementation success are well documented in the design and engineering department. This information is used to develop roles and requirements. Once the HR team has the information of roles' expectations, it then develops a model that helps in the decision making about training programme, leadership development, and performance assessment criteria.

Based on the description of roles, the HR department creates a competency profile for individual positions that progress through different levels and expertise. This is then used to communicate general responsibilities and expectation to employees. It also becomes a benchmark so when employees or teams are underperforming or need knowledge upgrade,

the HR team can provide insights to the management team to help them implement corrective actions. It is also used by the HR to target competitive salary based on performance. The role and competency profile of staff has a dramatic impact on the workforce as well as the organisation because it establishes the expectations of and the career path forward for the workforce and it also shows how the workforce can contribute to the company's strategic plans while sustaining employee retention.

6.5.3.2 Multilevel BIM Alignment Strategy

Different alignment strategies were adopted by CS-Gamma to develop and maintain relationships with external BIM constituents. The analysis of these various strategies has identified three main areas:

- Relationship with NBS National BIM library: for creating the products as smartBIM objects and hosting them in a web-based BIM library
- Accreditation from and endorsement by reputable building regulations and standard bodies as the basis of specifying product quality in the BIM library.
- Technical and practice-based supports for external supply chain organisations (approved suppliers and installers) that do not deem it viable to implement BIM by their own volition.

Each strategy with the different constituents, their involvements in delivering the company's BIM agenda, and how that influences the BIM trajectory in CS-Gamma is discussed, and is illustrated by extracts from respondents' statements in this section.

Hosting of CS-Gamma's products on a BIM objects web portal: The mainstream BIM platforms are oriented around generic native object that exhibit the properties and behaviours of their real world counterparts. The challenge though, has been to get the manufacturers of building components to provide more specialised BIM-ready objects for designers and products users. CS-Gamma has come to a realisation that if manufacturers include their product specifications into a 3D BIM object, the object could provide realistic information, as well as saving the design office from having to model it. As more and more construction professionals are becoming aware of the government's level 2 BIM mandate, manufacturers that provide BIM libraries of their products to the AEC community are much more likely to be nominated or used.

There are a number of BIM component suppliers who are operating in the UK such as National BIM Library (NBL), BIMstore and BIMObject. These companies are global players providing free downloadable BIM components of manufacturers' products from their web portals to designers around the globe. CS-Gamma nominated National BIM Library to produce intelligent 3D objects of its products in a variety of formats (ArchiCAD, Revit, Bentley, Tekla and IFC), supporting 2D details and 3D sections with material properties and specifications.

During the course of this study, there was a more ambitious plan in CS-Gamma to author all of its products in a web-based BIM library. For a start however, all of its factory-made pre-insulated building envelopes for floors, roofs and walls have been authored as BIM objects as shown in Figure 6.14. These products are authored in the BIM library with a comprehensive range of technical literature for designers, engineers, contractors and end users. The literature contains clear advice on typical design, design considerations, thermal properties and site installation guideline. The 3D objects are available to download from the NBS BIM library with a complete manufacturer's manual. The BIM platform is designed to provide fast, accurate technical advice on the web. The hosting package with the NBL is subscription based and subject to annual renewals.



Figure 6.14 CS-Gamma's range of authored BIM objects

The BIM library also provides benefits to subscribers from a managed account, such as content update, marketing support and easy access to products manufacturers. After the products of CS-Gamma have been launched in the BIM object portal, the company gets access to analytics and marketing statistics that show how many of its BIM components are being used and designers can send queries via the portal on issues such as performance and

prices. A technical manager emphasised that, the company is “*committed to customer service and satisfaction*”, and the creation of BIM objects ensure “*predictability of costs, programming, and in use performance.*” thereby mitigating defect risks. [Ro-M]

Product quality specification in a web-based BIM library: A technical manager acknowledged that it is not enough to ensure that the company’s product range in the BIM libraries are reliable and perform to expected levels without providing any evidence to users. This is why the company seeks certification from independent reputable bodies that promote competency as described by a technical manager:

“...registration under such schemes provides reassurance to any architect or contractor that the products are delivered but subject to a rigorous independent assessment process.” [Ro-M]

Due to the above realisation, the company has been monitoring developments in building regulations and standards to ensure that its solutions are matching or exceeding best practice. Hence each product solution in the BIM library is backed by Building Regulations and Standards such as the BREEAM (Building Research Establishment Environmental Assessment Method). The company is also certified to ISO’s management quality system standards, and thus, all its products are manufactured and installed to ISO 9001 quality assurance. These endorsements are specified in the BIM library to assure users and designers of the products’ quality.

Support for approved suppliers and installers: Out of necessity, the BIM implementation protocol was widened to include other organisations working for or on behalf of CS-Gamma. The company has two main supply chain partners that ensure that its range of construction products are distributed and installed across the UK. They are: 1) Stockists (qualified and approved suppliers/distributors) and 2) Specifiers (qualified and approved installers). A director asserted that many of these supply chain partners are SMEs who may not, by their own volitions, implement BIM and accompanying work process changes without external support. Thus, the company has developed training and support packages for all its active supply chain partners. “*We actively seek to promote awareness of our policies and procedures to everyone working for or on behalf of the company.*” [Ch-W]

The training encompasses theoretical and practical workshop on new developments in the industry and related work process changes. Beyond the regular awareness workshop, the

company also provides comprehensive technical advisory services for specifiers and stockists during bidding and installation phases of projects:

“We assess our design, the suitability of our product as well as installation compliance with regulations and detailing, this is all to provide clients, consumers, and specifiers, the assurance when buying or installing our products.” [[Ro-M]

By providing more efficient support and maximising the level of ability to offer designers, engineers and contractors, via its trained suppliers and installers, the company hopes to maintain a healthy and rewarding customer relationship, overall a winning situation.

6.5.3.3 Mobilising BIM solution on a project

CS-Gamma was involved in the development of a £85 million public sector project located in London. The client set out a clear project brief of achieving an outstanding BREEAM rating. According to a technical manager, in order to achieve sustainability status as high as BREEAM outstanding, a minimum ‘A’ rated Energy Performance Certificate (EPC) CO2 (water) index of 25 (0 is carbon neutral) must be obtained, and the product range from CS-Gamma could contribute in meeting those targets. Because of CS-Gamma’s strategic business objectives, it has a strong reputation for green buildings and porting its product information in a public-domain BIM-object library means that architects and engineers can easily compare and validate its products specifications with other competitors’ products and make a quick and valid judgement. CS-Gamma was nominated by the architect, in consultation with the design and build contractor to assist the design team in providing the best solution for the building envelope, comprising the walls, roof and the floors that meet the BREEAM requirement and also to supply and install these design outputs.

One of the key drivers for the specification of CS-Gamma’s systems was the company’s ability to create object models of its energy efficient products in a format compatible with different BIM platforms. The project was designed as a mixed-use building, providing office space for the council workers. The facilities also included a library, arts exhibition building, shops and a eating space. The design drawings were produced with Autodesk Revit. CS-Gamma’s engineering team was able to take the design information and develop it to a standard that meets specifications prior to factory prefabrication by the production department and site installation by the specifiers.

The relationship among the project level BIM stakeholders are discussed under three main headings: deliverables and lines of management; contractual strategy; and, appropriation of BIM tools for multipurpose solutions

Project deliverables and lines of management: In order to achieve the client’s ambition of BREEAM outstanding rating, willingness and a strong level of commitment from the client, main contractor and the other contracting parties was needed because particular objectives needed to be met at the design and construction stages. A project manager emphasised that, collaborative working, integrated project team, innovation in design, product selection and delivery mechanism, and clearly defined contractual arrangement were some of the criteria that had to be met in order to bring a project of that scale together.

CS-Gamma’s factory-tapered insulated roof boards were specified by the project architect to form an important part of the project’s energy saving performance. It ensures low heat loss through the roof, as well as preventing the build-up of rainwater, which can subject the membrane to thermal stress, alkali formation and mould growth. Also, as part of the exterior wall build-ups, insulated dry-lining plasterboard was installed. The case organisation’s pre-insulated building fabrics were a key part of the design solution, allowing the building to achieve outstanding thermal performance amongst other energy saving measures. Because CS-Gamma was appointed during the design phase of the project, it became part of the design team at an earlier stage and communicated directly with the contractor and the architect during the development of the project’s coordinated model, as mentioned by a director:

“It was a hybrid design that incorporated our thermal panels into innovative modular frames which we designed and developed at an early stage.” [Ch-W]

This design scheme was crucial to bringing the building envelope up to Passivhaus standard to minimise heating and cooling requirement.

The project was contracted under design and build contracting, thus, the design and build contractor was responsible for driving the design and construction process. The project team’s organogram is shown in Figure 6.15. The line of communication and the chain of management are illustrated in Figure 6.15 to reflect the relationships amongst the various functional units of the project stakeholders.

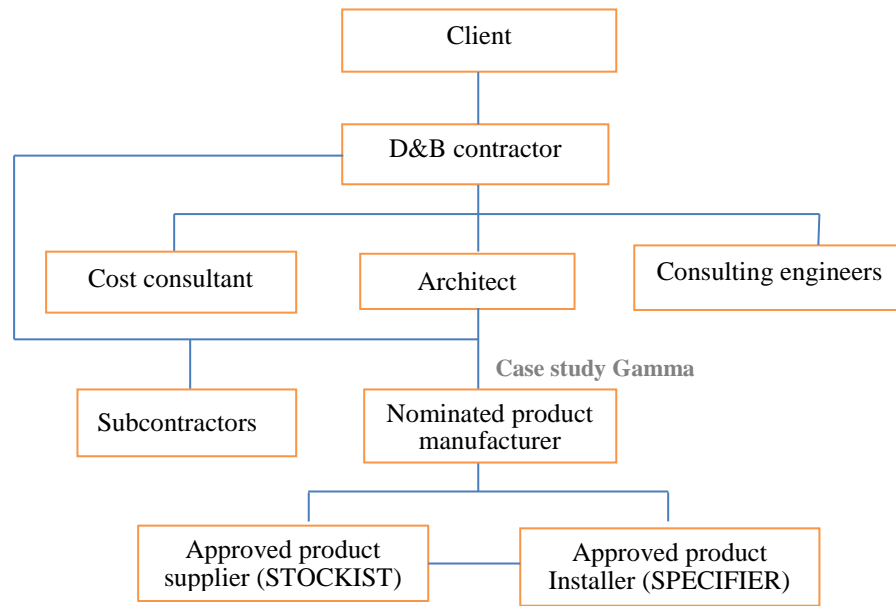


Figure 6.15 Functional structure of project Gamma's organisation

BIM project contractual strategy: The project stakeholders were contracted under the JCT Design and Build contract (JCT DB 2005: rev-2: 2009). According to a commercial director, collaboration among the design team through the construction phase is important for the project team, which the JCT DB framework provides. A bespoke provision in the contract states that the team will use “*all reasonable endeavours*” to assist the employer achieve the BREEAM requirement that has been expressly set out. This clause allows the parties to carry out the project in a way that is most effective to achieve the project's ambitious targets.

CS-Gamma became a key member of the design team from the outset and used the client's brief of an “outstanding BREEAM” requirement as the basis for designing an energy efficient building envelop solution for the roof, floor and the wall. The company's engineering and technical service division took the design and structural models plus the technical specification from the project's consultants and refined them to produce an accurate manufacturing model in compliance with regulations and the project specification as mentioned by a technical manager. It is the duty of the CS-Gamma's technical team, who share an open workspace, to provide technical support for clients; the team also provides onsite technical installation and design support for the local erecting team:

“We helped ensure the timely co-ordination of all design principles to ensure the client's critical requirements were met.” [Do-W]

The completed design information was incorporated with other federated models by the design team into composite design information. This became the basis on which all the specialist contractors developed their detailed production and fabrication models and acted as a useful map for each of the team members to see how their part of the work fits in the overall coordinated design: *“it allows us to thread the building without interfering in other people’s space.”* [Ma-P]

On the basis of the coordinated models, detailed production drawings were generated for the building envelope to be manufactured. The site installation was undertaken by the company’s construction partner with site logistics support by an approved stockist and an assigned technical manager. Because BIM objects were created from the design information the factory-made pre-insulated panels were able to clad the building in a reduced time compared with the time it would take for onsite individual build-up of material components.

“The ease of installation meant that the erection was successfully completed in a period of just over five weeks and because the panels were factory-measured and pre-cut it allowed simple onsite installation with minimal waste.” [Ma-P]

The site installers were able to make the building enclosures watertight at an early stage in the build process, allowing the internal trades to progress their work at a faster rate than usually possible.

Guided by its contractual obligation and the expanse of its work package, CS-Gamma developed an eight-page bespoke manufacturer’s terms and condition (T&C) of sales and installation which was seen as a binding contract, and addressed pertinent issues, including: issues of realistic timeline for design, manufacture, site-delivery and installation; product warranty; and contract sum and payment terms. The drafted T&C was bespoke, that took into consideration the project requirements.

Appropriation of BIM tools for multipurpose solutions in CS-Gamma: A director narrated that one of the things they had to do at the initial stages of the transition to BIM was to identify the BIM software products that were appropriate and could augment the workflow:

“Typically, it will be ourselves using drawings from architects, engineers and services design to develop our technical drawings, so at the very basics, we looked at what software we were going to use, and what versions we were going to use for our works.”

[Ma-P]

The above statement indicates that CS-Gamma's range of manufactured products is used by different construction professionals with preferences of different BIM platforms. Besides, the company's BIM objects in web libraries are designed as openBIM thus they are accessible in the IFC format and formats compatible to ArchiCAD, Bentley, Revit and Vectorwork products. Clearly, in order to widen its market opportunities, the company's preferred in-house BIM tools have to be compatible with all the mainstream BIM platforms, thereby meeting the requirements of its multiple clients. The IFC compatible format ensures that the customers can upload or download the company's objects of their choice into any specific BIM platform or coordinate them together with other disparate IFC-compliant models with a collaborative tool such as Solibri or Navisworks.

Another criterion for the selection of the BIM platforms was for the teams to work on a centralised intelligent system with parametric integrity, thereby coordinating the works of the disparate knowledge boundaries. The company has five functional departments that include: design and engineering; commercial; planning; production; and customer service department. Each of the various departments uses different BIM applications that are more appropriate for their work context. The company's workstations are thus configured with various BIM platforms that support design operations, object model creation, editing, and modification. The industry-neutral IFC format is used to facilitate the workflow from design, procurement, offsite manufacture, and onsite installation of the company's range of building components. The IFC enables collaboration via easy transmission and generation of data across the departments. Figure 6.16 presents an overview of how the various BIM tools are configured to assist in the workflow of the various departments.

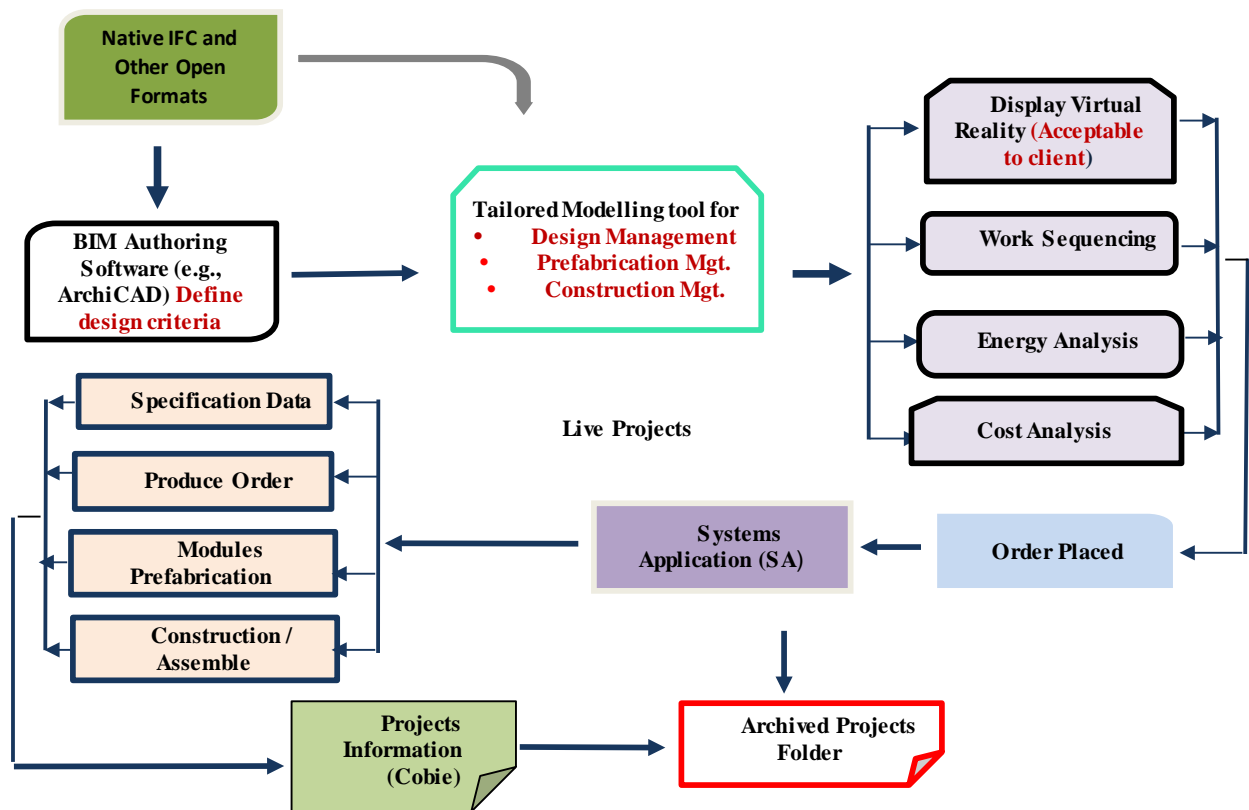


Figure 6.16 CS-Gamma BIM workflow

The organisation’s BIM platforms are oriented to the specific workflows of each department. The tools serve purposes such as modelling, producing drawings, energy analysis, coordination, fabrication, generating specifications and quantity takeoff for costing and/or scheduling. For instance, when there is a tender enquiry, the design and engineering team, made up of architects and engineers, translate the project requirements into a fully coordinated BIM model. The model provides information detailed enough to enable the commercial team to price for the works, so does it allow the engineers to develop energy simulation and the architects to display 3D virtual walk-through and sequencing. Upon a successful tender, the design team reuses the coordinated model by extracting production drawings, fabrication model and other data from it, in order to augment the construction process.

The organisation established relationships with different external BIM vendors to help incorporate technical competences and artefacts into the various internal functional units. To receive technical support from its BIM software vendors as and when needed, CS-Gamma initiated an ‘accreditation appraisal scheme’ that guarantees that any new system upgrade would be recompensed with staff competency training so that staff would be consistently up-

to-date with the use of the selected BIM platforms. Another critical technical consideration was the upgrade of the company's computer workstations. The head of the design and engineering department maintained that, corporate configuration of computer networks was critical to ensure uniform application of BIM across the business. The specific computer workstation requirements of the business were based on the recommendation from the company's preferred BIM product suppliers.

6.5.3.4 Summary of sociotechnical constituents' alignment strategy of BIM implementation processes in CS-Gamma

The summary of CS-Gamma's BIM implementation alignment strategy is depicted in Figure 6.17. This illustrates the build-up of CS-Gamma's BIM rollout and it shows the configuration of institutions and mechanisms aimed at nurturing and establishing BIM-enabled work processes across the inter-organisational units. Fundamentally, there is a divide between the core organisations' BIM strategies and the project-level BIM delivery strategy. This is where the value of mapping the STC alignment comes into play to trace and mobilise influencing constituencies outside of the immediate case organisation. The alignment is therefore embroiled in both the intra-organisational constituent of CS-Gamma and its interconnectedness with the broad institutional contexts which influence BIM deployment. Whilst the success of BIM deployment depends on the alignment of the goals and perceptions of the actors with CS-Gamma's goal and vision, human factors are difficult element to manage. This research revealed that the BIM implementation process is fraught with difficulties due to misalignment between the perceptions and pursuits of the interests of industry members.

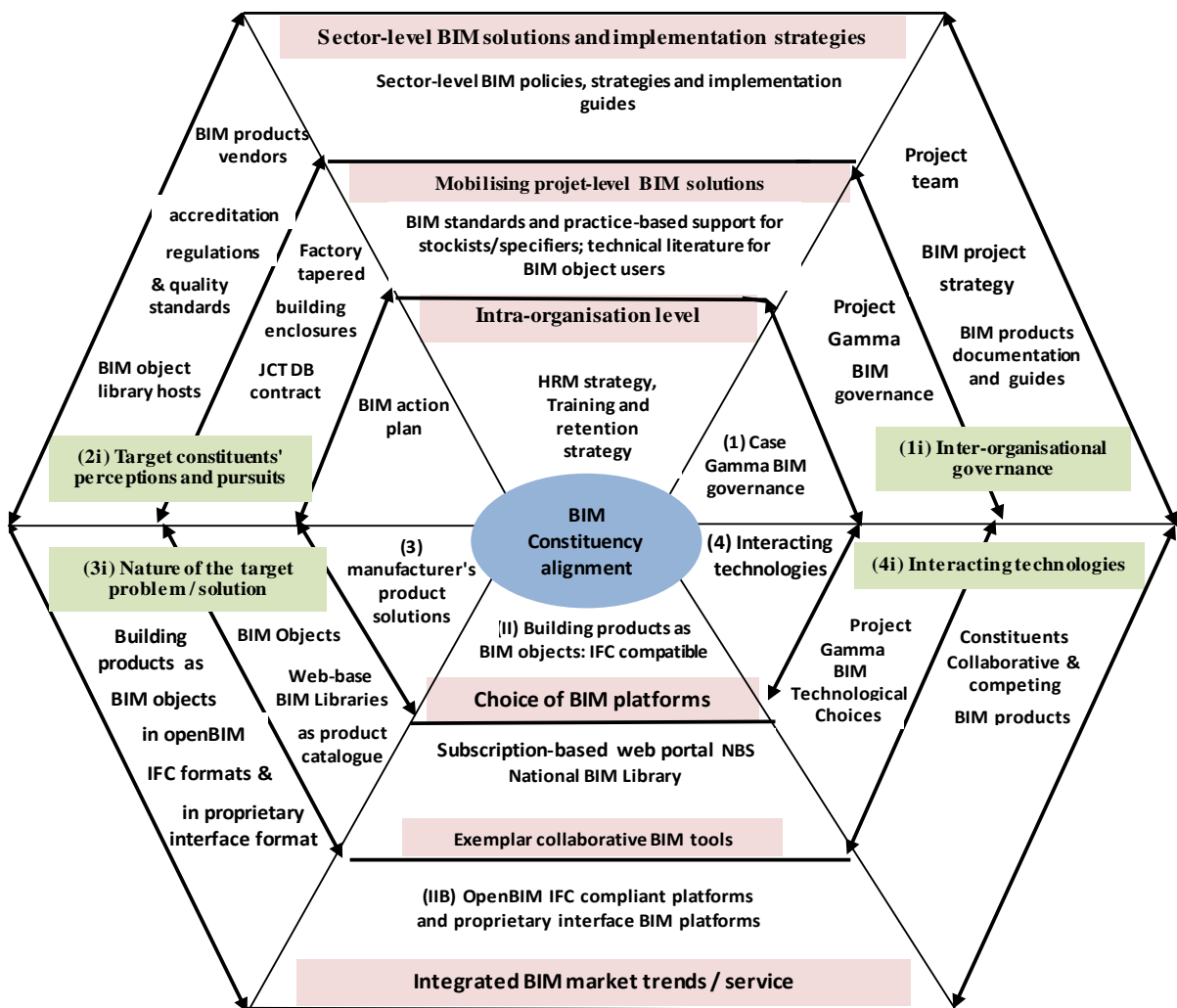


Figure 6.17 Inter-organisational sociotechnical constituents of BIM uptake in CS-Beta

It also revealed that BIM deployment would have a better chance of success if an alignment of the visions, interests and pursuits among the major actors in the constituency can be sought and the implementation process targeted to the most appropriate expertise, resources and areas of concern of the major actors. The difficulties of the BIM rollout process in the context of diversity of organisational interests and patterns of interaction are discussed in the next section.

