Enhancing Buildability through Improving Design-Construction Feedback Loops within Complex Projects

by

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Declaration

Certificate of Originality

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgments or in footnotes, and that neither the thesis nor the original work contained therei121n has been submitted to this or any other institution for a higher degree.

Author's signature ....

Date ....

Abstract

Current attempts to answer the questions of how learning can be nurtured within projects; and, how it can be shared within the supply chain make a conscious stance in support of one of two seemingly conflicting perspectives. These are; a first generation knowledge management systems perspective, or a second generation socialisation perspective. This study shrewdly identifies that to categorically anchor to simply one perspective is fundamentally flawed. It is a strategy which regards each as mutually exclusive and therefore negates the advantages of its opposition.

Each perspective is suited to differing needs. A first generation perspective satisfies the desire of organisations to create a tangible representation of their knowledge base. However, purely focusing on this need ignores the requirement of socialisation, which is essential for effective tacit knowledge transfer. This has astutely been identified as causing cycles of disillusionment due to its inevitable inability to perform effective knowledge sharing. In comparison, a purely second generation approach fails to satisfy the desire to produce a tangible resource base, which thus reduces the incentives for organisations to provide vital socialisation opportunities.

It has been widely acknowledged that learning within projects is needed to make strides towards continuous improvement. If this is not the case, the industry will continue to repeat flawed practices or continuously reinvent solutions unnecessarily. This is resulting in significant inefficiencies within the industry, reduced quality outputs and supplying reduced value. Furthermore, it is not simply the case that learning within individual phases of the construction lifecycle, or within organisations will realise these benefits. For true efficiency benefits to be realised, knowledge and learning from projects has to be shared throughout the supply chain.

This research's contribution has been established through the development of a feedback framework predominantly between construction and design teams throughout a project's lifecycle. The framework provides the capability to transfer lessons to not only individual organisations, but across organisational boundaries also. It seeks to improve internal knowledge management through incorporating critical facets such as live capture, multimedia formats and the ability to network with other knowledge owners/seekers. Accordingly, this project has made a significant theoretical contribution through identifying the ability and need to combine first and second generation knowledge management perspectives.

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List of Abbreviations

AA	Architect Associate
AAR	After Action Review
ACTS	Advanced Construction Technology System
AEDET	Achieving Excellence Design Evaluation Toolkit
AEPIC	The Architecture and Engineering Performance Centre Project
AEC	Architecture, Engineering and Construction
AECO	Architecture, Engineering, Construction and Operations
ASPECT	A Staff and Patient Environment Calibration Tool
BIM	Building Information Modelling
BLIP	Blob Inventory Project
CAD	Computer Aided Design
CAPRIKON	Capture and Reuse of Project Knowledge in Construction
CBR	Case-Based Reasoning
CEIS	The Civil Engineering Information System
CIRIA	Construction Industry Research and Information Association
CLEVER	Cross-sectorial Learning in the Virtual EnteRprise
CLLD	The Constructability Lessons Learned Database
COKE	Construction Knowledge Expert
COLA	Cross-Organisational Learning Approach
CPM	Construction Project Manager
CPD	Construction Project Director
C-SanD	Creating, Sustaining and Disseminating Knowledge for Sustainable Construction: Tools, Methods and Architecture
D&B	Design and Build
DBB	Design-Bid-Build
DTMs	Design Team Meetings
EBD	Evidence Based Design
FM	Facilities Management
FGKM	First Generation Knowledge Management
HBN	Health Building Notes
ICT	Information Communication Technology

IT	Information Technology
IS	Information System
KBS	Knowledge Based System
KLICON	Knowledge and Learning in Construction
KM	Knowledge Management
KMS	Knowledge Management System
KPI	Key Performance Indicator
LA	Lead Architect
LE	Learning Environment
LIFT	Local Improvement Finance Trust
LO	Learning Organisation
LS	Learning Space
M&E	Mechanical and Electrical
MEP	Mechanical, Electrical and Plumbing
NHS	National Health Service
OL	Organisational Learning
OLRL	The Bechtel On-Line Reference Library
OS	Operating System
P21	Procure21
P21+	Procure 21 Plus
PC	Personal Computer
PDA	Personal Digital Assistant
PFI	Private Finance Initiative
PM	Project Manager
POE	Post Occupancy Evaluation
PPE	Post Project Evaluation
PPP	Public Private Partnership
PPR	Post Project Review
PSCP	Principle Supply Chain Partners
RFI	Request for Information
SDBAM	Scheme Design Buildability Assessment Model
SGKM	Second Generation Knowledge Management
SIM	Subscriber Identity Module

SMAZ	Sustainability Management Activity Zone
SME	Small to Medium-sized Enterprises
SMM7	Standard Method of Measurement 7^{th} Edition
SPM	Senior Project Manager
SPV	Special Purpose Vehicle
SPVD	Special Purpose Vehicle Director
STS	Socio-Technical Systems
STSD	Socio-technical Systems Design
TOP	Technical, Organisational and People
TIOP	Technical, Industrial, Organisational and People
UAE	United Arab Emirates
UK	United Kingdom
USA	United States of America
VISCON	Visualisation and communication system
VSO	Virtual Social Organisation
VSO