6.5.4 Challenges Associated with the BIM Implementation Process

This section presents the findings on the challenges faced by CS-Gamma throughout the process of implementing BIM within the organisation. These are discussed under three main groups: 1) Complexity in creating object models; 2) Maintaining a reasonable file size of complex curved object geometries; and 3) Challenges with trainings and employees’

retention strategies. The section discusses each of the challenges and CS-Gamma's approach in addressing them.

6.5.4.1 Complexity in Creating Object Models

CS-Gamma's products are created as BIM objects and held on web libraries for designers and consulting engineers to port and overlay as building data models onto their geometry-based project models. This enables the users to achieve a significant increase in information quality. The concern however remains that, the geometry-based 3D models and the product data embedded in the objects are time consuming and challenging to create. A technical manager explained that, unlike the catalogue views of product display that have only glossy images of their products, the BIM objects are supposed to carry a high level of detail of product and model properties, realistic views of the item in plans and elevations and correctly rendered objects in views and animations. Also, the objects are expected to be compatible to the BIM platforms that are popular to the industry practitioners.

As the data available from the objects include all kinds of real-world specifics about the object, if the company develops a new product or there is a product amendment, this calls for the objects in the web libraries to be amended or updated accordingly. Thus, ultimately, as users download a BIM object into their models, it will represent the digital and functional characteristics of CS-Gamma's actual factory-made products.

The options for CS-Gamma are either to manage the BIM object creation in-house or via the external hosting organisation. Each alternative comes at a cost. Currently, the company is working in parallel with NBS National BIM Library who creates and maintains a variety of BIM objects for different products manufacturers in the web library. NBS expertise in the BIM object market provides assurance for the case organisation.

“There is no one fixed solution for creating good BIM objects. To get the best results the process also involves considering both the needs of the manufacturer and the needs of the objects users.” [Th-R]

To ensure optimum accuracy, the company worked with NBS to gather the corresponding 3D images of the products supposed to be authored into the web library. Using these files, various geometric profiles were produced and then assembled to create the required smartBIM objects.

“The objects were created based upon both trial and error on the modellers’ side as well as regular reviews with us [CS-Gamma] to ensure that we were representing the products correctly and to the level of detail that was important to the architects who would ultimately use them.” [Ma-J]

This statement suggests that the object creation required a significant amount of thought and experimentation to overcome the limitations of the array data structure.

Another challenge, according to a technical manager is for the company to honour its commitment to BIM by developing its complete range of products into BIM objects. By November, 2012 the company created its first BIM objects with five different sets of its insulation products. As at July, 2013, the BIM objects had increased to over thirty, covering a range of insulated building envelopes and raised access floor systems. Nevertheless, there are other products yet to be created as BIM objects, as stated by a technical manager:

“One of the challenging areas now is how to migrate all the products into BIM object libraries and maintain the existing ones...” [Th-R]

This is challenging because, CS-Gamma’s range of building products are many, and the existing object models diverge quickly to suit market trend. These changes always lead to a cascade of other modifications that have to be done to existing smartBIM objects. Without these modifications, the existing objects libraries will suffer from lack of consistency or accuracy.

6.5.4.2 Maintaining Reasonable File Size of Complex Curved Object Geometries

To accurately represent building components as BIM objects, NBS utilised CAD files and products documentations from CS-Gamma. However, from the outset, it was found that building exact details of the object geometries was a big contributor to large file size, slow performance and a bad experience for users. The objects modellers had a hard time representing all the detailed curves in an architecturally acceptable format down to a reasonable file sizes. Most importantly, when engineers and designers download the objects into their project folders, the objects should not be seen to occupy unnecessarily large memory space. This implied that the modellers had to build the objects in an acceptable size as explained below:

“This forced us to limit our model size as much as possible, and we redraw and constrained very complicated and redundant families as much as possible, this helped in alleviating a good portion of the file size.” [Ma-J]

Another interesting acknowledgement was that, some of the BIM applications are able to operate large file sizes than others. For instance, the Revit families were seen to get very large when containing more complicated object models as there are more native family objects loaded within the software. Also, other BIM products that contain in-memory systems such as Vectorworks and ArchiCAD can encounter problems with large object files by running significantly slow when too much demand is placed on the hardware, unless the files are managed on external systems such as the Delta BIM Server.

Despite the challenges encountered in creating the BIM objects, a director reckoned that the responses and clients’ reactions were worth the effort:

“The response has been excellent. Traffic has increased to the company website and the number of downloads of objects are significant along with a lot of interests in our other products. Architects are impressed with the objects and that confirmed we took the right approach.” [Ch-W]

This statement suggests that designers that rely on BIM objects for their project models influence the company’s decision to develop the smartBIM objects. Also, existing models upgrades and new objects creation that meet market demands may likely be the way forward. This decision differentiates CS-Gamma from other competitors who may not have taken the necessary steps to meeting the needs of BIM users.

6.5.4.3 Challenges with Trainings and Employees’ Retention Strategies

Not too long after creating the necessary smartBIM objects with the company’s products, it became clear that the products innovation was stimulating revolutionary changes in most aspects of the organisation’s processes; from training through HR management to external relations. The creation of the BIM objects of its products necessitated a change across the entire spectrum of work at the organisation-from design and engineering, through the commercial team to production and the site team. Some of the key organisational challenges which acted as impediment to BIM implementation, and ultimately strategies had to be devised to address them were:

- People often did not have the motivation to continue learning for self-improvement, once they were in employment.
- The HR department had a vague approach to managing people, and relied on “*some cocktail values*” for motivating, training and retaining existing staff.
- External supply chain partners (approved suppliers and site installers) did not have the same motivation as CS-Gamma to upgrade their systems and expertise to incorporate BIM, because of the efforts and the finance required.

In order to deliver high quality BIM products and services, it was recognised that the company had to train and retain BIM competent individuals. As mentioned earlier, one of the biggest changes was behavioural change in employees’ learning habits. According to a technical manager, one-off training is not enough because the BIM tools are continuously being improved, thus the company ensures that the skill-set available is continuously assessed and work is put in towards maintaining consistent knowledge across time.

One challenge the company did face, initially, was the disconnect between the HR practices and the human resource needs of the different departments-to the extent that a technical manager described the HRM as creating some “*other cocktail of values*” [Ma-J] irrelevant to the present training needs of the workforce. However, one of the noteworthy decisions was the company’s strategy to ensure that the HR department was fully involved in the decision to develop and sustain a BIM competent workforce. In order to derive the most from the investment in BIM, the HR team liaised with each of the departments in creating high-level business goals with respect to improving knowledge development and increasing staff retention via performance-based competitive rewards and training opportunities. These are targeted at the relevant needs of employees and their job requirements. The HR department is now the pivot through which skill development and new recruits are organised within the company; managing BIM training programmes, leadership development, and performance assessment criteria of all staff across each department.

Another key challenge was with the external supply chain partners who distribute and install CS-Gamma building products across the country. These companies are mainly SMEs. The transition to BIM by these organisations initially, did face some resistance-there was scepticism regarding the ability to deliver smoothly the desired quality of output, the lack of time and resources to update skills and systems while working on projects was a major challenge. To make the transition relatively easier, CS-Gamma organised a training and awareness workshop for its supply chain members. The technical (design and engineering)

department has a dedicated team who went about educating the supply chain members on pertinent issues which included; operating the smart object library; organising BIM workflow; compatible BIM platforms and vendor licensing acquisition; and computer workstation upgrades. The workshops were aimed at bridging the learning gaps as well as showcasing the smart-objects created with BIM to help motivate them to shift to BIM. These workshops provided clearer understanding and encouraged BIM implementation across the supply chain organisations.

6.5.5 Summary of CS-Gamma

The section has presented the findings of the third case study conducted at west Midlands with a large energy efficient building envelope manufacturing firm. The background of the CS-Gamma was firstly presented in section 6.5.1. This included the organisation's objectives and description of personnel that participated in the study. The evolution of BIM in the organisation was discussed in section 6.5.2. The driving force for implementing BIM in the company could be attributed to different factors including: to enhance its position and popularity among designers and contractors; to show market leadership and relish competitive advantage; and, BIM object libraries replacing the need for glossy products catalogues and new products trade shows. The inter-organisational constituents' influences in the BIM implementation process in CS-Gamma was presented in section 6.5.3. This section also addressed inter-organisational work relationships as BIM was introduced and mutated through the supply chain. These included: the hosting of products as BIM objects in a web-based library; HRM strategic role and action-plans for training and sustaining high level staff retention; and supports for approved suppliers and installers with their BIM uptake. Following this, the project-level BIM implementation strategy was also discussed, encompassing BIM deliverables and lines of command amongst project stakeholders, contractual strategy, and appropriation of BIM tools for multipurpose solutions. Finally, section 6.5.4 presented the challenges associated with BIM implementation in the organisation. These were grouped under three main categories, including: complexity in creating object models, maintaining reasonable file sizes of complex curved object geometries; and challenges with trainings and employees' retention strategies. The next chapter (7) presents the cross case analysis and analytical discussions of the findings revealed in the three case studies.

CHAPTER SEVEN

7 CROSS CASE ANALYSIS AND VALIDATION OF THE RESEARCH OUTPUT

7.1 Introduction

At the end of the exploratory investigation in Chapter Five, the study sets out a sociotechnical constituency framework on which to hang the empirical analysis of the case study organisations. Three case study organisations, and their approaches to implementing BIM were observed and the individual results presented in Chapter Six. Following the analyses of the findings from the case studies that were presented in Chapter Six; this chapter looks at the differentiations amongst the case study organisations as they transform by the appropriation of BIM solutions and reveal a range of antecedents that influence these transformation and differentiation. The chapter is structured into five main areas of discussion. Section 7.2 highlights the organisational differences and similarities with regards to BIM implementation in the three case organisations. Section 7.3 discusses the sociotechnical antecedents that drive the implementation effort amongst the organisations. Section 7.4 describes the key findings emerging from the cases. Analytical discussions are made in section 7.5 to highlight the implications of the key findings to the extant theories and the existing BIM policy mandates. Following the cross-case analysis that highlights emerging issues from the case studies, section 7.6 presents the findings of the evaluation of the research output. The summary of the chapter is presented in section 7.7.

7.2 BIM Implementation in the Selected Case Study Organisations

The three construction organisations studied, implemented BIM to help resolve a variety of construction challenges they have experienced. Accordingly they subscribed and appropriated the use of different BIM platforms applicable to their specific needs and organisational objectives. They also experienced different problems, and realised different benefits through the implementation process.

Nevertheless, there are some common drivers and denominators amongst them. BIM as a construction innovation process and as part of conglomerate technological products is seen in relation to a broad vision of construction transformational changes being driven by wider market forces such as government policy mandates, technological changes and clients'

demands. BIM is also viewed to propel widespread “root and branch” reforms in the AEC sector. For instance, one BIM manager described that:

“It [BIM] is a wholesale change in all respects [...] new processes, new training required, new mind-set required, new possibilities, different ways to communicate, different ways to collaborate, different outcomes, everything is different. It is a game changer.” [Ma-B]

There was a broad consensus on the intensity of change as a result of implementing BIM. These shared notions position BIM as a critical advancement beyond the bounded drafting system to an unbounded innovation with the potential to coordinate diverse information spanning different knowledge boundaries. Nevertheless, the case organisations diverge when the practicalities of implementing the existing BIM platforms and the specific organisational contexts are considered in tandem. As a major UK contractor, CS-Alpha was particularly keen on integrating its project information in a central BIM repository. It hired an external BIM consultant and set up an in-house BIM team to expedite the implementation process across its regional offices. CS-Beta, being an SME specialist firm, was critical of initial investments and the positive return on investment (ROI). It particularly subscribed to “an all-inclusive” deal with Tekla for software provision and systems installation, training and technical support and annual systems upgrades and renewals. CS-Gamma on the other hand, wanted to make available its range of smartBIM objects (representing its building envelope solutions and insulation products) online for designers to freely port and integrate into their design and production models. Table 7.1 summarises some of the main similarities and differences between the three case study organisations in terms of expertise, visions, key actors, BIM artefacts and challenges encountered in the BIM implementation processes.

Table 7.1 Similarities and differences between the case study (CS) organisations

Criteria	CS Alpha	CS Beta	CS Gamma
Specialist field	Large construction organisation	Small specialist firm	Large building components manufacturer
Application areas	Building infrastructure development – lead contractor, project supply chain management and site installation supervision	Structural engineering design consultants (Primary and secondary steel design and fabrication). Design development of production and prefabrication drawings / models	Energy efficient building envelope solutions. Project-specific bespoke design, factory-made and site-installed
Main vision	Develop BIM competency and Achieve efficiency in managing and integrating data in a central database	Develop an operational BIM-based design and construction work environment;	Develop a web-based IFC-compliant smartBIM objects accessible on a web repository;

	for constructability and project management; Obliges project actors to access and contribute to BIM dataset model	Validate and maintain integrity of design information thereby augmenting project transparency	Continuous objects development to reflect current products and to accommodate market demand in a loosely coupled systems
Primary actors	In-house professionals; External consultants; project supply chain;	In-house professionals; subscribed technical and product supports from selected BIM vendors	Different departments; approved supply chain (stockists and specifiers); web-based object developers; consumers;
Primary BIM artefacts	Hardware – vendor-specified compliant workstation. Software – Autodesk proprietary solution such as Revit, Buzzsaw, Navisworks, BIM 360 field	Hardware – vendor-specified compliant workstation Software – Tekla structure and add-on solutions e.g., Tekla and BIMsight	Hardware – vendor-specified compliant workstation. Web-based BIM object development and hosting infrastructure. IFC compliant smartBIM objects
Challenges encountered	Collating multidisciplinary federated models into a coordinated whole Downstream supply chain partners bypassing ‘agreed’ platforms for a range of other competing BIM platforms	Preference of Tekla products and licence agreement limits the ability to coordinate with other range of BIM platforms	Need to occupy ‘reasonable’ computer memory space limits LOD in smartBIM objects Not able to create detailed product specific BIM objects due to limitations of existing software

In comparing the three organisations, several significant antecedents which contribute to the roles and functions of BIM in each context were revealed. Some inherent aspects of BIM were imperative across all the organisations, such as the reliance on IFC for the exchange of data between models, and also, the use of collaborative BIM platforms (e.g., Navisworks and Solibri) to integrate disparate models was also obvious in each of the case organisations. On a more individual level however, some antecedents were more situated or context-specific, such as the visions and expectations from BIM, context-specific practices, existing organisational conditions and sociotechnical constitution of each organisation. To discuss these in detail, the next section looks into the sociotechnical antecedents in the case study organisations.

7.3 Sociotechnical Antecedents of BIM Implementation

In considering the specific activities or artefacts that constitute the sociotechnical antecedents of BIM implementation, the intricacies of exactly how connections between technological artefacts, people, uses and contexts are formed and reconfigured become crucial. The idea of innovation assemblage, positioned as an outcome of multiple interaction and influences of physical artefacts and work systems elements in a seamless work, needs unpacking to see

what these influences are and the roles they play. The findings of the exploratory enquiry presented in Chapter Five reemphasised that BIM implementation in the construction context is sociotechnical in nature; requiring the implementation process to acknowledge the evolving antecedents of technological solutions and the associated change processes in the work context. The study has also shown that successful BIM implementation largely depends on the control measures put in place not only in the immediate work context, but also the project-level influences where the actual work usually manifests.

Due to the multidisciplinary nature of typical construction practices, it was revealed in chapter five that it is important to integrate STS requirements from MLP into the BIM implementation process. Accordingly, the exploratory findings thus revealed two key insights for the sociotechnical systems analysis of BIM implementation, comprising; 1) multilevel systems perspective that bridges the intra- and inter-organisational sociotechnical influences; and 2) the creation of alignments between the sociotechnical systems constituencies. The alignment describes the compromises, accommodations and social and technical interaction which underlie the constituency building process. Molina's (1998) STC stresses the point that no single constituent alone can augment the development and appropriation in inter-organisational sociotechnical constituents. Molina's concept embraces the MLP and the STS perspective to ensure that, not only social and technical antecedents are taken into consideration, but also, that divergent organisational perspectives are acknowledged, appropriate compromises reached and subsequent actions coordinated.

One key challenge for the implementing organisations is the limited abilities to reconfigure and align inter-organisational relations without the support of the wider networks of developers, facilitators and users of the BIM platforms. Table 7.2 uses the STS analytical framework, developed in chapter five (Figure 5.5) to position the inter-organisational perceptions and pursuits across the three case organisations. The bounded innovation of the persisting conventional practices, such as paper-based CAD or BOQ preparation, grant individual firms control over their work. However, as an unbounded innovation, the conditions required for the utilisation of BIM coordinated platforms extend beyond the activities and the sphere of influence of single organisations.

A common factor between the case organisations, presented in Table 7.2 is that technologies are deployed within, and developed by, organizations which in turn are constituents of broader contextual arrangements. This was discussed earlier in section 5.3 using the concept

of sociotechnical constituencies and the process of sociotechnical alignment (Molina, 1990; Molina 1993; Molina 1998; Molina 1999).

Table 7.2 Inter-organisational sociotechnical constituents' perceptions and pursuits across the case study organisations

	Alpha	Beta	Gama
Constituents' perceptions and pursuits	Case organisations' perceptions and pursuits		
	Multiple intra-organisational professionals (e.g., PM, QS, planners, BIM coordinators), central corporate BIM team	Structural engineers, technical managers, contracts managers	Five functional departments (i.e., design and engineering, commercial, planning, production, and customer service)
	Project-level perceptions and pursuits		
	Multiple project supply chain team (e.g., client, design and engineering team, specialist contractors and suppliers)	Multiple project supply chain team members comprising the client, lead contractor, subcontractors and suppliers, architects and consulting engineers	In-house team (5 intra-departmental units), products suppliers and installers (specifiers and stockists), clients and smart-objects developers
	Macro-level perceptions and pursuits		
	Reliant on expertise from external BIM consultant to support the case organisation and also, project teams	Reliant on BIM vendor for training and technical support	Reliant on NBS smartBIM objects hosting system and standards issued by products accreditation bodies
Constituents' Governance	Case organisations' BIM governance		
	23page BIM strategy document drafted by in-house corporate BIM team	Organisation BIM strategy document; The vendor's product specification manual; Training and management support strategy	Web-based BIM library rules managed by external consultants; All products comply with open IFC standard interface
	Project BIM governance		
	Project BIM Execution Plan (pBXP) Project-specific BIM deliverables; Client's BIW documents management system;	BIM deployment plan, Project-level BIM working strategy; Design and build contract arrangement for the different functional units	BIM objects web libraries; Design and build contract arrangement for the different functional units

	Design and build contract arrangement for the different functional units		
	Macro-level BIM governance		
	Expertise from external BIM consultants; Cloud-base vendor-support system; BIM products specification manuals	Adherence to BS standards; BIM product specification manual	BREEAM and ISO 9001 quality assurance accreditation, energy performance certification (EPC)
Nature of Targeted problem	Case organisations' targeted problem		
	Lead-contractor for building infrastructure development	Structural engineering design development, production models and prefabrication details	Energy-efficient building envelope solutions and insulated products that comply with BS regulatory standards
Interacting technologies	Case organisations' interacting technologies		
	Open interface "mix-and-match" BIM applications to realise benefits of best-of-breed BIM solutions	Tekla product suites	IFC, Revit, ArchiCAD, Tekla, Bentley, BIMstore, National BIM Library, BIMobject
	Project level competing and collaborative technologies		
	Autodesk products suites to augment proprietary interface	Different BIM platforms compatible with the IFC and coordinated with Tekla BIMsight	Able to integrate with BIM platforms that comply with IFC format
	Macro-level competing and collaborative technologies		
	Range of integrating BIM platforms such as Bentley, ArchiCAD, and Tekla product suites	A range of collaborative BIM platforms	Competing range of smartBIM objects' library providers and BIM applications

The BIM uptake and the unbounded innovative activities which develop around it within the three case organisations are affected by a wider competing and complementing range of sociotechnical antecedents across the inter-organisational constituents. These include among others, the constitution of supply chain partners, constituents' competencies, visions and expectations, specific projects' activities and goals, and selection and appropriation of particular technological platforms. In many cases these antecedents not only impact on the implementation outcomes, but have the potential to impede on the original intents of the visions set out to attain. The case studies demonstrate the negotiations to enrol constituents in a sociotechnical constituency many take unexpected directions.

7.3.1 Different Contextual Antecedents, Visions and Expectations

One of the most intriguing things about the case studies is the variation in visions of, and expectations from, BIM applications which inform strategies for the implementation processes. These include, for instance, management of the case organisations and visions about the projects' operations, different actors and their expectations about existing practices brought from other practices and the developers' intents of the software. Although the study focuses on specific organisational contexts, the sociotechnical antecedents impacting on the BIM implementation processes do not necessarily or solely emanate from those contexts. They come from heterogeneous contexts but have effects among the intra or inter-organisational constituents. For instance, certain restrictions configured in some of the collaborative platforms to only interface with other proprietary platforms (e.g., the use of Navisworks in CS-Alpha), originate from the original intents of the vendor's development lab but were dictating the coordinative processes in CS-Alpha. For CS-Gamma, although the company's vision was a significant contributing factor in creating BIM objects for public use, but so were others. For instance, the technical experts from the NBS's web-based object hosting team reshaped the intended visions and expectations by creating objects that were technologically feasible and desirable for widespread end-users by toning-down the requirement of high-performance computing and high-speed networking.

The concept of inter-organisational perceptions and pursuits such as the inscriptions embedded in some specific artefacts serve to demonstrate how these visions and expectations set up tensions between not just different ideas of implementing BIM, but in effect, the appropriate competitive ranges of BIM platforms to be configured and utilised within a particular setting.

Different visions outline particular versions of expectations and influence decisions regarding what are the acceptable or unacceptable processes, BIM artefacts and configurations. The fragmentation of the construction industry has been attributed to the presence of these different functional skills that are needed in any single project. The case organisations thus show that different contexts and visions produce different assemblies of artefacts and shape both the artefacts and the environment of use. Similarly, Dainty et al. (2007) stated that each project is different in terms of both the product and the people involved, however, the diversity and fragmentation of the industry are due to various cultural values, processes and interests of diverse participating organisations in project delivery. Consequently, construction project environments have been described as multi-skilled and multi-functional requiring the coordinated efforts for effective performance. However, the current situation of the BIM vendor market does not particularly help matters with respect to the industry fragmentation. This is because the competing range of products does not support the integration of other applications and workflows through open interfaces. They rather maintain proprietary interface, thereby promoting individuals' market interests. Meanwhile, the various construction professions prefer different systems applications to meet individual work needs.

7.3.2 Comparison of BIM Technological Platforms' Selections and Appropriation Across Cases

There are finely grained variations for the selection and appropriation of BIM platforms within the three organisations. The way that CS-Alpha incorporated BIM protocols into its work practices, and for that matter, onto the project level, was not a simple case of selecting specific product solutions that aptly connected into the grand vision of the work system. It was as a result of developing practices and transforming artefacts based on negotiations between many juxtaposed visions across corporate constituencies, intertwined with priority setting for usefulness, professional identity, competency, product efficiency and ease of use to ensure sociotechnical alignment. For CS-Alpha, the original intention was at least to “mix-and-match” software tools to get a best blend of capabilities beyond what could be offered by any BIM suite from a single vendor. This ambition was however, overshadowed at the project level. The use of multiple ranges of BIM applications by the different supply chain partners has the potential of causing difficulty in interchanging project data with parametric integrity. The decision was therefore made to use a single vendor BIM suite in order to ensure proprietary interface of data exchanges. This suggests that different constituencies recognise

the interplay between what might be desirable and what is realistic or acceptable practice to incorporate into everyday technological or process configurations.

For CS-Beta, the BIM platform was seen as a design and product tool and formed an integral part of the working practices and organisational strategy. The organisation assessed the many different BIM platforms and settled on one that it perceived to be well-suited for structural design and detailing. Beta settled on Tekla, because CS-Beta was using Xsteel for structural design and detailing, which was one of Tekla's popular conventional steel design tools. Tekla structure thus represented an upgrade and improved BIM version of the Xsteel. In addition, for CS-Beta, Tekla was a modelling tool with native library files specifically designed for structural design and detailing (e.g., the use of CNC data for offsite automated fabrications), thus, suiting Beta's specialised field of operations. The main concern with Beta's strategy of configuring to one particular platform would be the lack of ability or the difficulty of switching to other equally efficient platforms.

For CS-Gamma, the need to meet different market demands was a key influencing factor in the selection and appropriation of BIM applications. Thus, the company's systems were configured to be compatible to the four major BIM platforms; ArchiCAD, Revit, Vectorworks and Bentley. The company's BIM library objects were also available in industry-neutral IFC formats. Gamma also sees the platforms as part of a strategy to model generic objects with accurate information of its range of building components and freely make this available to designers in a virtual space. This replaces the need for trade shows and distribution of glossy brochures to potential customers. Likewise, the actual products emerging from the original vision were a result of a negotiation between technological possibility and the expertise of BIM object developers coupled with the requirements of designers. As stated by a technical manager; the strategy initially, was to develop an exact digital replica of the company's physical products, with all the necessary features. In the end however, more 'modest' objects were developed, in a reasonable file size that would not be seen as occupying unnecessarily high computer memory space, also in formats accessible to a wider BIM user. This is done to increase the market patronisation of the developed BIM objects of the company's insulation products.

It is clear from this analysis that, the details of how BIM is appropriated in these distinct contexts generate practices which are unique to those contexts and are different from each other. And the motives influencing decisions regarding the selection and appropriation of the tools vary from each context.

7.3.3 Comparison of Intra-Organisational Support Structures across Cases

The process of working in a BIM-enabled environment requires construction professionals to re-skill in some areas to add to their own skill base. This signifies a reconfiguration of existing skills. The skills gained through mastering the technological platforms were directed towards fulfilling individual roles. Thus, the innate knowledge gained through the learning process remained with the particular individuals. In CS-Gamma for instance, the concern was that it was possible for trained experts to be tempted by better offers and go elsewhere, especially, as BIM competency is currently in high demand. Thus, the HR department was engaged to ensure that rewards and salary structure are highly competitive and commensurate with peoples' BIM competences and performance. Essentially, during the implementation period, the HR team was also reinvigorated, readily on-board to incentivise the focal team with the support they need.

In CS-Beta, people strategy was a bit different. The idea was to avoid the situation where BIM would be considered more or less, as a “bolt on attachment” rather than a language the entire company had learnt to speak and understand. Thus, the BIM concept was incorporated in the “syllabi” of the apprentices, engineers and senior engineers as shown in Figure 6.6 (training and management support structure). Opportunities existed for some form of skill sharing and transfer through “learning by doing” on the job for those less familiar with the BIM work process. A BIM coordinator opined that, aside the theoretical training exercises, practical BIM training is very necessary: *“you need to work on at least two or three projects...anytime I go back, it just gets better, and I am still getting better at it.”* In CS-Alpha, an in-house corporate BIM support team was on-hand to setup project BIM strategies and also, provide technical support for local BIM projects. Thus, the organisations learnt to align and transform practices through supporting activities like developing standard procedures, providing standard training and staff retention via performance-based competitive rewards and training opportunities. This underlines the importance attached to training and development and retaining core competent staff within the industry on BIM workflows.

7.3.4 Comparisons of Inter-Organisational Relationships and Multilevel Innovative Assemblages across Cases

There are variations between possible ways of using BIM across different organisational contexts that aim at developing practices which make use of the BIM solutions. The cases

reveal how three distinct construction organisations envisioned a need for BIM uptake and appropriated different BIM solutions to fulfil these needs. Appropriation of BIM solutions across the case organisations involves the transformation of different technological artefacts through negotiations between different visions and expectations. In fact, in most instances, the functions and development of BIM processes such as smartBIM objects in CS-Gamma were actively negotiated and constructed as they were incorporated into new sociotechnical practices and into external project fields of other organisations' visions.

The visions and the artefacts are not particularly immutable or fixed. They are transformed as new knowledge is acquired. As pointed out by Geels & Schot (2007), the diversity of approaches to a problem yields more robust solutions. Suggesting that, there is something to be learned about the effects of interdisciplinary efforts, and innovation assemblage beyond the proximate of the implementing organisation. Thus, the process of decoding previously precluded actors' knowledge, information, visions and so forth, in a way that exposes them for debate, interpretations, discovery and development allows the concerns to scale sinuously between local contexts to the universal generalisations. As visions are eventually narrowed, the principles of BIM processes are jointly developed and the technological choices and uses become standardised or more fixed. Four main issues are discussed under this theme:

- BIM work processes
- Contractual protocols and obligations
- Inter-organisational team structures; and,
- Common data environment (CDE) and information sharing protocols

7.3.4.1 BIM Work Processes

There are various BIM working processes established in literature including the government's adopted BIM strategy (discussed in section 2.7.2.1), Succar's BIM capability stages (discussed in section 2.7.2.2) and the ten-stage maturity model (discussed in section 2.7.2.3). There are also protocols for collaborative information exchange, the Cobie format for information management and handover to clients, and Penn State University's standard practices for BIM implementations. These have been discussed in chapters two and five.

None of the case study organisations intuitively followed the existing standards in the pursuits of their BIM agendas. In all the three cases, organisations are introduced to the BIM work protocols on individual basis. The individual organisations settle and continue to follow the BIM work processes in the manner in which they are introduced, provided it fits into their

work context and contributes in their particular organisational and professional niche. The interesting observation in all the cases is the fact that the BIM work processes are never cast-in-stone in all the cases. The processes were twisted and amended as deemed fit.

CS-Gamma solicited the technical expertise of an external BIM consultant who helped draft the company's BIM strategy, provided training, configured computer systems and helped established an in-house corporate BIM implementation team. One of the key organisation's initial BIM implementation requirements was to adopt the best-of-the-breed BIM platforms in order to realise optimum functionality which otherwise could not be achieved by relying on a single or limited BIM platforms. This strategy reflects the government's level-3 BIM strategy which consolidates team objectives by ensuring optimal design solution via integrated lifecycle delivery. This agenda was however downgraded at the project level, when reality confronted CS-Alpha's BIM team. At the project level, CS-Alpha's BIM delivery process and integration with other external stakeholders could, more appropriately, be described as proprietary rather than an open-BIM interface.

CS-Beta constrains its abilities to a single BIM vendor and acquired a license to use that vendor's BIM product-suites subject to annual renewal. The vendor also provided technical training to staff, systems support, and maintenance agreement. CS-Beta's ability to share or exchange models with a wider project network thus, is dependent on the vendor's compliance to the IFC open data exchange format. CS-Gamma on the other hand, solicited the technical expertise of web-based BIM object developers to develop its building components into 3D object geometries with parametric integrity and launched these on web libraries for easy access by designers and contractors. The library objects are available in formats compatible with the mainstream BIM platforms-this is to encourage widespread download and integration into project models (as discussed in Chapter Six, CS-Gamma).

Rarely mentioned by the case organisations, but perhaps, important to the BIM implementation processes is the size of organisations. Large organisations typically have more slack resources allowing the space and scope to experiment and innovate than smaller ones (Barrett & Sexton 2006). The importance of resources for innovation can be seen in CS-Alpha and CS-Gamma for employing external support team with a mandate to develop BIM strategy and the subsequent involvement in developing BIM strategy in the case of CS-Alpha, whilst CS-Beta, being a small-size firm, restricted to the expertise of a BIM products vendor.

Another intriguing observation was that none of the three organisations inertly set out to follow the patterns described in the BIM maturity capability stages outlined in the Government's BIM strategies. Each of them assessed their particular needs and developed processes tailored to their needs and organisational niche. This supports Bijker's (1996) assertion that technological innovation is not a black box when it mutates between the realm of development and the social context where it is appropriated. There is therefore the lack of a single definitive way of appropriating BIM artefacts in any particular context. Every team ensured that its interest was protected, especially in financial and contractual terms. Collective responsibility manifest among the members only in a situation where there was incentives in the contractual framework to steer towards particular work process. Observed in CS-Alpha for example, some integrated team members used the contractually agreed BIM protocols and tools retrospectively within contractual limits and for the mutual benefits of the interdependent team members - while relying on entirely different BIM protocols appropriate to their in-house internal works and site production. This underlines an industry in which working attitudes are depended on financial motives and the fulfilment of contractual obligation. Integration of teams that operate within construction contexts, will involve a change in attitudes and perceptions to focus more on the need to complement and co-operate with each other to deliver an acceptable project to client. This opens up the argument as to whether any particular BIM work protocol alone can lead to the appropriation of BIM without the necessary contractual obligations and incentive to support the implementation efforts.

7.3.4.2 Contractual Protocols and Obligations

It was discussed in chapter two that contractual forms by which projects are regulated have the potential can facilitate or constrain BIM implementation. The exploratory investigation in chapter 5 also revealed that contractual and legal considerations are required on several fronts to augment the rollout of BIM across construction project organisations. Especially, the reliant on some standard collaborative processes and protocols by the team to guide work relationships in a BIM-enabled inter-organisational work environment was seen to be a prerequisite. Standard contract document provides a useful point of reference to the construction practitioners and can acquire the status of managerial procedure manual guiding the key parties throughout the project delivery processes.

The cases have shown that within any project team structure, the governance of the organisations that make up the constituency is very important. All the cases studied were

governed by some form of a procurement strategy which encompassed clearly written rules highlighting contractual obligations and expectations. CS-Beta's BIM project was procured as design and build contract. CS-Beta however, did not influence design decisions from the onset as it tendered for the project at RIBA stage F. The contract obligation for CS-Beta was design-development, where it was required for it to further progress the specialist work package from RIBA stage F to full design, fabrication, site installation and commissioning. CS-Beta was not communicating directly with the top hierarchy of the project team as it was contracted by the M&E contractor thus reporting directly to the M&E contractor from the tail end of the organisational structure.

Like CS-Beta, CS-Gamma BIM project was also procured under an amended version of JCT design and build (JCT D&B 2005). But unlike CS-Beta, CS-Gamma was procured directly by the D&B contractor from the outset, thereby influencing key design decisions regarding the drafting of technical specifications for energy efficient building envelope solutions for roof, floor and wall that warrants and guarantees the achievement of BREEAM excellent rating. CS-Gamma, thus was a key member at the top of the management hierarchy throughout the design, fabrication and construction phases of the project.

On the other hand, CS-Alpha's BIM project was procured on the traditional design-build option with the lead contractor taking up design and management responsibilities. Bespoke clauses were however, included into the contract, one of which restricted the teams from using the BIM models for any other purpose other than to consider it as construction issued drawings. This was to prevent any of the parties from using the model as the basis of raising contractual concerns as it was a work-in-progress. Both parties had not particularly developed a full understanding of the model (with regards to its development and use) and the BIM work relationship was nascent to all parties. Further, the defect and liability period was extended to three years instead of the usual one year, effectively, granting the client three years warranty, during this period, the contractor was liable in ensuring that the virtual models and the actual build components corresponded effectively as designed for the operations and maintenance phase. This could mean two things: first, it highlights the continued existence of suspicion and lack of trust among member organisations of the project delivery team, or 2) it protects the client from the associated uncertainties and risks with the BIM technological solutions as they are nascent and pretty much evolving.

The bespoke clauses attached to the main conventional contracts witnessed in all the three cases call for the mainstream professional institutions such as ICE, RICS, and RIBA to

develop more standardised contractual frameworks that are appropriate for BIM projects and address the key concerns that the various parties may have. Also, the tall hierarchical structures undermined the requirement for the use of integrated project personnel and the early incorporation of key subcontractors as advocated by the IPD framework and earlier discussed in chapter 2. The IPD emphasised that the higher the level of integration of team members in the early design stages, greater the opportunities to get maximised benefit out of BIM.

7.3.4.3 Inter-Organisational Team Structures

It was discussed earlier in Chapter Two that flexible organisational structure, in which each element in a hierarchy is connected to every other element immediately above and/or below it, might be more appropriate for BIM workflow as it provides greater flexibility and improved communication. The types of organisational structures observed in all the three case studies were functional but tall. To a large extent, the functional structure suggested that roles and responsibilities were spread across the functional expertise of the inter-organisational teams and individuals. This configuration is expected as the project team selection criteria are based on specific professional skills and expertise.

CS-Gamma had a multi-functional intra-organisational structure as five different in-house departments were performing different professional duties. The relationship with the outside organisations (e.g., clients and designers) was established on a digital BIM object repositories where sales terms and conditions of a range of BIM objects, standard specifications and installations terms and conditions were predefined. Direct contact and information-sharing protocols was established between team members through the repository. Sharing of the collective knowledge and expertise was required in achieving the overall inter-organisational projects' goals and ambitions. In CS-Gamma therefore, responsive order was easily maintained and there was no obvious boundary between senior management and those at the bottom of the hierarchy as the web-based repository acted in coordinating the different interests. However, CS-Alpha and CS-Beta had a tall inter-organisational functional structure. This distanced those from the top of the hierarchy to those from the tail end of the hierarchy. This does not reflect the less rigid functional structure that augments high-level skills integration as advocated for BIM projects in Chapter Two.

The long hierarchical structures existing in the team organograms do not help some team members, especially the tail end trade-contractors to integrate into the project team. There

were also no attempts to engage them in site coordination meetings as they were almost always represented by the lead contractors at the top of the hierarchy. This was evidenced in CS-Alpha and CS-Beta. In CS-Beta for instance, the case organisation had to follow a time restricted procedure to issue the right information to the M&E contractor prior to site coordination meetings - as there was no direct access to the lead contractor by the case organisation, but via the M&E contractor. This management structure could not prevent information flow to and fro the targeted sources without distortions. In order to facilitate BIM project delivery, the traditional hierarchical and functional structures have to be overshadowed by more flatter, cross-functional ones for the purpose of increasing teamwork, enhancing communication and building trust (Nicholas 1994).

The organisation structure witnessed in the cases, in relation to the ideal structure discussed in literature speaks of an industry that is very comfortable working alone and in a fragmented manner. This impacted on the level of interactions that occurred across the various teams. In CS-Alpha for instance, the bi-weekly coordination meetings were kept to a single representation from each specialist team, that is, a representative from MEP contractor and consultant, architect, client, structural engineer, quantity surveyor, etcetera.

One key condition that caused a tall structure to be maintained in the cases probably could be attributed to the size and number of different organisations represented on a typical project. The supply chain team, from the top down to the tail end of the hierarchy working on these projects were too large that, it was virtually impossible to have full representation for the coordination and other site meetings. This underlines the difficulties faced by project delivery teams in bringing all the teams together in a lateral communication structure and line of command. Nevertheless, all the three case studies have an effective means of communicating and sharing of information via the cloud-based BIM repositories where information is distributed and assessed simultaneously by the team members. The essence of BIM is integration and teamwork that combine technological solution, skills and knowledge to design, construct, and operate facilities. Each of the trades have public folder in the web-repositories for uploading and sharing their validated models for coordination. This highlights the important relationship between the BIM concept and organisational structure. The issues of information sharing protocols and data integration are discussed in the next section.

7.3.4.4 Common Data Environment (CDE) and Information Sharing Protocols

Data exchange protocols and access to information is a key requirement in a BIM working environment. Each of the organisations defines different processes for projects collaboration and efficient data-sharing protocols. Models interchange and information access among the various BIM users follow two fundamental systems configuration approaches; open IFC format and using common native file extensions (proprietary interfaces). CS-Alpha follows the latter while CS-Beta and CS-Gamma follow the former. CS-Alpha relied on Navisworks to interrogate and coordinate the federated models from the different practitioners. Thus, all the other team members were contracted to use BIM platforms with file formats convertible into Navisworks cache file (.nwc).

For CS-Beta the team decided to use platforms that comply with the IFC rules to interrogate and coordinate the different models. Thus, the BIM tools that were used on the projects such as Revit, Tekla, Synchro, and QTO, all comply with the IFC rule. The situation in CS-Gamma is somewhat similar to CS-Beta. Being a construction product manufacturer, CS-Gamma subscribed to a BIM web portal to introduce its range of BIM objects to the design community across the world. The objects, which were compliant with the IFC file format, were freely available to download. Sale enquires, objects' downloads and order placements are tracked on the portal. If the BIM web portal become popular with the design community, and are patronised by a widespread users, CS-Gamma foresees the situation where there would not be any more need to promote its products in glossy brochures and tradeshow.

All the three organisations relied on cloud-based digital repository to distribute and share model information. CS-Alpha used two systems; Buzzsaw was used by the project team, and it contained separate information folders for all the trade contractors, while the client subscribed to BIM 360 field to track progress and as also to collect as-installed digital information. CS-Beta relied on Tekla's Web Viewer to share information while CS-Gamma subscribes to the NBS' national BIM library to host and distribute its range of smartBIM objects. The presence of the dedicated web-based systems in all the three case studies is necessary to ensure uninterrupted access to information. This is important if the sociotechnical constituents are to allow a simultaneous access to project information irrespective of location and reinforces the point that effective integration is enhanced when the complementary skills and knowledge are shared on a common data repository. The merits and demerits associated with the use of both the proprietary interface and the open IFC interface have subsequently, been discussed in chapter 2 and 6. The IFC format is considered

as still going through the developmental cycle thus, some files, especially, parametric exchanges are lost as models are transferred from one platform to another. Also, the proprietary exchanges have a limitation of not able to support the use of best-of-breed BIM solutions as a variety of the BIM tools may not be able to fit into a proprietary platform.

7.4 Discussion of Key Findings of the Cross Case Analysis

The results of the case studies provide three examples of strategies, policies and practices involved in an attempt to implementing BIM. There are some interesting findings attributed to this study. The findings suggest that the concept of BIM is seen as an important means of improving construction performance. Also, public policy mandates, individual firms and clients' efforts to request BIM services, technology vendor and R&D institutions are acting as a gravitational-pull to driving the BIM implementation efforts. Due to this, there is now a heightened awareness, than before, of the need for construction organisations to actively seek better approaches, better processes and new technologies in delivering projects. Nevertheless, there are disconnects between policy drivers, organisational BIM strategies, the technological products and the idiosyncrasies of the construction organisations. In evaluating the results of the case studies, five main observations can be extracted. Table 7.3 provides a summary of the findings and recommendations that were drawn from the case study analysis.

The insights gained from the STS theoretical analysis and the empirical observations suggest that the introduction of technological artefacts is not a value-neutral innovation that is just appropriated by an organisation. Rather, the artefacts are viewed as non-human agencies that translate and are translated throughout the implementation process. Essentially, it is not just a matter of implementing technological artefacts, but crucially, the translation of ideas and techniques packaged into a black box that will eventually be divulged to become an active part of a sociotechnical assemblage (Orlikowski & Iacono, 2001). As a result, there is a need for an on-going translation process which will determine the success or failure of the implementation process. The process of introducing technological artefacts into construction organisation is a process of constituency formation in which different constituents seek to persuade others to become enrolled and promote the acceptance of their views of the ways particular tools should be mobilised to resolve identified problem. In this instance, the artefact itself is one of the prominent sociotechnical assemblages involved in shaping the constituency. The implementation effort, thus, is contingent on mutual translation, in which different actors with different insights mutually define each other through negotiations and persuasion. The ongoing translation process is exemplified by Aslıgül Göçmen and Ventura

(2010) who found that the issues of organisational coordination and conflicts, management support, and data standards and integration can inhibit or enhance the use of collaborative technologies.

Table 7.3 Summary of findings

Findings	Implications
The introduction of technology is not a fixed or innovative-neutral entity which are configured into existing organisations	The process of BIM implementation should be seen as a seamless web of innovation assemblage in which different actors seek to persuade others to accept their choice of a product, solution to a problem or a way of working
Proposed changes to organisational practices are intrinsically political	Constituents require a well-articulated explanation of why to enrol artefacts and people who will, in turn, augment the change in the work system. Promote the constituents to generate sufficient momentum to confront change resistance
The technological platforms are inscribed with different ideas that may not be accepted by the different users they are designed for	During the appropriation process the inscribed ideas of the technological platforms change according to the influences of different users based on their own ideas. Once translated, the use of the technological platforms may also yield different outcomes from the initial idea
Each of the construction organisation coming together to form a constituency enrol in a unique capacity with distinct expertise, role, visions and tools	The BIM technological platforms that is capable of inter-linking the various constituency members and their federated artefacts stand a better chance of acceptance and use
A prospect for change management: the transition to BIM involves a change in role, processes and a progressively shared dataset with an emphasis on interoperability via open format and proprietary format	The BIM uptake is accompanied by organisational change, mainly focusing on disruptions to existing practices, people and technological artefacts

Persuasions and negotiations are required in an attempt to inscribe use of BIM artefacts within constituencies, with intrinsically political intents to it, unless all users are in agreement. To understand the implementation of BIM solutions, one should focus on the appropriations of the ideas and techniques contained within the tool, not the implementation of the tool itself. Just as the users in the constituencies bring their own ideas, politics, roles definitions, responsibilities and agendas, so do the selected BIM software tools. It is unrealistic that all actors will pick up and align their interests with a new innovation as artefacts or processes may not have a dramatic immediate effect, but a gradual effect over time. Law (1992) argues that the translation process is ongoing, rather than being achieved once and for all. Therefore innovative assemblage that mobilises a combination of different sociotechnical elements is important for generating sufficient momentum to confront resistance. This assemblage

requires a well-articulated explanation of why and what is necessary to enrol actors and artefact that will, in turn, change work practices and bring anticipated solutions. While being willing to accept translations from other actors in the constituency to further promote appropriation, the core organisation must maintain the original project goal. Importantly however, every one of the project actor need to be able to understand what transpires and why, otherwise they may perceive the changes in the constituency as inconsequential or a threat to their own practices. This situation is well documented in CS-Alpha, in which substantial number of subcontractors enrolled different BIM platform other than the recommended Revit suits onto the project.

The case studies also demonstrate that BIM software packages embody different ideas that may or may not be accepted by the potential users they were designed for. These ideas are inscribed in the software artefacts and form the basis on which the lead constituent sets the requirements for the entire sociotechnical constituents. The translation process involves gaining important feedback based on experiences from different users where the feedback is enrolled or is fed into the work system. During the translation process however, the inscribed functions of the technology change according to the influences of different users based on their own ideas. Once translated, the use of the technological platforms may also yield different outcome from the initial idea. The case studies provide examples of translation processes that show attempts to allow the translation of visions based on the capability of BIM solutions. In CS-Gamma for instance, momentum was not gained to develop exact object replica of its construction products onto BIM web libraries because the existing BIM platforms require significantly higher computer memories in order to achieve such a vision. Nevertheless, if CS-Gamma has been able to achieve its vision, the design community; the targeted users may consider such BIM-objects too unwieldy to run on standard computer platforms, but rather calling for the deployment of high-performance computing and high-speed networking.

The translation process may also present some risks and uncertainties. If the users of the technological platforms perceive the potential of the choices of the technologies as unclear for improving their current practices, they will withdraw and develop an attitude that may be difficult to change in the future, and/or they may pursue alternative direction in terms of technological choices. This situation was witnessed in CS-Alpha where attempts to introduce BIM suites from the same vendor aimed at promoting proprietary interface did not achieve full consensus and support from the manifold users. Moreover, BIM-enabled construction

organisations are made of distinct practitioners who are tasked with different roles and responsibilities within the work system. The appropriate technological software behaves as ‘unbounded innovation’ and is able to interlink the multifarious knowledge and intents, thereby forming a comprehensive whole. The better the collaborative BIM software can connect federated models, the better the chance of its acceptance and ultimate utilisation by the different practitioners.

Another key finding is the prospect for managing change. People attach themselves to a practice for reasons best known to them. Changing these habitual practices also requires a critical evaluation of the alternatives imagined to transform the existing practices (Binder, 2008). Oakley (2012) provided insights into the implementation of BIM in construction projects, by arguing that a BIM solution is not about the software, but more about the organisational change, with a focus on disruptions to existing people and processes. Oakley (2012) also discussed some serious reasons for BIM implementation failures that have little to do with the software, and everything to do with how fast the software is introduced and what impact it has on people’s current practices. Oakley (2012) then advised that having a change management strategy in place before the technologies are introduced is vital. This advice of management willing to champion the implementation of the innovation solutions was essentially missing from CS-Beta, and only partially existed in CS-Gamma. CS-Alpha on the other hand, elected to hire a team of BIM consultant to drive the initiative, but ultimately, formed an in-house corporate BIM team to sustain the initial successes. The in-house support team members were the ones that ultimately ensured that the entire organisation became conversant with the software and the processes it required. As the cases demonstrate it is neither simple nor technically straight forward to enlist management to champion the implementation process.

Oakley (2012) provides the J-curve shown in Figure 7.1. It shows the typical BIM implementation timeline, which begins with hyped expectations, then moves into a long learning curve, including organisational change processes and then gradually ascends to a realistic outcome. In other words, it signals a learning curve in the form of the expectations, the optimal, and the actual path towards BIM implementation.

The J-curve could be applied to any of the case studies presented in this thesis, and it portrays a picture of what many organisations expect/experience when implementing BIM (Mondrup et al., 2012). Oakley (2012) concludes that BIM conversations are always focused on the inscribed capabilities of the technological artefacts, but rarely on the “*softer issues like*

interpersonal dynamics, change management and organisational design.” While Oakley (2012) did not clearly articulate recommendations, literature points out that many people are resistant to change of any kind (Azhar, 2011; Weston, 2001; Ehie & Madsen, 2005), thus strong implementation management strategy is needed to confront sceptics by demonstrating the benefits of implementing BIM to them.

It is clear that there is a dearth of literature that focuses on evaluating the mutual translations between technological artefact and its surrounding actors that take place during the process of technology implementation in construction contexts. The case study analysis has shown that what may work for one construction organisation, may not work for another and vice versa. By following the translation process of BIM within a context, an insight can be gained into the dynamic negotiations, when and where barriers appear, how the constituents negotiate through them, and ultimately, transforming the constituency.

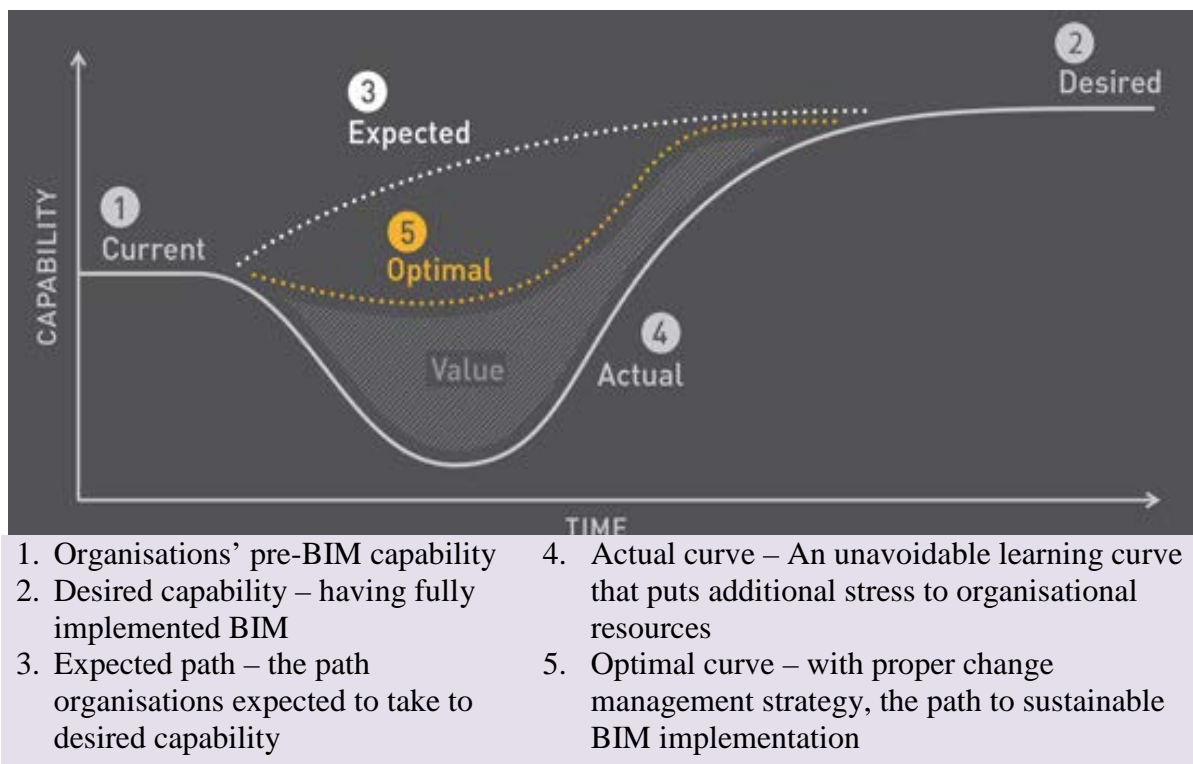


Figure 7.1 BIM J-Curve (Oakley 2012)

Even with plethora of research and investment in the development and deployment of BIM technological solutions within construction context, these BIM solutions have taken over a decade of continual translation between developers and users. As noted by Linderoth (2010), the first reports of the potential of BIM to transform processes in the AEC sector began to emerge in the late 1980s and early 1990s, nonetheless, it was not until the mid-2000s that the frequent reports regarding BIM utilisation within construction contexts started to emerge (e.g.,

Olofsson et al., 2008; Eastman, 1999). BIM products evolve in parallel with emerging technologies, thus the various BIM platforms are “constantly (often annually) upgraded” (Sackey et al., 2011). Even recently, Ilozor & Kelly (2012) have questioned some of the empirical findings regarding the purported benefits associated with the use of BIM on some projects and suggested a need for a more thorough investigations with respect to BIM’s potential positive impact on productivity, efficiency and positive return on investment. In reality however, BIM solutions and work practices are currently, being demonstrated, largely, in some pilot, mostly large projects (Oakley, 2012). Hence, it remains a rare approach in practical projects; therefore the benefits are not clearly well articulated and/or widespread. This is also reflected in the UK government’s strategy to mandate the gradual rollout of BIM on public procurement projects, from level 2 at the start of 2016.

These suggest that, the development of BIM artefacts and attempts to appropriate it into construction practices can be viewed as part of an ongoing translation process. The application of sociotechnical constituents’ alignment on the case studies make clear of two things: firstly, the process of introducing BIM into construction practices will always be subject to negotiations and compromises, and secondly, BIM platforms are unlikely to be used within construction contexts, exactly in accordance with the inscriptions embedded in the artefacts, and may not achieve the exact results as envisioned by the developers. In other words, users determine the path of technology, not that technology determines the path of usage. And these have some major implications to the current scheme of things.

7.5 Implications of Key Findings to Existing Theories and BIM Policy

Mandates

The inscriptions embedded in the BIM technological solutions are promoted as having the potential to streamline costs and processes, as helping different disciplines communicate effectively and to ensure little confusion on a job site - which may be rightly so. However, BIM implementation is not really about the technological artefacts. To get to what the artefacts are designed to achieve, organisations needs to cross the chasm separating the “utopian” design intents and implementation process. The implementation process, at least, within construction contexts has been shown to involve wrenching disruptive changes to the status quo, negotiations amongst multifarious sociotechnical constituents involving people, processes and artefacts. Thus, the extent of changes to the implementing organisations and the outcome of the implementation cannot be hinged on the inscriptions embedded in the original artefacts, but rather, on the negotiated outcomes of the multilevel sociotechnical

constituents - interpersonal dynamics, vision casting, change management and inter-organisational redesign. This then debunks the notion of technological determinism that holds the technology to be the impetus for utilisation and its utilisation with an organisation changes structures (Garson, 1999) which has currently entrenched the BIM implementation literature. The implications of the findings are discussed under four themes. These include: *Dynamic and emergent nature of BIM appropriation in socially-mediated contexts; disconnects between existing BIM maturity models and realities of BIM implementation; divergent visions between coordinated BIM platforms and the idiosyncrasies of construction practice; and government BIM policy mandates and realities of BIM appropriation.*

7.5.1 Dynamic and Emergent Nature of BIM Appropriation in Socially-Mediated Contexts

This study locates STS analysis of BIM implementation within three construction organisational contexts, specifically, across a large civil and building construction organisation, SME specialist construction firm, and a construction components manufacturer and installer as analysed in chapter six. This pattern indicates some important tenets for the study of innovative technologies in construction contexts. The first is the socially-mediated contexts in which BIM is appropriated and the second is the dynamic and emergent nature of BIM appropriation. The concept of appropriation is intended to account for the specific ways on which BIM platforms are incorporated and applied in different professional practices and institutional patterns.

The first overarching observation is that organisational consequences of the BIM rollouts are not unidirectional or predictable in their manifestation. This means technological appropriation in construction contexts is mutually constitutive and institutionally mediated (e.g. Orlikowski, 2000). This highlights the non-rational nature of BIM solutions as it is subject to socially constructed legitimating and rationalising forces that operate within and between different institutional fields. The AEC contexts where the BIM artefacts are deployed and the sociotechnical constituents' boundaries they cross vary from one organisation to the next. Recognising the contextual variation in the development of BIM implementation strategies as well as the expectations from such contexts are very important. This is because, the introduction of new technology triggers different responses and actions and different context requires appropriate implementation strategy befitting to that context (Knox et al., 2007). This marks the point of departure between well-defined BIM maturity

models which are influenced by the capabilities of the technologies but ignores the institutional translations and dynamics.

There is a reiterative relationship between the BIM products selection and appropriation in the different case study organisations that is fundamentally different to the well-structured BIM implementation strategies found in the literature. As discussed earlier in chapter three, the literature on BIM implementation appears to focus on dogmatic strategies and systematic standards and guides adoptable across every construction organisation contexts such as the BIM maturity stages (NBS 2012) and BIM standard framework and guide (Richards, 2010). This sociotechnical schism is echoed in Pollock & Williams (2010) who argue that the acquisition of technology is often attributed to exclusively social relativism or rational determinism across different scholarly disciplines. This research findings have however, stressed that technological determinism on the one hand, or social constructivism on the other, do not adequately capture the process of technological change (Kimble & McLoughlin, 1995). Indeed, Noble & Lupton (1998) have also emphasised that technological artefacts are reshaped into individual sets of meanings, and in turn, shape the work contexts where they are appropriated.

The second observation relates with the dynamic and emergent nature of BIM appropriation. Aside of the subjectively grounded and malleable approaches to BIM implementation, the accounts given by the three case organisations also reveal a picture of an emergent and dynamic nature of the 'innovation journey' (Van de ven, et al., 1999). Alexander (1989) indicates that implementation effort is an evolutionary process that manifests from interaction between controlling actors, the disposition of these actors, and the structure of policy. Within the organisations and inter-organisational constituencies, members have different roles and responsibilities and are accountable for the delivery of work, thus coordination is negotiated in the context of wider and often, unique organisational goals. Consensus thus becomes a significant variable within this dynamic BIM implementation scheme rather than a pre-plan arrangement. CS-Alpha for instance, adopted a phase-transition where regional offices are equipped with competencies to develop project-specific BIM requirements and strategies. CS-Beta on the other hand, affiliated itself with a particular vendor and signed a flexible licenced agreement covering technical support, training and access to a range of BIM products. CS-Gamma liaised with web-based BIM objects developers to create a range of its building products into smartBIM objects and hosted these on web libraries for designers to upload into project models.

Even though strong instrumental visions were the initial driving force behind both case organisations, the processes and the strategies evolve as unfolding realities meet with contrasting visions. This resonates with Latour's (1986) argument that technological innovations travels through time in the hands of actors, who may accept it, modify it, deflect it, betray it, add to it, appropriate it or let it drop. The idea that BIM will evolve and continue to effect change in construction organisations is almost incontestable. The relationship, dynamics and direction of change, however, remains a contested terrain. Linderoth (2010) advised that research should analyse the "processual and emergent nature of ICT-mediated change." Based on the analysis thus far, this study adds to the dynamic and emergent nature of BIM implementation by revealing that intra-organisational knowledge workforce are in a constant loop of learning in order to realign to the constantly evolving technological products and the concomitant work processes associated with the BIM implementation. The importance of this finding thus lies in guarding against the principles of placing analytical distinctions between policies, maturity stages and contexts. It sets the scene for understanding the relationships and the interrelated position of the actors, structures, rules and regimes thereby locating these in a dynamic innovative-assemblage (Kling & Scaachi, 1980; Bijker, 1987; Orlikowski & Iacono, 2001).

7.5.2 Disconnects Between Existing BIM Maturity Models and Realities of BIM Implementation

Scholars have put forward and intensely debated BIM capability models - there are multiple models that explain BIM capability maturities stages. However, the literature has rarely discussed standardised approaches of implementing BIM. On the one hand the maturity models are "conservative" in nature that shows different stages of BIM implementation across time. On the other hand, the approach to implementing BIM is 'consensus' by nature that requires multiparty negotiations and compromises. If the consensus is disrupted, the implementation process may shift dramatically, and may not reflect the directives of any maturity model. The theme that emerge from the empirical observations in comparison with the existing top-down BIM maturity models is that the existing models do not account for multiple actors, and various constraints that hinder the implementation process. This can produce a negative valence among multiple constituents and thwart the actual implementation efforts. This resonates with Thomas Smith's (1973) examination of policy implementation. He developed a model for policy implementation that includes four variables in which emphasises tensions within the implementation process. The variables include idealised

policy, implementing organisations, target groups, and environmental factors. He argues that there is an invalid assumption that policy is implemented once it is formulated. Tensions can develop between or within these variables inside the implementation process. Smith (1973) claims that the tensions between these variables are result of interactions that can sustain or reject the implementation of a policy.

The maturity models thus represent a black box that require unravelling by investigating the implementation processes of each maturity stages through empirical observation and validation. At the implementation strategy level, the maturity models will obtain the “collective absent of multiple actors” (Bardach, 1977). This implies that, those multiple actors whose ideals were not initially incorporated into the inscribed artefacts would twist the artefacts to suits their personal agendas at the implementation phase. If the models require the implementing constituents to reorganise their operations or structures, then the implementation process inscribed in the maturity model will be dramatically affected. Montjoy & O’Toole (1979) however, suggested that innovation strategies should be implemented by organisations that have a mission statement that is parallel to the objectives of the innovation “...*which is already well-suited to the proposed mandate on the basis of routines, goals, and world views*” (p.473). The direction towards achieving the maturity models thus, should be directed towards encouraging construction organisations to develop internal BIM objectives commensurate with the maturity models.

7.5.3 Divergent Visions Between Coordinated BIM Platforms and the Idiosyncrasies of Construction Practice

One of the key antecedents as a result of introducing BIM within the three case organisations is that the BIM platforms being introduced are connected in a seamless web across sociotechnical constituencies at multiple levels. Within the inter-organisational constituents, multiple organisations use collaborative BIM platforms as enablers to work together in a collaborative manner. Collaboration is the cornerstone of inter-organisational interactions in construction project works (Rahman & Kumaraswamy, 2005). In order to ensure that work gets done, efficient collaborative design tools that augment the work practices must be realised (Anumba & Newnham 1998; Krishnamurthy & Law, 1997; Alshawi & Faraj, 2002). At the core of the collaborative BIM platforms is the coordination of federated models to perform a task that cannot be performed effectively or efficiently by the reliant on the individual federated models. The reliant on the various skills, and the effectiveness of the

existing coordinated platforms, collectively, are responsible for the performance of the tasks and consequently, stand to benefit from an effective integrated team efforts.

The various knowledge practitioners use many different suits of BIM applications to model and analyse different elements of an overall building system. An important characteristic that the collaborative system has to have in order to be considered efficient is that, it should provide a platform for easy and reliable exchange of project information among the different project team members. The integrated platforms which form the repository for coordinating the individual federated models define the configured status of the sociotechnical constituents (e.g., McLaughlin et al., 2002). This is an enabling rather than constraining factor, as it interlinks the characteristics and contents of different platforms and makes knowledge and information available to a wide range of users. At least, this paints the picture of the collaborative BIM platform imaginable.

Currently, there are no precedents or policy protocols for guiding the use of BIM across multiple project participants. As discussed in chapter two, Eastman et al. (2011) suggested two approaches, either using a single vendor for proprietary interface, or using different BIM vendors compliant with open IFC standards. Each of the case organisations devised different mechanism to collaborate, including the regular coordination meetings, and the use of different tools. For instance, CS-Alpha relied on Navisworks for coordination, cloud-based Buzzsaw repository and BIM 360 field during biweekly BIM coordination meetings. CS-Beta used BIMsight for design reviews and coordination, whilst CS-Gamma subscribed to a third party BIM web-library to host and maintain its smartBIM objects. There were many discrete differences in how the collaborative platforms were manifesting. In some instances, the selected collaborative platforms could only configure proprietary models or models convertible to some standard formats. The tensions derive from the use of competing BIM products across the various organisations succinctly reveal and reinforce the existing divisions between the heterogeneous knowledge boundaries of a typical construction project. Similar entrenched and hard-to-overturn perspectives are found among the competing BIM vendors who are unwilling, or unprepared to look beyond the competition to produce products that augment inter-compatibility.

Paradoxically, the much criticised high level of fragmentation and limited collaboration in the construction sector is also prevalent in the competing BIM vendor organisations. Similar to this, van Lente & Bakker (2010) have described how ‘various technical options often compete in terms of their performance and in terms of expectations about future performance’

(van Lente & Bakker, 2010, p.693). In effect, there is no common vision for the different collaborative BIM platforms. Attempts to promote vendors' commercial interests seems to drive the imposition of native data rules to augment parametric data exchanges in proprietary formats rather than in an openBIM interface across different BIM vendors. Users that appropriate particular BIM application which ran contrary to the proprietary rules of the chosen coordinated platforms are constrained by the systems' configurations, thus limiting the end-users' options of the BIM platforms to choose from. This points to the top-down inhibitions posed by the commercially-conscious BIM vendors as they strive to capture proportionate market share of the end-users.

There is therefore a sharp contrast between the industry-wide expectations from the use of BIM and the functions the various software developers inscribed to their products' development. As an example, the government's chief construction advisor, Paul Morrell, has stated that, the public interest in implementing BIM is mainly because, it could lead to integration of the industry's players which is the biggest challenge facing the industry (Morrell, 2010). Nevertheless, this does not reflect in the current disjointed BIM platforms. In fact, the inscribed uses of the current BIM products reveal and re-enact the assumptions about the fragmented landscape of construction practices. One main observation from the case study organisations was the issue of direct models integration; the various organisations cannot directly exchange models from different BIM platforms of different vendors, due to the top-down configurations of the BIM applications. Eastman et al. (2011) have explained that the problem for this lack of interoperability is due to the fact that different BIM design applications rely on different rule types in the BIM tools and their base-object families.

The assumptions made by the vendors inscribe the segregated nature of activities such as design, engineering, energy analysis, 4D costs and 5D programme simulations; and consequently they subtly develop competing range of BIM products, that address portions of the fragmented problems whilst maintaining commercial interests in their captured niche. In this case, each vendor precludes the parametric engagement with other vendors' BIM product in the coordination processes. This is to ensure that they capture and maintain enough market shares via proprietary interface with their BIM product suites. Also the BIM coordination platforms such as Solibri and Navisworks which are meant to integrate the disparate models are developed by the same competing vendors without any realistic industry standards to work with. This dilemma is inauspicious to the construction sector as a whole; nevertheless, it

is commercially worthwhile to the vendor market. A consultant for a leading BIM vendor explained this dilemma:

“Everybody will like to see it happens [direct models integration] but I know it may never happen because it’s not in an individual company’s best interest to do it. If we say we are going to spend a lot of money making our software interoperable to everyone else’s its detriment to our own users-our own customers. It’s like we are not spending their money on their products we are spending their money on other people’s products. If you make your software interoperable you are not giving any incentive to anybody else to change over to your software or to use your software or for new customers to use your software.” [Ia-M]

This explanation implicitly implies that, the leading BIM products developers such as Autodesk, Tekla and Bentley have their scope of market to protect, therefore, they may not on their own inference, make their applications interoperable to the wider BIM market, because that might negatively impact on their market share. These current arrangements have consequences not just for the different end-users, but also for the very problem the industry wishes to address. In this case, the incompatibilities between the inscribed uses of the disparate BIM platforms and the visions of the implementing organisations meant that the artefacts could not be incorporated into practices without being transformed or risks yielding unintended or unanticipated outcomes. Indeed, one of the tentative conclusions that can be drawn from this study might be that without any appropriate policy mandates to address this issue, it may inadvertently add to the often observed fragmented and adversarial nature of the construction sector instead of transforming the sector into an efficient work system.

7.5.4 Government BIM Policy Mandates and Realities of BIM Appropriation

The UK government’s 2016 level-2 (L2) BIM implementation strategy is fast becoming the newest shibboleth among academics and practitioners in the built environment. The government’s Industry Strategy Report (2011) stated that: *“Government will require fully collaborative 3D BIM with all project and asset information, documentation and data being electronic) as a minimum by 2016.”* This effectively will raise the bar for qualification criteria of Government projects from 2016, and will favour those construction organisations with BIM competence. The government BIM philosophy concentrates on “reinventing” construction practice by streamlining processes with an emphasis on and an aspiration to improve construction performance and eliminate waste through collaboration. Some have

argued that since the government is the major client in the construction industry, the enforcement of the 2016 BIM strategy could become the catalyst to ultimately, deliver the benefits that BIM promises - that is, to streamline and change a fragmented and often inefficient industry in need of modernisation. Edwards & Sharkansky (1978) indicated that the most pressing concern with government policy mandate is that of moving from a policy decision to implementation in such a way that what is done bears a reasonable resemblance to the expectations of the policy requirements, and functions adequately when appropriated in institutional or project contexts. Elmore (1979) studied the efficacy of policy implementation and also suggests that “it begins not at the top of the implementation process but at the last possible stage, the point at which administrative actions intersect private choices” (p.604).

The challenge associated with achieving the 2016 BIM implementation goal lies in ‘how’ to do rather than ‘what’ to do. The survey of the NBS National BIM Report (2013) indicated that the ‘what’ and the ‘why’ of BIM have largely been relegated, because there are plethora of literature that characterises how BIM would address construction-related problems, but the main concern people are having is with the ‘how’ to implement the BIM process. Whilst the government construction strategy clearly sets the goal to level 2 of the BIM maturity model (discussed in chapter 2) there is as yet no clear roadmap to accomplishing this and overcoming some of the issues associated with skills, knowledge gaps and processes which are critical to answering the ‘how’ question associated with effective BIM deployment. Pandey et al. (2006) have previously indicated that the clearer and more concise tasks and goals are communicated, the more likely personnel will be able to perform the tasks and accomplish the goals at a high level of proficiency. The complexities of the concomitant change processes associated with the BIM technological artefacts have largely been ignored in this regard.

Whyte et al. (2011) acknowledged that construction technological artefacts often do not exist in isolation, and mobilised the concept of “boundary objects” to articulate how technological artefacts are used in coordination across different inter-organisational contexts. Collaborative efforts are therefore needed from the preponderance of BIM stakeholders who one way or the other, influence the implementation efforts. These multilevel stakeholder ranges from BIM vendors, systems developers, AEC organisations, academic and research institutions, BIM consultants, and public institutions. Negotiations of goals and requirements across these multiple stakeholders may yield a collaborative effort towards facilitating a common vision on a whole range of issues. Among these could include:

- the development of open BIM platforms with inscribed functions to interlink with other BIM applications at the users' end
- development of standardised and efficient BIM workstations with high-speed networking and specifications
- development of BIM contractual and procurement arrangements
- development of training strategies and establishment of training centres for end-users, and
- development of easy-to-follow BIM implementation protocols and processes that align with the different maturity-stages for end-user organisations to follow

In effect, the introduction of the BIM concept via a policy-mandate into the broader AEC work context can trigger “emergent-state” that cannot be predicted from an understanding of the constituent parts (Sackey et al., 2011). Thus, the outcome of the open dialogue on the adaptation and appropriation processes through learning, visions formulations and systems development among the high-level BIM stakeholders can be incorporated into policy visions. As visions are formulated through negotiations, a more realistic and robust implementation closure will emerge from the “self-organising” process but not through a conservative BIM policy mandates (Clarke, 1999).

Another particular area that needs consideration is with regards to support strategies for the multitude of the small and medium (SME) construction stakeholders. Both the exploratory studies and the three case study organisations reveal how the SMEs particularly struggle with the implementation process. The large organisations have more slack resources and that particularly allow them the scope to innovate and invest into the end-users. Moving forward, the lack of slack resources for the SMEs could potentially affect the pace of BIM implementation. Bardach (1977) indicates that financial shortfalls, and unclear goals, which are consequences of uncertainties, inefficiencies, and convolutions of the process, are the impetus for failed policy implementation. According to the office of national statistics (2012) 94% of the construction industry is made up of contractors employing less than thirteen people. Without any support structures for the SMEs which comprise the majority of the UK construction business, the implementation efforts could only present ‘vague hopes’ that have no connection with the capacity or ‘will’ of the end-users expected to implement BIM (Clarke, 1999).

While the government attempts to have a mass BIM user-group by 2016, there may merely be partial benefits If only few large-size construction organisations can afford to implement it

(Koskela & Kazi, 2003). Markus (2004) argues that successful technology implementation requires a ‘critical mass’ of users – mass user learning and sharing barriers can block the growth number of users and ultimately not achieve the intended benefits. Thus, end-user empowerment and support structures, especially for the SME construction organisations are very important for mass implementation of BIM across the AEC sector. The government BIM taskforce thus has the arduous task of developing and implementing a compliant template that could measure BIM users’ attitudes, activities and performance regarding the policy so they can tailor the policy strategy to link organisational goals and BIM outcomes through performance management strategies.

7.6 Research Evaluation and Validation

The objective of this section is to establish the validity of the research findings by evaluating its trustworthiness with the academic communities and industry practitioners. The approach to ensuring the trustworthiness of the research was briefly discussed in section 4.7.3. This section details out the purpose, the objectives and the process used in validating the research outcome. The selection of participants and results of the research evaluation are also discussed in this section.

7.6.1 Assessing the Trustworthiness of the Research Output

Since this study makes use of qualitative research methods, it is more appropriate to assess the quality of the study and findings through qualitative/interpretive means. Typically the trustworthiness of qualitative enquiries is judged through the criteria of credibility, dependability, confirmability and transferability. These criteria are analogous to reliability, validity and objectivity which are postulated for use in the positivist research paradigm but found to be unfitting by Lincoln & Guba (1985) for interpretive, qualitative research. The evaluative roles of these criteria for both qualitative and quantitative research evaluation is summarised in table 7.4.

Table 7.4 Criteria for assessing rigor / trustworthiness in qualitative and quantitative research enquiry

Criteria	Trustworthiness (qualitative Research)	Rigor (Quantitative research)
Truthfulness	Credibility	Internal validity
Consistency	Dependability	Reliability
Neutrality	Confirmability	Objectivity
Applicability	Transferability	External validity / Generalisability

Adapted from (Guba, 1981, p.80; Lincoln, 1995, p.277)

According to Lincoln & Guba (1985, p.290), in order to establish the trustworthiness of interpretive research, the researcher should be able to address certain questions associated with each criteria. These are:

- *Credibility*: How can one establish confidence in the truth of the findings of an inquiry for the subjects/respondents in the context within which the enquiry was carried out?
- *Dependability*: How can one determine whether the findings of an inquiry would be repeated if the inquiry were replicated with the same (or similar) subjects/respondents in the same (or similar) context?
- *Confirmability*: How can one establish the degree to which the findings of an enquiry stem from the characteristics of the subjects/respondents and the context and conditions of the inquiry and not from the biases, motivations, interests, and perspectives of the enquirer?
- *Transferability*: How can one determine the extent to which the findings of an inquiry may have applicability in other contexts or with other subjects/respondents?

The criteria for establishing the quality of the research were carefully considered throughout the research process. Table 7.5 made the case of how each of the criteria of credibility, dependability, confirmability and transferability are met within the overall research process.

Table 7.5 Achieving the trustworthiness of the research findings

Trustworthiness criteria	How each criterion of the trustworthiness was met in the study
Credibility	<ul style="list-style-type: none"> • Triangulation of primary and secondary data sources (detailed literature review, exploratory interviews and case studies) • Exploratory studies by experts' sampling with sixteen (16) construction practitioners representing twelve (12) BIM-enabled organisations • Three (3) multiple case studies representing context-specific BIM implementation analysis. • Academic publications in journal and peer review conference proceedings for scholarly validation • Evaluation of findings with industry experts
Dependability	<ul style="list-style-type: none"> • Triangulation of methods produced complementary results. • The whole research process was documented in detail (data collection, analysis and interpretations) • Comprehensive literature review covering a broad time horizon. • Analysis of exploratory findings with sixteen (16) exemplar BIM-enabled construction organisations. • Cross-case analysis (cross-validation) of multiple case studies • A detailed first-order analysis (thick description) of the settings was provided so that others can judge the plausibility of the findings and their applicability to other settings • Scholarly and practitioners evaluation of findings to ascertain trustworthiness
Confirmability	<ul style="list-style-type: none"> • Triangulation of data sources • Cross-case analysis (cross-validation) of multiple case studies • A detailed first-order analysis (thick description) of the settings was provided so that others can judge the plausibility of the findings and their applicability to other settings • Rigorous scrutiny by academic and research community through journal and peer review publications • Evaluation of findings with industry practitioners
Transferability	<ul style="list-style-type: none"> • Theoretical sampling / context-specific analytic generalisation • A detailed first-order analysis (thick description) of the settings was provided so that others can judge the plausibility of the findings and their applicability to other settings • Cross-case analysis (cross-validation) of empirical findings

Table 7.5 has described how the criteria for trustworthiness were achieved throughout the research process. As discussed earlier in chapter four, the concept of credibility (in view of using rich and multiple sources of evidence to increase corroboration) was a concurrent process undertaken continuously through the two-stage empirical process. The degree of transferability of the results to other environments are key to the concept of theory development where the intention is to move from the specific results of the individual case studies to demonstrate the theoretical knowledge gained from the case studies. The empirical findings are structured to describe both the exploratory study and the cases as completely as possible. Both Chapters 5 and 6 make explicit the details of each participating organisation.

Beyond the design of the overall research process, the trustworthiness of the research was also confirmed by two main methods, 1) scholarly evaluation and 2) industry practitioners' evaluation. These are discussed in the next section.

7.6.2 Scholarly Evaluation of the Research Findings

The process of disseminating the findings of this research to practitioners and the wider academic community through the publication of articles in international journals and conference proceedings involved a review and assessment of the trustworthiness of the research findings by independent referees. The scholarly evaluation of the research findings is in the form of publications in journal and peer review conference proceedings (as shown in appendix 7). The peer review provides an opportunity for the methodologies, meanings and interpretation of the research to be questioned (Xiao & Lucking, 2008) thereby providing an informed, fair, reasonable and professional opinion about the merits of research work (Runeson & Loosemore, 1999).

During the course of this research five peer review conference papers were published and presented at carefully-selected reputable academic conferences. A further journal paper was also subjected to a rigorous peer review process in a special issue journal (see table 7.6). The special issue journal was specially targeted for its rigorous peer review procedures. Feedback from such a process serves to enrich research work and potentially improve its findings (Alkass et al., 1998)

Table 7.6 References cited in journal and conference papers

No.	Authorship	Year	No. of references cited
1	Sackey et al.	2011	77
2	Sackey et al.	2011a	54
3	Sackey	2013	25
4	Sackey et al.	2013a	37
5	Sackey et al.	2013b	20
6	Sackey et al.	in press	65
Total			278
Total average			46.33

With the continual challenge and feedback from the academic community which have been incorporated in the research and into this thesis, the research has been improved significantly thereby confirming the credibility and dependability of the findings. It has been noted that the

peer review publications also validate the trustworthiness of the content of the research, including the interpretations, arguments and the published research cited in them. This is built on the premise that the publications make arguments, interpretations and evaluate findings against existing published research and as such once the papers are accepted both the content of the papers and the published research cited in them are validated (c.f., Proverbs, 1998; Ankrah, 2007; Tuuli, 2010). Consequently, the acceptance of the peer review papers for publication in the selected forums after going through a rigorous peer review process indicates that this research has met the high standards set by these forums and is therefore scholarly and academically credible.

7.6.3 Evaluation Approach with Industry Practitioners

As an ultimate validation procedure, industry feedback to assess feasibility of the findings is reported in this section. The objective of the validation is to find out whether the findings of the research are congruent with the responses of practitioners and experts of which the research is designed to help (Bryman, 2004). There are four main objectives for evaluating the research objectives with industry experts. These are:

- To confirm whether industry practitioners and experts agree with the sociotechnical antecedents identified in the research findings as influencing successful implementation of BIM.
- To examine the completeness of the research output in dealing with all the sociotechnical issues that influence BIM implementation processes in construction.
- To gather practitioners' opinions on the practicality and feasibility of the research recommendations put forward for BIM-enabled practitioners.
- To identify the benefits to be gained by construction organisations for following the recommendations captured in the research output.

The evaluation thus provides some support for the trustworthiness of the research outcome, recommendation for practice and also, for the developed STS analytical framework. A group discussion with practitioners that enables the practitioners to scrutinise and evaluate the output of the research by involving them in an active discussion and a question-answer session was preferred (e.g., Riley & Rosanske, 1996). The next section presents the background of the respondents.

7.6.3.1 Selecting Industry Participants for the Research Evaluation

The validation was particularly limited to two of the case organisations that participated in the research and supplemented with one additional BIM-enabled construction organisation which did not participate in the main study. There are two main reasons for this. Firstly, the results discussed in the cross-case analyse were conducted within certain prevailing conditions found in the participating organisations. Thus, the validation was conducted within the same teams to preserve the context within which the case studies were accomplished, however, the additional inclusion offers outside perspective to the result. According to Lincoln & Guba (1985), the credibility of a research can be reinforced by prolonged and substantial engagement at the site of inquiry, and checking the meaning of data interpretations with the stakeholder groups who originally provided the data. Secondly, the STS analytical framework developed in chapter five to analyse the BIM implementation process was applied in the case organisations, thus, the same case organisations (and one other participant) were used to evaluate the factors identified in the BIM implementation analytical framework.

The participants were selected considering their standpoint (i.e., academic background, practical understanding of BIM and experience on a BIM project), which provides them with epistemic privilege in understanding the issues concerning BIM implementation processes. In other words, since they are actively involved in BIM-enabled projects, they are in a better position to validate the credibility, transferability, and confirmability of the research objectives and the ensuing outputs. Seven participants (three from the case organisations and four from a new BIM-enabled organisation of which the researcher has some dealings) were convened to review and evaluate the research output. Data collected on the participants shows that the participants occupy various positions in their respective organisations and their years of experience range from eight to twenty nine years. Six out of the seven participants were aware of BIM and four out of the seven participants had been involved on BIM project. Table 7.7 presents the practitioners represented in the validation process. With this background of the participants, all viewpoints put forward were deemed highly valuable in evaluating the contributions of the research output.

Table 7.7 Description of personnel that participated in validating the research output

	Organisation represented	Position in the organisation	Years of experience in construction	Familiar with BIM	Involved in BIM projects?
P1	Civil and building contractor	Senior design manager	22	Yes	Yes
P2	Civil and building contractor	Head of design and engineering	13	Yes	Yes
P3	Civil and building contractor	Technical manager	9	Yes	Yes
P4	Lead contractor on infrastructure and building projects	Design manager	16	Yes	No
P5	Lead contractor on infrastructure and building projects	Project manager	9	No	No
P6	Lead contractor on infrastructure and building projects	Commercial manager	29	Yes	No
P7	Lead contractor on infrastructure and building projects	Planning engineer	8	Yes	Yes

7.6.3.2 Engaging with Participants

Interactive discussions, including presentations by the researcher were held with the selected participants at various times suitable for each of the participants. After a brief introduction of the purpose of the meeting, the participants introduced themselves and the presentation started. Prior to the presentation, the participants were given the hand outs of the presentations, and were provided with an evaluation form to complete. The main objective of the evaluation form (see Appendix 5) is to gather information about the evaluators and assist the validation by providing a means to make the evaluation process more unambiguous. A brief outline of the programme for the evaluation includes the following:

- A brief introduction of the research aim and objectives
- An overview of the research methodology
- Literature findings of BIM implementation processes and challenges
- Exploratory findings of BIM implementation across some selected organisations
- Overview of oversight experiences associated with BIM implementation

- An overview of the STS theoretical framework for analysing BIM implementation
- Sample cases illustrating STS analysis of BIM implementation
- Implications of key findings to existing theories and BIM implementation mandates
- Questions and answers
- Discussion and feedback

The presentation and interactions with the participants lasted approximately two hours. The presentation can be categorised into four main parts: introduction, research methodology, findings/implications and discussion/feedback. The first part of the presentation involved the introduction of the research, identification of the need for BIM implementation analysis and an overview of the challenges associated with BIM rollout within construction contexts. The second part of the presentation aimed at providing an overview of the approach to the research; the need to embed the study within the context of BIM practitioners in order to understand the nuances as BIM mutates through practice. Since the analytical framework utilised a sociotechnical theory, with which some of the participants may not be familiar, a brief outline of STS and its application was also presented. The third part presented the results of both the exploratory findings and the case studies. The implication of the findings for theory and practice was also discussed prior to the question/answer section.

The participants were permitted to comment or ask questions during the presentation, which aided an interactive discussion and thus contributed to a better and deeper understanding of the subject. After the presentation the participants were asked to fill out the evaluation form which consists of two sections: the first section contains general questions regarding the participants' experience and in particular, their understanding of BIM and years of experience. As recommended by Miles et al., (1994) the evaluation form was used to collect evaluators' opinions on the research agenda, methodology and outputs. Data from the evaluation form shows that, majority of the participants are familiar with BIM and have been involved in BIM projects as shown in table 8.4. The second section contains questions designed to reflect the objectives of the research and the outcomes as presented at the workshop. Also, there are some open ended questions in the second section of the evaluation form. For the open-ended questions, respondents were allowed to make general and intuitive comments on the research output, relevant for industry/practice and suggestions for improvement. The results of the evaluation are presented in the next section.

7.6.3.3 Results of the Research Evaluation with Industry Practitioners

The responses to the validation statement on the evaluation form demonstrate an agreement on the benefits and usefulness of the research output. The results are discussed in four main parts. Firstly, the respondents' views on the importance and relevance of the research are presented. Secondly, the respondents view on the completeness of the recommendations of the research is presented. Thirdly, the practicality and feasibility of the research output to the industry is discussed. And finally, the recommendations made by the respondents to improve the BIM implementation processes are discussed. The respondents' assessment of the importance and relevance of the research output are discussed below.

1. Importance and Relevance of the Research Output

All the participants recognised the importance of the research agenda to improve the understanding of BIM implementation, and ultimately, the industry. All the respondents also agreed that there is a causal interrelation between the main STS elements that affect the BIM implementation processes. Accordingly, the study identified the sociotechnical requirements of the implementation process, which includes four main aspects 1) nature of the target constituents; 2) interacting technologies; 3) inter-organisational governance; and 4) constituents' perceptions and pursuits. Each element has sub-elements across a multilevel context. The causal links across these STS constituents are enforced via a system of rules, structure, and contractual obligations across multiple levels. These protocols firm-up holistic visions and responsibilities across the implementing organisations. The usefulness and applicability of the research to BIM-enabled organisation proved to be very positive by the respondents. The respondents recognised the importance of meeting not only the technical objectives, but also to fulfil different organisations' expectations.

In summary, an overwhelming majority of the participants considered the research output as well-structured, clear and relevant to the current debate of BIM implementation issues. And in particular, it unearths the causal relationships amongst the sociotechnical antecedents that are associated with the nature and structure of construction setup, thus making it particularly cognisant and relevant to the current challenges affecting construction organisations pursuing their BIM ambitions. Participants' evaluation of the completeness of the research recommendations are discussed below.

2. Completeness of the Research Recommendations

All the respondents view the recommendations put forward in the research output as comprehensive in dealing with the relevant issues affecting the rollout of BIM across construction organisations. Indeed, the research findings identified four key areas of the BIM implementation processes which are currently not at par with the current debates and strategies of BIM in the literature and in the BIM policy mandates as discussed in section 7.5. In summary these include:

1. *The dynamic and emergent nature of BIM appropriation in socially-mediated contexts;*
2. *The disconnects between existing BIM maturity models and realities of BIM implementation;*
3. *The divergent visions between coordinated BIM platforms and the idiosyncrasies of construction practice; and*
4. *Government BIM policy mandates and realities of BIM appropriation*

The respondents believe that the recommendations have covered all the important factors affecting their experiences with the rollout of BIM. On the whole the participants' responses demonstrate that the recommendations are consistent with their expectations of the proper modalities required to be in place for effective utilisations of BIM across construction contexts. The evaluation of the practicality and feasibility of the research achievement is presented next.

3. Practicality and Feasibility of the Research

The participants view the research recommendation as practical. They recognised that the recommendations fit in with their thinking and understanding of the approach to managing construction organisation's strategies for BIM uptake. Particularly, the results of the study indicated that activities associated with BIM implementation within a context require the provision of a suitable environment for the implementation, including strategic directions (vision), required resources, and appropriate policy and systems. Similarly the pattern of involvement of inter-organisational relations impacts on the implementation. Thus the appropriation process of BIM endures in a causal chain of influences across multiple levels of sociotechnical constituencies. These constituencies first establish their 'localised' ambitions and make logical decisions on their own business operations with regards to BIM appropriation, in terms of artefact type, training requirement, organisational structures, and

expectations / anticipated visions of BIM. Eventually, a compromise is reached amongst the constituents by engaging them to establish a consensus on a 'holistic' vision and expectations of preferred artefacts and distributed responsibilities. Thus, as visions are eventually narrowed, the principles of BIM processes are jointly developed and the technological choices and uses become standardised or transformed and enforced with contractual obligations and protocols.

These findings indicate the feasibility of the recommendations put forward in the research outcomes. In view of the findings, the respondents foresee no negative implications with regards to the practicality of implementing the research recommendations as they already have, to a certain extent, been practicing aspects of the findings within their respective BIM-enabled organisations. Overall, the results have demonstrated a converging opinion on feasibility of the study among the participants. All the participants evaluated the study's achievement as technically and socially feasible for implementing BIM in construction organisations.

4. Recommendation to Improve BIM Implementation Processes

The responses to the open ended questions, which were also the focus of the discussion, identified some recommendations given by the respondents to improve the BIM implementation processes. In the interest of brevity, verbatim quotations have not been included within the texts in presenting the findings of the validation statements of the respondents' recommendations. The key conclusions drawn from the feedback of the open-ended questions can be summarised as follows:

- The ambition towards a BIM-enabled sector is feasible to implement but may require radical changes in the current practice.
- Involving organisations at an early stage of implementation strategies would enable them to be aware of policies and implementation plans and also, to offer operational level inputs for effective implementation strategies.
- Staff redeployment / early stage training may be necessary to efficiently use BIM.
- Activity-based (on the job) training would expedite employees' knowledge on BIM.
- Senior management commitment could contribute to quick rollout and company-wide buy-in.

- BIM organisations to be structured and act as ‘learning organisations’ where knowledge workers continuously learn new practices and skills. This enables them to efficiently acquaint with the rapidly evolving nature of BIM and construction IT.
- Emphasis on ‘partnership’ arrangement would improve relationships among inter-organisational (multilevel) BIM-project team members.

Overall, Participants’ interpretations of BIM implementation analysis is in line with that of this study; that is, in brief they acknowledged that a strategy for BIM implementation would be dependent on the contexts in which it is generated, influenced by the negotiated actions of the sociotechnical constituents at multiple levels of abstraction. BIM implementation process is therefore shown to be context dependent.

Although the respondents generally concurred with the research findings, others also expressed some issues. The key problem with the arrangement however, is the relatively deterministic approaches to BIM implementation, and the timelines with regards to achieving different levels of BIM standards. Nonetheless, some of the participants raised some pertinent issues regarding the research which point out practical and essential factors that need more attention in the system development and rollout. These issues are discussed in the future research section. For instance, the participants emphasised that assigning the root causes of challenges and BIM implementation drivers into structural, operational and decision making strategies would facilitate the process of BIM appropriation and other related technologies across construction organisations.

In some few specific instances, other respondents also expressed cynicism, indicating that BIM is the latest shibboleth of the construction industry and may ‘die-down’ with time, just like its other predecessors such as total quality management (TQM), process/product reengineering, lean construction, just-in-time (JIT) and others, which are rarely mentioned in practice. Other concerns raised by the participants have been discussed in the future research section.

In summary, the evaluation of the experts’ opinion with regards to the 1) importance and relevance of the research output, 2) completeness of the research recommendations, 3) practicality and feasibility of the research; and 4) recommendation to improve the BIM implementation processes are confirmed to be cognisant and coherent to the current debate of BIM implementation issues. The next section presents the conclusion of the research.

7.7 Summary

This chapter has presented the cross-case analyses of the results and findings from the three case studies described in chapter six. The evidence presented in this study provides a unique contribution to the BIM implementation research literature, both from a theoretical and an empirical perspective. Implementation efforts have often been driven by top-down, disparate, discrete and ad hoc policy strategies drawn together under umbrella terms such as BIM maturity models, government's BIM strategy or BIM software solutions. The study has shown that current BIM strategies and processes circulating in the literature and policy mandates, including the vendor markets' approach to products development do not provide a clear picture of the requirements of a BIM implementation process.

The prevailing situation as observed in the case studies is that there is no 'one standard way' of implementing BIM. Every construction process is different in its circumstances. The various organisations operate within their niche areas and rely on artefacts and protocols that benefit their niche interests. The empirical observation of the cross-case organisations is strikingly different from the prevailing literature both in terms of implementation strategies and in terms of the theoretical analysis. The significance of this study for the BIM implementation research literature is that it enhances the understanding of the BIM implementation processes. The case organisations have shown how different organisations understand the BIM implementation differently and 'make sense' of its reality by constructing context-specific rationality of its benefits and wider discourses or negotiations on its use. The implementation processes thus concentrate on connecting local rationality and causal relations through multilevel discourses and negotiations among the different BIM/construction stakeholders. The BIM discourse is seen as a discursive process in which key stakeholders are aligned in causal relationships. Understanding the discourse provides a means of understanding cohesion in which knowledge, rationality, power, policies and practices are articulated and inextricably linked.

In terms of the theory relating to the social implications of technology in construction organisations, and the BIM literature specifically, this study also makes an important contribution. This is achieved notably by the contribution it makes to ideas relating to BIM implementation processes, building upon combined insights from previous research such as STS theories, digital infrastructures in design and engineering practices, innovation assemblage and sociotechnical constituency building (e.g., Whyte, 2010; Molina, 1998; Cherns, 1976). Through the study of the BIM concepts as it mutate into different work

systems, this study succeeds in broadening the theoretical knowledge relating to the concepts, and also with regards the sociotechnical antecedents that influence the outcomes. The chapter contributes to knowledge by suggesting four theoretical and practical implications of the findings, which are of relevant to the current BIM discourses. These include: 1) dynamic and emergent nature of the BIM concept and the socially-mediated contexts in which it is appropriated; 2) disconnects between the current BIM maturity models and reality of implementation; 3) disconnects in the divergent visions in the inscribed BIM platforms and the idiosyncrasies of the construction practices; and 4) gaps in the existing BIM policy mandates and the reality of implementation.

In the latter section, the chapter sets out proposed extension to Molina's sociotechnical constituency which describes how multiple constituents, with different ambitions and interests come together within a single integrated-space. This is discussed from the multilevel perspective in a form of "innovative assemblage" and proposed that a similar coming together of the high-level constituents, ranging from the policy makers, BIM vendors, systems designers, R&D and academic institutions and the AEC organisations is required. Contrary to the predetermined government BIM policies, BIM maturity stages, and the top-down inscribed BIM platforms, the proposed assemblage do not need a priori precedence between the top-down and bottom-up constituents. Moving forward, strategy for BIM implementation is contingent, subject to negotiations between many juxtaposed visions and expectations across the enrolled constituents, intertwined with the efficient use of the emerging BIM platforms to ensure a sociotechnical alignment. The next and the final chapter discusses and consolidates the main findings of the study and highlights the research contributions to knowledge, limitations and opportunity for further research.

CHAPTER EIGHT

8 RESEARCH CONCLUSIONS

8.1 Introduction

This chapter presents the overall summary of the work that was carried out to achieve the research aim and objectives by highlighting the key findings, contributions to knowledge, limitations and future research opportunities. Section 8.2 addresses how the research aim and objectives were achieved. Following this section 8.3 presents the contributions and section 8.4 highlights the limitations of the study. Based on the limitations of the finds, recommendations are made for future research direction in section 8.6, and finally, the research ends by reflecting on the achievement in the research epilogue (section 8.7).

8.2 Achievement of Research aim and Objectives

Before concluding the research, it is appropriate to reiterate the aim of the thesis and the objectives by which it was to be achieved. The overall research aim was to *carry out a sociotechnical systems analysis of BIM implementation in construction context*. Research objectives were developed in section 1.6 of chapter one in order to achieve the research aim. There were six objectives that were achieved through various methods as summarised in table 8.1. This section provides a brief description of the processes that were followed to establish the achievement of the research aim and objectives.

Table 8.1 Methods for achieving research objectives

Research aim	Research objectives	Methods of achievement	Related chapters in the thesis
Carry out a sociotechnical systems analysis of BIM implementation in construction organisations	R1. Review existing literature and theories on technology implementation in construction organisations	Review of literature	Chapters 2 and 3
	R2. Explore the contributions of sociotechnical approach in dealing with BIM implementation opportunities and constraints within construction organisations	Review of literature on STS analytical frameworks Exploratory interviews by experts' sampling with 16 different BIM-enabled construction practitioners	Chapters 3 and 5
	R3 Investigate the new organisational processes associated with BIM implementation in construction organisations	Exploratory interviews by experts' sampling with 16 different BIM-enabled construction practitioners Three case studies involving participant observation, document analysis and in-depth interviews	Chapters 5 and 6
	R4 Examine the implication of BIM uptake on the changing roles and responsibilities of construction professionals	Exploratory interviews by experts' sampling with 16 different BIM-enabled construction practitioners Three case studies involving participant observation, document analysis and in-depth interviews	Chapters 5 and 6
	R5 Propose a framework for BIM implementation analysis that addresses the challenges confronting BIM implementation	Back-and-forth iteration between literature comparison analysis and empirical observations of the exploratory studies	Chapters 3 and 5
	R6 Evaluate the relevance of the analytical BIM implementation framework	Validating the feasibility and relevance of the research contribution to practice with different construction practitioners	Chapter 7

Objective one: review existing literature and theories related to technology implementation in construction organisations.

The first objective was achieved by reviewing the relevant literature. The research work began with the detailed understanding of the nature of the BIM implementation processes. This was presented in chapters two, five and six. Based on the literature review in chapter two, and the exploratory study in chapter five, this research summarised the general facts that currently underpin BIM implementation approaches in the UK.

The main empirical study in chapter six has also revealed that BIM-enabled construction organisations do not have a unified systematic management tool for management of the implementation process. Although the basis of the implementation processes and the process requirements are similar in many respects, each separate construction organisation has used their own bespoke systems to manage their implementation processes. There are different sets of criteria in the development of BIM implementation plans at both organisation-levels and the project-levels across the participating construction organisations.

Furthermore, the implementation process is more complex and dynamic. There are many requirements with many parties and various constraints, both technological artefacts and human, involved in the process. The rapidly evolving nature of the technological artefacts and the contextual factors are among the issues that fluctuate the implementation processes across different contexts. It is important that all these factors be thoroughly managed in order to have a successful rollout of BIM. The appraisal of these issues indicated that there is a need to develop a comprehensive understanding of sociotechnical issues that influence BIM implementation processes. To address these gaps this thesis contends that information technology is inextricably embedded in providing or supporting the vast majority of organisational functions and practices and that, technology and organisation are mutually constitutive; their ongoing socio-material relations both restrict and enable future possibilities of each other.

Objective two: explore the contributions of sociotechnical systems approach in dealing with technology implementation opportunities and constraints within construction organisations.

The main challenges identified about BIM implementation issues concern the theoretical perceptions about innovation in organisation. A review of the literature revealed gaps in understanding across two parallel fields of study: technological innovation studies and organisation studies. Innovation studies have traditionally been technocentric, disregarding the finer point of practice and power relations. This generally leads to technologically deterministic

accounts of innovation, and for that matter BIM deployment in construction. Equally, in the field of organisation studies, technology is often black boxed (Azad & Faraj, 2008), with exogenous inscriptions pre-packaged to resolve identified problems emanating from organisational contexts. In order to find a way of resolving this problem and those in accordance with objective one, the research reviewed the sociology of technology literature, digital infrastructure study and feasibility of using STS to analyse the BIM implementation process. The review was carried out and elaborated in chapter three. After obtaining theoretical knowledge for analysing BIM implementation, various research methodologies were adopted to achieve the defined objective of the research. This was reviewed in detailed in chapter four. The study adopts an abductive research approach, the underlying epistemology is interpretative and a two-stage process is formulated for the empirical data collection - comprising: 1) initial exploratory study to help establish the framework for analysing BIM implementation in construction context; and 2) case studies approach to provide a context for formulating novel understanding and validation of theory regarding BIM implementation in construction organisations. STS theoretical framework was used as an analytic tool to analyse the implementation process across multilevel contexts of three case organisations.

Objective three: investigate the new processes associated with BIM implementation within construction organisations.

Since the emphasis of this study is on the practical world, it has been essential to examine the state-of-the-practice within BIM-enabled construction organisations. With this objective, in chapter five, the new and emerging roles of the various construction practitioners were examined. The empirical observation with industry practitioners presented in chapter five explored the experiences of participants in relations to their organisations' BIM initiatives and their emerging roles and associated training needs. The outcome of this was reported in section 5.2.6 and in the case study analysis. An important lesson derived from this was the need for an analytical framework that would assist companies in dealing with the management of sociological and technical issues that confront the different construction organisations that converge at the project-level with the aim of delivering BIM projects. Accordingly, a multilevel STS analytical framework was developed that incorporates the crucial elements for understanding and managing key stakeholders across their sociotechnical constituencies. This was the basis for the analysis of the three case studies. Furthermore, the results of the analysis provide a general overview of issues associated with BIM implementation initiatives that can be

utilised to assist construction organisations in articulating approaches to deal with the associated challenges.

Objective four: examine the implication of BIM implementation on the changing roles and responsibilities of construction professionals

The fourth objective was achieved through conducting a two-stage empirical research strategy. The first stage of the strategy consisted of an exploratory study of some selected BIM-enabled construction firms in order to gain an initial understanding of their BIM implementation practices, review queries developed during the literature review, and identify emerging themes to help formulate an appropriate STS analytical framework for the case study research analysis. This was followed by the second-stage, which consisted of case studies of three different construction organisations, focusing specifically, on their BIM implementation processes. The findings of the exploratory studies augment the findings of the second stage and also provide much broader views of the intricacies of the BIM implementation process. Such a multidimensional construct is crucial for a thorough understanding of events and also augments triangulation in qualitative enquiry. The emerging roles and responsibilities associated with BIM rollouts are particularly discussed in section 5.2.6. On the whole, the study provided some insights into how BIM uptake affects the roles of construction professionals. An important theme that ran through the analysis of the empirical data reflects how BIM-supported work processes emphasise the need for early and continual collaboration of the project team, including the client, designer, contractor and the specialist trades to provide collective agreement from the outset towards the achievement of the overall project goals.

Objective five: propose a framework for BIM implementation analysis that may address the challenges confronting BIM implementation

Chapter five was intended to address this research objective. Chapter four particularly reviewed various sociotechnical systems frameworks which could potentially help analyse BIM implementation in the construction context. It is important to understand which STS model best explains the rollout and utilisation of BIM. Chapter five turns to the investigation of which theoretical model best explains the utilisation of BIM. Following the back-and-forth iteration between theory and empirical observation as informed by the abductive research approach, chapter five is divided into two main sections. Firstly, after carrying out exploratory studies with twelve (12) BIM-enabled construction organisations, a narrative was presented that traces the BIM implementation processes within those organisations. The second section linked the

observed BIM processes and expectations to the appropriate STS model and determined which model best explained the BIM implementation process. Accordingly, the study identified the sociotechnical requirements of the implementation process, which includes four main aspects 1) nature of the target constituents; 2) interacting technologies; 3) inter-organisational governance; and 4) constituents' perceptions and pursuits. Each element has sub-elements across a multilevel context. It particularly draws on STS theory, sociotechnical constituency model, organisational studies literature and digital infrastructure studies in construction. This framework maps influences beyond the bounds of the case organisations with a causal link of crucial and recursive interactions. The STS analysis of the case organisations also confirm that while the day-to-day delivery of BIM projects were routinely governed by organisations' contractual obligations, the rationalities underlying the choices of technology, its anticipated use, and its value to the organisation, were all co-dependent on inter-organisational relationships and negotiations. As scholars continue to investigate BIM benefits and clients continue to encourage its deployment, the presented framework can help in diverse ways to unveil deeper understanding of the causal STS factors that impact on the implementation processes.

Objective six: evaluate the feasibility and relevance of the research contribution to practice with relevant personnel

The last objective was achieved through interactive discussion between the researcher and seven construction professionals with varying experiences and expertise. Section 7.6 discussed how the overall research approach was carefully designed to maintain the research quality through the criteria of credibility, dependability, confirmability and transferability. Having interactive discussions with industry experts also helped validate the research achievement and also, provide feedback for further improvement. The feedback from respondents verified the rationality and the relevance of the study to the current debate about the STS issues affecting BIM implementation. All the respondents agreed that the factors identified in the empirical observation to inform BIM-implementation strategies are important and relevant to BIM-enabled construction organisations. They also viewed the recommendations put forward as comprehensive in dealing with the sociotechnical issues that confront construction organisations as BIM mutates through their 'context-specific' practices (see section 7.6.3.3). Although participants view the recommendation of the study as practicable and achievable, they also acknowledged the difficulties in implementing those practices. The feedback and specific recommendations put forward by the respondents to improve the research have provided valuable recommendations for further research.

Following the presentation of the above processes that establish the achievement of the research objectives, the next section discusses the contributions of the research.

8.3 Research Contributions

The contributions of this research are classified into two main categories, comprising; theoretical and practical. This section presents each of the categories.

8.3.1 Theoretical Contributions

The thesis argued from a sociotechnical point of view, that the dominant rational, reductionist tools and methods as proposed by technological determinists, and the knowledge comprehended within these boundaries are typically too narrow for explaining the processes involved in BIM implementation. The thesis thus proposed that the STS point of view, in particular, the Molina's sociotechnical constituency can accommodate the rollout of BIM process within the AEC context. The theoretical contributions of the research are presented below:

1. As demonstrated in chapter two, there has been a plethora of research findings in recent times on BIM capabilities and anticipated benefits. This is in response to the visions of both policy and industry interest groups to use BIM as a riposte to the challenges faced in construction. However, the trend has mainly been on BIM policy mandates and capability maturity models with associated benefits. This research contributes to the body of knowledge by identifying the various sociotechnical antecedents that influence the appropriation of BIM solutions within construction organisations.
2. The thesis has provided a set of conceptual tools for BIM-enabled organisations to map their contextual environment by making use of the STS analytical framework. The STS inspired multilevel sociotechnical constituency alignment framework enables policy makers to understand the key causal dimensions in the BIM appropriation process within construction context. The developed framework can be used as an essential tool to assess and evaluate the rollout of BIM over time and it enables policy makers to identify target problems within a constituency and seek realignment of holistic visions and expectations through compromises and consensus-building among the different constituents.
3. The findings of the thesis also revealed that the nature of BIM appropriation is far more problematic than most policy-makers anticipate. The appropriation process requires transformation at multi-levels, across different domains, involves multi-actors and necessitates systemic transformation. The study thus suggests that BIM uptake cuts

across technological determinism, organisational issues and even policy-mandates and regards to these not as mutually exclusive. In effect, their complementary insights enrich our understanding of the complications in the BIM appropriation process. A lesson from this theoretical perspective is that, a rigid BIM policy or a predetermined BIM capability mandates may not be successful unless it is formulated from the viewpoints of the actors within their work system. Hence, policy-makers are advised to consider a variety of policy instruments and differentiate them with the different construction contexts and their BIM technological trajectories rather than universal generalisations.

4. A contribution is also made through the analysis of the key findings and its implications to the existing theoretical underpinnings and BIM policy mandates. It describes how BIM practices particularly debunk the notion of technological determinism which has currently entrenched the digital infrastructure literature. As described in chapter three and reemphasised in the cross-case analysis in chapter seven, the analysis reveals that the implementation process of BIM is socially-constructed and dynamically-determined. The appropriation is also mediated through negotiated-actions between many juxtaposed visions in multilevel constituencies. The outcome of the implementation thus becomes context-specific.
5. This research further contributes to theory by identifying the key constraints and concerns that impact on BIM implementation. These issues were fed into the development of the STS analytical framework for analysing BIM uptake in the case organisations. Generally, the key systems to align per each implementing organisation comprise the interacting technologies; the inter-organisational governance; constituents' perceptions and pursuits; and the nature of the target constituents. The role of institutional dynamics across nested levels (Lawrence et al., 2009) was seen to be influential in shaping patterns of technology utilisation in the case study organisations. The lack of this causal sociotechnical alignment explains the disconnect existing between BIM policy mandates, capability maturity models and realities of BIM practices.
6. Furthermore, the study provides a better understanding of the nature of BIM implementation. In both case studies the patterns of BIM appropriation and subsequent organisation transformational practices were linked to institutional influences that existed across multiple levels. While the analysis remains focused on the case study organisation, the theoretical and empirical work extends beyond the boundaries of each case study organisation. This responds to a gap in institutional literatures to the extent that the

formation and evolution of institutional patterns are understood in terms of their mapping of similarities of general forms of arrangements (Kallinikos, 2007) and that limited empirical work has been conducted to indicate how ‘macro’ institutions are formed from ‘micro’ level organisational practices.

8.3.2 Practical Contributions

This thesis has contributed to the understanding of BIM implementation process through the perspective of STS theory. The practical contributions of the research are highlighted below.

1. Despite the rapidly evolving research in BIM technological solutions, there rarely exists a systemic analysis of BIM implementation that considers contextual issues of construction organisations. This thesis pulled together insights from the concept of STS to help clarify BIM implementation issues. The implementation process is defined in terms of two dimensions, namely the social and technical, and jointly optimising these dimensions. The attributes of BIM implementation in these two dimensions were explained and elaborated. This analytical perspective laid the ground work for future researchers and policy analysts who seek to define BIM implementation processes. Also, by having a better understanding of BIM implementation issues from the STS analytical perspectives, BIM stakeholders can develop better strategies for BIM uptake.
2. The sociotechnical constituency alignment framework developed for the analytical process provides a set of conceptual tools by enabling policy makers to understand the key dimensions in the rollout of BIM. The developed framework can also be used as an essential tool to assess and analyse the process of the rollout of BIM in a particular constituency. The three different case study organisations (as presented in Chapter Six) have also shown that there is no single ideal policy for BIM appropriation. The distinct case study organisations generate BIM practices which are unique to those contexts. This shows that a flexible implementation strategy to meet the demands of a range of construction settings as well as the changing needs at different stages of BIM rollout is ideal.
3. One of the key issues that this research sort to address was to explore how the aspirations of construction sector organisations towards BIM-enabled work practices can be met. This is because, currently, the deployment of BIM is not in the mainstream construction practice and the practicality of the implementation process is not well understood. Chapter Two indicates that in reality BIM solutions and work processes, including

purported benefits and efficiency gains, are not widespread as most of the BIM potential benefits are currently, being demonstrated, in some pilot, mostly large projects. Hence, it remains a rare approach in a typical project; therefore the benefits are not clearly well articulated and/or widespread. Accordingly, the research provides the industry with a sense of how BIM utilisation is developed and maintained within construction organisations. From a practical perspective, the primary contribution of this research is that it provides a clear understanding of the BIM implementation processes for successfully traversing through a complex black box of sociotechnical constituencies.

4. The implementation process as presented in this study is designed to stimulate the recognition of BIM as a change process and provides support to practitioners by ensuring that they can fully participate in the change work. The existing BIM implementation strategies as discussed in Chapter Two have largely been ignored by BIM-enabled organisations, who rather, rely on somewhat bespoke implementation strategies that befit their organisational niches. These strategies mainly revolve around BIM work processes; contractual procedures and obligations; inter-organisational team structures and information-sharing protocols. This study therefore provides construction organisations wishing to implement BIM with a sense of awareness of the necessary structures required in a BIM-enabled work environment.
5. The significance of this study for the BIM implementation research literature is that it enhances our understanding of the contextual issues associated with the BIM implementation processes. The research therefore offers insight not only into the nature of BIM as a change process but also allows its reception and ‘assemblage’ throughout the project team to be described through the use of STS theoretical framework. By making legitimate the experiences of the entire project team through the multilevel sociotechnical constituency arrangements the study suggests that, inter-organisational rationality, environmental conditions and how constituents respond to these environments are important antecedents that need to be considered during the implementation efforts.

8.4 Limitations of the Study

The research started with the aim to *carry out a sociotechnical systems analysis of BIM implementation in construction context*. This was an ambitious aim given the limited theoretical discussion and previous empirical research on sociotechnical systems in construction, particularly from a technological innovation perspective.

The study is limited to a small-size data sample. The research participants were not drawn from a large number of organisations but were selected from among the participating case study organisations. The analysis of the BIM implementation processes were therefore examined in a very specific organisational context. Clearly, the findings of the study are not statistically generalisable to a wider population, thus allowing only tentative conclusions to be drawn. It is likely that the opinions of the participants may neither wholly represent their organisations nor the overall views of all BIM practitioners in the UK. A counter argument however is that the judgement of the participants are shaped by their expertise and experience which is held in high esteem and as such their response and hence the eventual research findings are a credible reflection about experiences regarding BIM implementation phenomenon. Hence, the study provides generalisation through theoretical abstraction. The findings are therefore of relevance to construction firms as they present novel STS analytical insights into BIM implementation processes.

The other limitation of the study relates with time and resource constraints. In-depth, interpretive case studies are time-consuming to conduct and complete. The dimension of time is a common constraint on qualitative research, especially where in-depth and synchronous data collection is involved. A potential weakness of this study is when to begin and end data collection. Meanwhile, the research was conducted within a three-year period, constrained by the requirement of the funding body. The limited time impacted on the ability of the researcher to yield deeper insights into the issues emerging from the case organisations as a result of BIM implementation. It is emphasised however, that the internal dynamics of each case organisation and the access to those organisations are the elements that helped develop further understanding of sociotechnical change rather than a delimited amount or period of data collection.

Although the adopted qualitative case study approach adds to our understanding of technological innovation in organisations, this approach does not have the same hard and fast view of technology as a quick-fix for resolving the particular problems emanating from a work system. For this reason, the implications for practice from this kind of research are likely to appear far less precise than those by technological determinist accounts, which are often influenced by positivist quantitative enquiry. The ambiguous theory-practice relationship is solidified further by the inability to generalise from specific cases to produce techniques to be put into practice. Whilst the logic and possibilities of real-world technological determinism have been rejected at a theoretical level throughout this thesis, the alluring nature of such deterministic accounts for managing innovation in practice still presents a barrier in the transfer of theory to practice.

Therefore, it is acknowledged that further data collection, using a quantitative approach, could add to the level of description and detail for the research.

Another limitation of the research relates to the evolving nature of BIM as it is relatively new and its evolution is inextricably linked to the rapid advancement in information technology. Therefore this study cannot demonstrate all the advantages and also, the challenges that may confront construction organisations across time as BIM mutates into the realm of development and the social context where it is appropriated.

Although there is an inherent weakness in the ability of this research design to examine institutional change and trace the mechanisms for BIM implementation in the construction context this is perhaps best viewed as a platform for future research. The next section highlights some directions for further research.

8.5 Future Research Direction

In view of the limitations inherent in this study as discussed previously, further research directions are recommended to address them. These are discussed below.

1. Due to the dynamic and rapidly evolving nature of the technological artefacts associated with the BIM concept, it is recommended that a longitudinal study is conducted over a period of time to identify any changes to the implementation process. This could enhance understanding of the nature of the technological innovation, thus the work system can be manipulated to improve BIM practices over the long term.
2. Secondly, the study of the impact of the change processes should also extend to other important areas such as regulations, contractual obligations, organisational structures, inter-organisational relationships, technological viabilities and other STS influences as identified in this study.
3. Another area for future research is to explore BIM implementation issues via quantitative methods within a much larger data sample of BIM-enabled construction organisations. This could provide interesting point of comparison to the conclusion derived from the qualitative interpretive findings. Such a finding could strengthen or increase the validity of this research. Industry wide survey could also confirm the statistical generalizability of the relationships among the factors identified in this study.
4. In addition, the findings from this study also present an opportunity for further research into different organisations across the construction sector in order to understand how BIM manifests as it mutates through different settings. Research into different contextual

environments may provide further insights into factors that enhance innovation supporting behaviours across the AEC sector organisations.

5. Again, whereas this research responded to the chasm existing between the micro-macro dichotomy of innovation development and organisation research, it has been unable to draw cogent insight to the mechanism of institutional change following the BIM rollout within the construction context. However, the theoretical underpinnings used here concerning both the ontology of technology and institutions (Orlikowski, 2000) implies that the micro patterns of organisations highlighted in this thesis are constitutive of the institutions (macro) identified as shaping factors in the process of BIM implementation. Using this research design, it has been possible to produce (micro) organisational analysis through an (macro) institutional lens, but not an institutional analysis through an organisational lens where the micro, constituting mechanisms of institutions are identified. That is to say macro-micro influence is far more amenable to study using this research design than the build-up of micro phenomena in the constitution of the macro environment. This aspect of the research is discussed as a potential avenue for future research into BIM deployment. This is particularly important as there are wider institutional interests (e.g., public institutions, technology vendors, system developers, R&D institutions and professional institutes) in the development and deployment of BIM, thus, analysing the implementation processes from such lenses towards the micro context would be important.
6. Finally, despite the limitations of this research to provide an account of institutional change as a result of BIM utilisation, it has illuminated the centrality of both macro and micro institutional factors in shaping BIM deployment in construction. It has produced accounts of technological innovation that are strongly mediated by their institutional contexts and the immediate social context of organisations. As a complement to further research, it suggests that future research accounts for the role of construction-related innovations in (re)producing institutional logics and as part of shaping patterns of sociotechnical change in the AEC sector organisations.

8.6 Epilogue

BIM appears to be a useful concept by virtue of augmenting efficiency in the construction practice, however, it has been critiqued on the basis of its lack of corporate/internal coherence and the wide gap existing between the rhetoric and the reality. As Linderoth (2010) has observed, to date, BIM usage is mainly limited to a niche user-community, mostly on large and

complex projects. And there rarely exist a large sample a quantitative research to quantify the purported benefits and the efficiency-gain associated with its use. Nevertheless, the reality with BIM is that the very information (textual data) necessary for effective design evaluation and construction, such as material quantities, costs and programme information, specifications, and energy simulation are captured in the 3D graphical data and stored in a digital repository for use and reuse by the different construction stakeholders throughout the different stages of a project lifecycle. Also, the current BIM software solutions with their parametric integrity have the capability to ensure that the coordinated models are designed to provide efficiency gain for users from the onset. This is achieved by reducing design errors and construction time, improving design quality, and shortens construction time (Eastman 1999). Due to these purported benefits associated with BIM, construction organisations that do not embrace these solutions runs the risk of being outdated and outdone by competitors. The complexity of understanding BIM as it mutates through different organisation contexts should not be underestimated and this study has made an important step towards bridging the gap between the theoretical knowledge relating to BIM-rhetoric, and the empirical evidence relating to BIM-reality. Bridging the gap between these two seemingly unrelated areas of research, requires exploring complex relationships, and as a result has succeeded in enhancing our understanding of the BIM implementation process. The theoretical challenge addressed in this thesis is to accommodate the dualism of both technology and organisation and allow for the analysis of their interactive combination in generating the true outcome of BIM in the organisational context.

The research achieved the aim and objectives through three major steps: literature search, exploratory interviews by experts sampling; and case studies. The adoption of the abductive research approach (discussed in chapter four), depicted convergence links between the three major investigations. Having obtained the literature findings regarding BIM implementation approaches, challenges and benefits, including theoretical underpinnings (chapters two and three), exploratory interviews were conducted among BIM practitioners. The exploratory studies assessed the practitioners' perceptions of BIM implementation; identify the extent of use in practice; and assess benefits and oversight experiences in performing BIM-enabled activities, among other things. Chapter five presented the results of the exploratory studies.

The abductive approach that links the empirical findings and the STS analytical lenses helped develop an STS analytical framework for further detailed investigations in the case studies. Having developed a firm grip of the sociotechnical antecedents that influenced BIM implementation and respective involvement of multiple construction constituencies at the BIM-

project level, further investigations were performed as to how BIM activities practically materialise across three selected BIM-enabled construction organisations. This process was assessed through the lenses of the STS analytical framework presented in chapter five. It is clearly evident from both the within-case (chapter six) and cross-case (chapter seven) analyses that, all the causal STS antecedents identified in the analytical model become crucial at some stage in the implementation process within the organisational contexts. The implementing organisations have a greater role in the adaptation and appropriation processes of BIM as the artefacts mutate through the organisation contexts.

Contrary to the dominant understanding of BIM, the study identified that, a deterministic, top-down agenda of inscribed BIM capabilities and policy mandates that rely on maturity stages with standardised protocols and procedures were not followed in practice. The inscriptions embedded in the BIM technological platforms do not operate in isolation. Especially with the nature and practice of the construction sector, different organisations with plethora of visions, expectations and skills combine with artefacts to form or transform sociotechnical practices. This transformation occurs across multilevel constituencies. The results indicated that activities associated with BIM implementation within a context require the provision of a suitable environment for the implementation, including strategic directions (vision), required resources, and appropriate policy and systems. Analysis of the cases also shows that a similar pattern of involvement of inter-organisational relations impacts on the implementation. Thus the appropriation process of BIM at the project level endures in a causal chain of influences across multiple levels of sociotechnical constituencies. These constituencies first establish their 'localised' ambitions and make logical decisions on their own business operations with regards to BIM appropriation, in terms of artefact type, training requirement, organisational structures, and expectations / anticipated visions of BIM. At the project level, a compromise is reached by engaging with these different constituencies to establish a consensus on 'holistic' visions and expectations of preferred artefacts and distributed responsibilities. Thus, as visions are eventually narrowed, the principles of BIM processes are jointly developed and the technological choices and uses become standardised or transformed.

The compromises and the holistic visions are enforced among the constituents via contractual obligations, organisational structures, BIM work processes and information sharing protocols. It therefore becomes apparent that BIM appropriation is part of broad interconnected systems of rules, structure, actors and groups across multiple levels (Geels, 2005). Inter-organisational protocols that are formally written down and understood by organisational members have been

shown to engender stabilising effect because everyone becomes aware of what to expect in terms of appraisals and appraisal levels. Thus, the contractual protocols related to BIM implementation processes are likely better instituted and established in organisations to enforce and firm-up the holistic visions associated with the BIM implementation processes.

The use of the STS approach in conjunction with the analytical framework add greater substantiation to the phenomenon seen in the case studies guided by Molina's STC framework that bridges institutional field and organisational levels of analysis. Molina's sociotechnical constituency approach (Molina, 1998) allows a vivid depiction of the seamless web of ensemble (Bijker et al., 1987) active in shaping the changes seen. The sort of technological artefacts and the concomitant process solutions that manifest from a variety of institutions are negotiated, assembled and aligned into a coherent set of practices and processes. This pattern of causal sociotechnical antecedents has already been discussed across the chapters particularly in chapter seven (section 7.3.4). The findings reinforce the results by Harty (2005) and Taylor & Levitt (2007), which have identified the need for a systemic perspective when implementing technologies crossing organizational boundaries. In summary, the concept of sociotechnical constituents' alignment captures the complex dynamics, interactions and dependencies between people, practices and technologies occurring across different construction contexts, and allows for the visions and expectations which inform actors' activities. It is in favour of more iterative interactions and relations and reflects the emphasis on the interdependence of social and technical as work systems alignment progresses. More importantly, the STS inspired multilevel BIM implementation analytical framework as presented in this study provides both construction practitioners and policy makers with a sense of awareness of the necessary structures required in a BIM-enabled work environment. The study therefore enhances our understanding of the contextual issues associated with the appropriation of BIM in construction organisations.

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Appendices

Appendix 1: Research ethics and methodology documentation

- Appendix 1a: Loughborough University ethical mini checklist
- Appendix 1b: Request for participation in the research
 - Appendix 1c: Participants information sheet
 - Appendix 1d: Informed consent form

Appendix 2: Profile of organisations and research respondents

Appendix 3: Exploratory study data collection guide

Appendix 4: Case study data collection guide

Appendix 5: Evaluation statement for industry practitioners

Appendix 6: Summary of overall research process

Appendix 7: Publications and achievements

Appendix 1: Research ethics and methodology documentation

Appendix 1a: Loughborough University ethical mini checklist

School of Civil and Building Engineering

Ethical Mini-Checklist

What is this checklist for?

This checklist asks you to consider the consequences of your proposed study on any human affected by it; by participating in your work or otherwise. It is a precursor to a formal submission to the University's Ethical Advisory Committee where required by the University. The University's ethical process is there to support and protect you. If ethical problems were to arise and you have followed the full University procedure, the University will fully support you.

This checklist has been produced to help investigators consider the often amorphous issue of "ethics." It should assist in the development of high-quality research protocols that stand a better chance of being successful. Or, at least, not failing to secure funding or approval for any ethical oversight.

What does this checklist signify?

That, where your study will engage with or otherwise influence human subjects, the potential consequences of that interaction upon: the participants; you; your colleagues; your department and institution; and your funders has been considered in your research design insofar as is possible at this initial stage.

Completion, submission and acknowledgement of this document does not validate or otherwise approve the ethical considerations of your proposed research design. It merely signifies that, where relevant, you have initially considered these issues.

Careful consideration of the questions below will help you develop a proposal that contains an appropriate ethical treatment of human subjects. This reduces the likelihood of its rejection on that basis.

Do I have to complete this checklist?

Yes. All RX2 forms will only be signed by the Head of Department and PhD progressions approved if a completed Ethical Mini-Checklist is provided. Completion of this checklist is not optional. It is good practice and, thus, should not create additional work.

Why am I being asked to complete this checklist?

Everyone has to. Even if your study doesn't involve people in any way.

Questions

Q. 1a. Does your proposed study involve people? YES

If YES, consider Q. 1b. If NO, please complete Q. 7 and Q. 8 only.

Q. 1b. Is there a possibility that a person could be harmed, could be thought of by others as having been harmed, or could consider themselves to have been harmed as a consequence of your study; by participating in it or otherwise? NO

If YES, please consider Q. 2 through to Q. 6, remembering to also address any issues they raise in the design of your study. Also complete Q. 7 and Q. 8.

If NO, please complete Q. 7 and Q. 8 only.

Q. 2. Obligations to society.

Have you ensured the proposed research design:

- a. carries an appropriate degree of risk for the advances it aims to make? YES / NO
- b. appropriately balances any conflicts of interest? YES / NO
- c. will be conducted objectively? YES / NO

Q. 3. Obligations to your subjects (i.e. the individuals participating in or affected by your study).

Have you ensured the proposed research design:

- a. is not unduly intrusive and respects subjects' privacy, feelings and sensitivities? YES / NO
- b. will obtain consent (either informed or by assent) from all subjects? YES / NO
- c. adopts appropriate protocols to protect subjects from harm if obtaining informed consent is not possible? YES / NO
- d. protects the interests of subjects? YES / NO
- e. prevents the disclosure of subjects' identities without their express permission? YES / NO

Q.4. Obligations to your colleagues.

Have you ensured the proposed research:

- a. will be conducted impartially? YES / NO
- b. will present its findings honestly and accurately? YES / NO
- c. will not expose you or your colleagues to the risk of physical or mental harm? YES / NO

Q. 5. Obligations to your host institution and funders.

Have you ensured the proposed research design:

- a. clearly defines the roles and responsibilities of those involved? YES / NO
- b. is appropriate, and was selected after careful consideration of alternative approaches? YES / NO
- c. does not pre-empt its outcomes? YES / NO
- d. will protect the gathered data appropriately? YES / NO

Q. 6. The research team.

Have you ensured the proposed research design:

- a. identifies the investigators and explains their experience? YES / NO
- b. establishes the competence of the investigators to identify and address ethical issues (with appropriate external support if necessary)? YES / NO

Please consider the above issues carefully. They are significant and, if not fully considered, may have harmful consequences, potentially including the rejection of your application by a funding body.

If you have answered NO to any part of Q. 2 to Q. 6, please further consider those responses. If you are not completely convinced that answering NO is justified by the nature of your work, then revise your study design until you are able to answer YES.

Q. 7. Proposal Title: Socio-technical Systems Analysis of Building Information Modelling (BIM) Implementation in Construction Organisations

Q. 8a. Student (Name & signature where applicable): Enoch Sackey

Q. 8b. Principal Investigator / Supervisor (Name & signature): Dr Martin Tuuli and Professor Andy Dainty
Date: 01/11/2011

This document is derived from The Social Research Association's Ethical Guidelines. These are available from www.the-sra.org.uk

Appendix 1b: Request for participation in the research

School of Civil and Building Engineering

Loughborough University Leicestershire LE11 3TU UK

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REQUEST FOR PARTICIPATION IN BUILDING INFORMATION MODELLING (BIM) IMPLEMENTATION RESEARCH

I am Mr Enoch Sackey, a Ph.D. researcher of the School of Civil and Building Engineering, in Loughborough University. This letter is to seek the help of your organisation regarding the above captioned study. The research is being undertaken under the supervisions of Dr. Martin Tuuli and Professor Andy Dainty of Loughborough University.

The target respondents are construction professionals who are BIM users. The questionnaire should take approximately 20 minutes to complete, and it required that the respondents reflect on their broader career experience to provide responses to the questions. In return for participating, we will provide your organisation with the findings of the research findings.

In line with good research ethics, please be assured that the information obtained from this research will be kept strictly confidential and use only for the purpose of this research. Anonymity of individuals and organisations will be maintained. If you require any further information or a clarification, I will be happy to answer your questions. My contact details are shown below.

We thank you in advance for spending some of your valuable time to participate in this research. Without such expert input the intended contribution of this research towards advancing the construction industry will not be realised.

Thank you in advance for participating in this vital study.

Sincerely,

Enoch Sackey
Doctoral Researcher
School of Civil and Building Engineering
Loughborough University
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Please use this template as a guide for your Information Sheet. Please remove or add sections as appropriate to your study.



Appendix 1c: Participants information sheet

Project Title: Socio-technical Systems Analysis of Building Information Modelling (BIM) Implementation in Construction Organisations

Participant Information Sheet

Contact Details of Investigator / Supervisors

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Tel: 01509 228544
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E.Sackey@lboro.ac.uk

What is the purpose of the study?

Building Information Modelling (BIM) has been shown to enable, and also demand collaborative working relationships among the multidisciplinary project members; also, there are direct cost savings for organisations who adopt the use of BIM on their projects. Thus, both the private and public sector construction clients are beginning to demand for the incorporation of BIM-enabled practices into the design, construction, and operational stages of a facility.

The demand by both the private and public sector construction clients, coupled with the expected benefits from the use of BIM suggest the need for construction organisation to develop their organisation's capabilities for the use of BIM in order to stay competitive.

The question that remains is how can BIM be effectively implemented in construction organisations in order to realise the optimum benefits for the multidisciplinary project stakeholders? Though the BIM concept is relatively nascent, several researches have proved that, by virtue of purchasing 'off-the-shelf' information system (IS) technology does not guarantee the full realisation of the benefits due to several influential factors during the implementation process.

The ultimate goal of this research is to develop and evaluate a framework for successful BIM implementation. The focus will be on a socio-technical system perspective which encompasses technological influence, people attributes and organisational processes.

Empirical data will be collected through exploratory interviews with construction practitioners who have expertise / knowledge in BIM-enabled projects. This will help ensure that information gathered through literature review for the initial framework is in alignment with reality and current practices. After the exploratory studies, Inductive case studies will also be conducted on construction projects where BIM communication tools and processes are being used for the delivery of those projects. Data collection in the case design will comprise interviews, participation observation, and document analysis. The case studies will help in the development and validation of best practice BIM implementation framework through a socio-technical systems perspective.

Who is involved in the research?

This research is part of a Doctoral Thesis being conducted by Enoch Sackey and sponsored by the School of Building and Civil Engineering, Loughborough University. The research supervisors are Dr Martin Tuuli and Professor Andy Dainty.

Are there any exclusion criteria?

N / A

Once I take part, can I change my mind?

Yes! After you have read this information and asked any questions you may have we will ask you to complete an Informed Consent Form, however if at any time, before, during or after the sessions you wish to withdraw from the study please just contact the main investigator. You can withdraw at any time, for any reason and you will not be asked to explain your reasons for withdrawing.

Will I be required to attend any sessions and where will these be?

Interviews will be conducted with participants. However, location, date and time of the interviews will be arranged prior; to suit both the participants' and the researcher's availability.

How long will it take?

Please outline either the expected time requirement for each session or the total time required. This should include the expected amount of time any questionnaires, interviews or focus groups will take to complete.

Is there anything I need to do before the sessions?

The selected criteria for this studies is construction professionals who have expertise in BIM tools and processes thus the scope of the discussions will focus on BIM-based working and practices as the researcher aims to understand from the perspective of the participants how BIM works in practice. You are not therefore required to do anything before the sessions.

Is there anything I need to bring with me?

Any information that will contribute to the understanding of how BIM tools and processes manifest in practice (or contributes to the delivery of the project) is very much welcome.

What type of clothing should I wear?

Participants are free to decide what type of clothing to wear.

Who should I send the questionnaire back to?

All correspondences should be sent back to Enoch Sackey

Email: E.Sackey@lboro.ac.uk

Mobile: 07950819048

Address: Department of Civil and Building Engineering, Loughborough University, Loughborough, LE11 3TU

What will I be asked to do?

Data for the study will be gathered through documentation analysis, participation observation and semi structured interviews. BIM-enabled construction projects will be selected as case studies for data collection purposes. Participants are expected to provide information on BIM implementation from industry practitioners' perspectives. Discussions with participants will focus on the routine BIM practices and processes for the identified case study projects. Data collection will commence from January 2011 and it is expected to last for about 9 months.

What personal information will be required from me?

Participants will be expected to provide demographic information such as position in organisation, BIM experience, current BIM projects, nature of BIM projects and role on project, and finally tenure in project and the organisation.

Are there any risks in participating?

There are no anticipated risks in participating. Data collection methods could be conducted from the participants' premises; however, interview sessions with participants may be expected to last for about one hour.

Will my taking part in this study be kept confidential?

Participants are assured of the confidentiality of any information they provide and any response provided will be used for research purposes only. At no time will the true identity of the organisation or the respondents be linked to any particular information gathered for the studies.

What will happen to the results of the study?

The results will be analysed. The findings from the analysis will help in the development and evaluation of best practice BIM implementation framework for the construction industry. Findings will be published in a thesis that will be submitted to the Department of Civil and Building Engineering of the Loughborough University. Journal papers will also be published in top rated construction related journals.

What do I get for participating?

Output of the research will be issued to the participants, especially regarding best practice BIM implementation framework for the construction industry

I have some more questions who should I contact?

All queries or questions should be directed to Enoch Sackey. Alternatively, participants can contact Dr Martin Tuuli or Professor Andy Dainty at the School of Civil and Building Engineering or further clarification

What if I am not happy with how the research was conducted?

The University has a policy relating to Research Misconduct and Whistle Blowing which is available online at [http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing\(2\).htm](http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm).

Thank you

Appendix 1d: Informed consent form

School of Civil and Building Engineering

Loughborough University Leicestershire LE11 3TU UK

Switchboard: +44 (0)1509 263171 School: +44 (0)1509 222884



Research Proposal A Sociotechnical Systems Analysis of Building Information Modelling (STSaBIM) Implementation in Construction Organisations

INFORMED CONSENT FORM (to be completed after Participant Information Sheet has been read)

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in this study.

Your name

Your signature

Signature of investigator

Date

Appendix 2: Profile of organisations and research respondents

Profile of Organisations and Research Respondents

Exploratory Studies						
Participant (Pseudonym)	Work Title	Experience	Gender	Company ref.	Organisation Type	
1 Ga-B	BIM Coordinator	16year structural and civil engineering	Male	BCO1	Multidiscipline Consulting Engineering Firm	
2 Na-I	BIM Development Leader	8years BIM and CAD Design	Male	BCO2	Design/BIM Consultancy Firm	
3 Pe-B	Director	Over 30 years in architectural practice	Male	BCO2	Design/BIM Consultancy Firm	
4 Ma-B	Group BIM Manager	21years Wider AEC knowledge	Male	BCO3	Contractor Organisation	
5 Ti-E	Group Innovation and Knowledge Manager	Over 20years in innovation and best practice solutions	Male	BCO3	Contractor Organisation	
6 Ha-O	Graduate Estimator	Over 4years quantity surveying	Male	BCO3	Contractor Organisation	
7 Ia-S	Design and Project Manager	23years building design and facilities management	Male	BCO4	Architecture Practice	
8 Ma-M	Senior Quantity Surveyor	12 years construction projects	Male	BCO5	Cost Management Consultancy Firm	
9 Ia-M	Industry Consultant	17years construction and infrastructure consultancy	Male	BCO6	Software Developers for the AEC Sector	
10 Ma-S	UK Head of BIM	Over 25years civil/structural design management	Male	BCO7	Contractor Organisation	
11 St-B	Director	Over 18years in architecture and innovative healthcare design	Male	BCO8	Architecture Practice	

1 2	Ph-L	Head of BIM(M)	Over 37years in design and construction management	Male	BCO9	Civil and building
1 3	Do-B	Group Director	39 years architectural design	Male	BCO10	Infrastructure & building management
1 4	Va-V	Design Engineer	5 years design engineering	Male	BCO10	Infrastructure & building management
1 5	Ni-B	Director	22years Geodetic engineering	Male	BCO11	Geomatics and 3D Laser scanning to BIM
1 6	Ro-D	Technical Advisor	6years BIM and CAD design	Male	BCO12	Specialist Contractors

Case Study Alpha						
	Participant (Pseudonym)	Work Title	Experience	Gender	Company ref.	Organisation Type
1	Ph-L	Head of BIM(M)	Over 37years in design and construction management	Male	CS-Alpha	Civil and building contractor
2	Ch-K	Senior Design Manager	22 years in design and project management	Male	CS-Alpha	Civil and building contractor
3	Ch-J	BIMM Manager	7 years Architectural design and BIM application	Male	CS-Alpha	Civil and building contractor
4	Da-W	Senior Services Engineer	10 years in estimating and services engineering	Male	CS-Alpha	Civil and building contractor
5	Sc-D	CAD / BIM Design	4 years in BIM and architectural design	Male	CS-Alpha	Civil and building contractor
6	Ri-D	BIM Coordinator	10 years in BIM and architectural technology	Male	CS-Alpha	Civil and building contractor
7	St-R	Senior Consultant	25 years BIM / CAD Manager	Male	CS-Alpha	Civil and building contractor
8	Ph-M	MEP Engineer	7 years M&E design coordination	Male	CS-Alpha	Civil and building contractor
9	Da-S	Architect / Project	16 years in architectural	Male	CS-Alpha	Civil and building

coordinator	design and project management	contractor
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Case Study Beta						
Participant (Pseudonym)	Work Title	Experience	Gender	Company ref.	Organisation Type	
1 Da-L	Managing Director	13years structural steel design and fabrication	Male	CS-Beta	Specialist contractor (Structural engineering)	
2 Ne-S	Operations Manager	22years structural steel modelling and fabrication	Male	CS-Beta	Specialist contractor (Structural engineering)	
3 Ja-M	Technical Manager	15year structural steel design and CAM	Male	CS-Beta	Specialist contractor (Structural engineering)	
4 De-M	Design Engineer	3years CAD/CAM Management	Male	CS-Beta	Specialist contractor (Structural engineering)	
5 Da-M	Contracts Manager	35years Commercial and contract management	Male	CS-Beta	Specialist contractor (Structural engineering)	
6 Ro-D	Technical Manager	9Year design management	Male	CS-Beta	Specialist contractor (Structural engineering)	

Case Study Gamma						
Participant (Pseudonym)	Work Title	Experience	Gender	Company ref.	Organisation Type	
1 Ma-J	Head of Design & Engineering	13years design and engineering management	Male	CS-Gamma	Civil and building contractor	
2 Th-R	Technical Manager	9years CAD/CAM engineering	Male	CS-Gamma	Civil and building contractor	
3 Jo-F	Commercial Director	30years commercial/contract management	Male	CS-Gamma	Civil and building contractor	
4 Pa-G	Technical and Sales Manager	9years business development	Male	CS-Gamma	Civil and building contractor	
5 Ma-P	Project Manager	10years design and engineering	Male	CS-Gamma	Civil and building	

							contractor	
6	Ch-W	Marketing Director	22years strategies and implementation	B2B and	Male	CS-Gamma	Civil building contractor	and
7	Do-W	Technical Manager (Structural engineer)	5years structural design		Male	CS-Gamma	Civil building contractor	and
8	Ro-M	Technical Manager	4years business development / solar energy		Male	CS-Gamma	Civil building contractor	and

Appendix 3: Exploratory study data collection guide

Profile of Organisations and Research Respondents

Exploratory Studies

The exploratory study is part of a doctoral research investigating BIM implementation in construction organisations. The research focuses on a sociotechnical systems perspective which encompasses the technological influences, people attributes and organisational processes.

Purpose of the exploratory study

The study focuses on construction organisations involved on BIM project(s). The purpose of the exploratory study is to explore the participant' perceptions of the way BIM is being articulated and how it is manifesting / perceived at the individual, the organisation and the project level at the participating organisations.

Objectives of the exploratory study

- Explore exemplars of where and how BIM is being used in leading construction organisations
- Understand from the perspectives of construction professionals how BIM works in practice
- Examine the challenges to be expected in practice during the implementation process
- Understand how the challenges can be managed from practitioners perspectives
- Examine from practitioners the important factors to consider when implementing BIM
- Develop an STS framework for BIM implementation that will be tested and validated through abductive case studies.

Target respondents

Targeted respondents are construction professionals who are BIM users. Respondents are encouraged to rely on their broad industrial experience to answer semi-structured questions to the best of their ability. There are no "correct" or "incorrect" answers, only the valued experts' responses are requested. The research participants and their involvement/knowledge on a BIM-enabled project present opportunities to gather high quality, context specific empirical data that reflects the true manifestation of BIM implementation. This will lead to the development and evaluation of best practice BIM implementation framework. Information gathered will be treated as confidential and will be used only for the purposes of this research. Anonymity of individuals and organisations will be maintained.

The discussions with the industry practitioners are expected to cover issues such as:

- Capabilities of BIM and its complementary technologies
- Identification of main issues and understanding of problems experienced by BIM stakeholders that are likely to threaten successful BIM rollout
- Changing roles and responsibility of the multifunctional project teams
- Changes in the organisational processes to accommodate BIM

- Understanding of STS analytical framework to help analyse the BIM implementation process in the case study organisations

Interview questions

The interview is aimed at exploring the participants' BIM implementation success and oversight experience. Different research questions to be explored cover areas such as:

- A brief history about the interviewee and his/her experience/familiarity with BIM
- What is your understanding of, and experience with BIM?
- What should construction organisations expect to gain from successful BIM implementation?
- What are the important issues to consider when implementing BIM and how will these issues impact on BIM appropriation in construction organisations?

The findings from the exploratory study is expected to provide useful industry practitioners / experts perspective on BIM implementation. The responses will be compared with the existing literature to ensure that the literature review developed for this research is relevant and useful for the industry. It will also help in developing a more robust and significant research enquiry and STS analytical framework to analyse and empirically validate BIM implementation through abductive case studies.

Appendix 4: Case study data collection guide

Appendix 3a: Sources for the case study data

- Interview transcripts
- Notes of projects/sites meetings
- Observational notes
- Background information of case organisations
- Background information of organisations' BIM projects
- Materials (e.g., BIM strategy documents) collected from case organisations

Appendix 3b: Generic case study interview guides

Interview's Discussion Guide	
<i>Key themes</i>	<i>Examples of variables</i>
Part 1 Context	
Background information of organisation	<ul style="list-style-type: none"> • Organisational information • Technology and growth strategy • Organisation objectives
Part 2 BIM Initiatives	
6. Initiatives (e.g., motivation, vision and action)	<ul style="list-style-type: none"> • Vision • Motivation • Prime drivers of BIM initiative • Resources: needed and available • Actions: including inter-level alliance and persuasion
7. Make-up (components) of BIM (innovation assemblage)	<ul style="list-style-type: none"> • Technology / technical artefacts • Different actors • Tasks / emerging roles and responsibilities • Structure / Organisational reconfiguration
8. BIM implementation plan / strategy (Perceptions of what is required for the BIM implementation process)	<ul style="list-style-type: none"> • Targets: aim and objectives • Means of achieving targets <ul style="list-style-type: none"> - Access to resources - Constituency building and networking - Technological / choice of vendor and collaboration - Other aspects of development and competitive advantage - Streamlining BIM competency and maximising benefits
9. BIM governance (perceptions of how things actually manifest)	<ul style="list-style-type: none"> • Governance: formal and informal <ul style="list-style-type: none"> - Individual perceptions / personal circumstances - Organisational circumstances
10. Appraisals of BIM	<ul style="list-style-type: none"> • Successes and oversights experiences

(perceptions of any weaknesses/problems and strengths with regards to implementation realities)	<ul style="list-style-type: none"> - Building depth of actors' knowledge and relations - Process transformation/alignment to BIM concept - Strengthening/increasing technical capabilities - Strengthening the governance of the BIM initiative
Part 3 Inter-organisational sociotechnical BIM constituencies	
<ul style="list-style-type: none"> • Understanding of strategic aims BIM stakeholder organisations / construction professionals may have at inter-organisational level (micro-meso macro strategies) • Reflections on inter-organisational strategies and relationships 	
5. Networking at the project level (project stakeholders relationships and project BIM implementation strategies)	<ul style="list-style-type: none"> • Nature of links and role • Any agglomeration benefits • Any barriers to synergies/collaboration • Organisation to project BIM implementation plan
6. Choice of BIM vendor (technological institutions)	<ul style="list-style-type: none"> • Nature of links and role • Any agglomeration benefits • Any barriers to synergies/collaboration • Any knowledge sharing or technology transfer
7. Network supporting organisations (R&D institutions, policy mandates)	<ul style="list-style-type: none"> • Nature of links and role • Any agglomeration benefits • Any barriers to synergies/collaboration • Government's policy mandates and impacts • Any knowledge sharing or technology transfer



Appendix 5: Evaluation statement for industry practitioners

Evaluating the Research Output of the Sociotechnical Systems Analysis of BIM Implementation in Construction Organisations

Objective

The objective of the research evaluation is to gather practitioners opinions on the practicality and feasibility of the research recommendation captured in the research output.

Agenda

Introduction

A brief introduction of the research aim and objectives

An overview of the research methodology

Literature findings of BIM implementation processes and challenges

Exploratory findings of BIM implementation across some selected organisations

- Overview of the STS theoretical framework for analysing BIM implementation
- Sociotechnical constituency STC alignment of BIM implementation framework

Sample cases illustrating STS analysis of BIM implementation

Implications of key findings to existing theories and BIM implementation mandates

Questions and answers

Discussion and feedback

Participants are to receive hand-out of the research material / presentation

Feedback from participants

Name:

Organisation represented:

Position in organisation:

Years of construction experience:

Has your organisation carried out any BIM project? Yes / No

If yes, please give a brief description of the project:

.....
.....
Have you been involved in any BIM project? Yes / No

Questions on the evaluation of the research output

- The output of the research is important and relevant to the current issues associated with BIM rollout in construction organisations Yes / No
- The research output and the STS analysis of BIM implementation present a lens for identifying contextual elements influencing the BIM implementation outcome Yes / No
- The recommendations put forward in the research output are considered as comprehensive in resolving the issues associated with the rollout of BIM across construction organisations Yes / No
- The recommendations of the research are consistent with the expectations of the required modalities for effective utilisation of BIM Yes / No
- The practicality of implementing the research outputs and recommendations are considered as technically and socially feasible Yes / No
- Overall, the research objectives and outcome are considered to be understandable and useful for dealing with issues associated with BIM implementation Yes / No

What changes / amendments or critiques do you have regarding the research outcome?
.....
.....
.....

What additions or complementary BIM implementation approaches you will consider to be relevant to the study?
.....
.....

Please give any general comments that you feel might help improve the rollout of BIM in construction organisation:
.....
.....

Thank you.

Appendix 6: Summary of overall research process

Study title:		A Sociotechnical systems analysis of BIM implementation in construction organisations		
Problem/issue/rationale	Research objectives	Research aim	Sources of data and analyses techniques	Related chapters in the thesis
<ul style="list-style-type: none"> • Few studies have offered a clear conceptualization of STS implications on BIM appropriation in construction • The importance of context in (re)defining and (re)interpreting the original roles and expectations of technology when deployed in a social system cannot be ignored. • The important roles of actors, new structure of the organisation and understanding how the technology can be utilised to address the defined tasks/deliverables 	Review existing literature and theories on technology implementation in construction organisations	A Sociotechnical systems analysis of BIM implementation in construction organisations – to foster appropriate STS intervention for the appropriation of BIM in construction organisations. Such intervention recognises the mutual dependency existing between the	Synthesis of secondary data findings	Chapters 2 and 3
The prevailing literature on systems thinking on the interaction of systems' elements and its applicability in construction is examined. Explore BIM implementation from a sociotechnical perspective in BIM-enabled construction organisation	Explore the contributions of sociotechnical approach in dealing with BIM implementation opportunities and constraints within construction organisations	technological artefacts and contextual factors existing in construction organisations	<ul style="list-style-type: none"> • Synthesis of primary and secondary data findings • Exploratory study by experts' sampling • Within case and cross case studies • Qualitative content analysis (QCA) 	Chapters 3, 5, 6 and 7

<p>The transformation of construction processes as a result of BIM and related construction technology is rarely explored. A better understanding of organisational roles and processes that support BIM uptake is explored through empirical studies</p>	<p>Investigate the new organisational processes associated with BIM implementation in construction organisations</p>		<ul style="list-style-type: none"> • Exploratory study by experts' sampling • Within case and cross case studies <ul style="list-style-type: none"> • Qualitative content analysis (QCA) • Synthesis of research findings 	<p>Chapters 5, 6 and 7</p>
<p>BIM is expected to impact on employees' roles and responsibilities. This calls for management intervention and support without which there will be resistance to change. Such a support has generally lacked in construction organisations. An effort to understand how roles and responsibilities should and can be supported is important for this study.</p>	<p>Examine the implication of BIM uptake on the changing roles and responsibilities of construction professionals</p>		<ul style="list-style-type: none"> • Exploratory study by experts' sampling • Within case and cross case studies <ul style="list-style-type: none"> • Qualitative content analysis (QCA) • Synthesis of research findings 	<p>Chapters 5, 6 and 7</p>
<p>Synthesis of research findings used to develop an STS analytic framework to facilitate the analysis of BIM appropriation in construction organisations</p>	<p>Propose a framework for BIM implementation analysis that may address the challenges confronting BIM implementation</p>		<ul style="list-style-type: none"> • Synthesis of primary and secondary data findings <ul style="list-style-type: none"> • Abuctive research process 	<p>Chapters 5, 7 and 8</p>
<p>The need to validate the feasibility and relevance of the research contribution to practice</p>	<p>Evaluate the relevance of the analytical BIM implementation framework</p>		<ul style="list-style-type: none"> • Scholarly evaluation of research findings • Evaluation with industry practitioners 	<p>Chapter 8</p>

Appendix 7: Publications and achievements

Peer review publications

- Sackey, E., Tuuli, M.M. & Dainty, A.R. (in press). A sociotechnical systems approach to BIM implementation in a multidisciplinary construction context. *Journal of Management in Engineering*.
- Sackey, E., Tuuli, M.M. & Dainty, A.R. (2013) A sociotechnical alignment and innovation in construction: The case of BIM implementation in a heterogeneous context. In Boyd, D (edn) *ARCOM Doctoral Workshop, BIM Management and Interoperability*, 20 June, Birmingham City University, UK, Association of Researchers in Construction Management, 33-46.
- Sackey, E., Tuuli, M.M. & Dainty, A.R. (2013a) BIM implementation: From capability maturity models to implementation strategy. In: Soetanto, R., Tsang, N., and Ahmed, A. (edns.) *Sustainable Building and Construction Conference SB13, Integrated Approaches to Sustainable Building: Developing Theory and Practice through International Collaboration and Learning*, 3-6 July, Coventry University, UK, 196-207.
- Sackey, E., Tuuli, M.M. & Dainty, A.R. (2013b) Transitioning to Building Information Modelling capability: A sociotechnical systems perspective. In: *Procs of the Salford Postgraduate Annual Research Conference*, (SPARC), Salford, 5 – 6 June.
- ** Sackey, E., Tuuli, M.M. & Dainty, A.R. (2011). Dynamics of empowerment in projects. In: Laryea, S., Leiringer, R.T.F. & Hughes, W. (eds). *Procs of the West Africa Built Environment Research (WABER) Conference*, Accra, Ghana, 19-21 July 2011, pp. 347 - 359.
- ** Sackey, E., Tuuli, M.M. & Dainty, A.R. (2011a). A spatiotemporal perspective on empowerment. In Wamelink, H., Geraedts, R. & Volker, L. (eds.) *MISBE2011, Procs of the international Conference on Management and Innovation for a Sustainable Built Environment*, Amsterdam, Netherlands, 19-23, June,. 195-210.

Awards

- July 2013 – Award Winner** (Best research Paper in Building Information Modelling) at the sustainable Building Conference, Coventry University. Research paper entitled “BIM Implementation: From Capability Maturity Models to Implementation Strategy.” Award sponsored by Vinci (UK) Construction Limited.

***These papers are not directly related to the research reported in this thesis, but were developed and published during the duration of the study.*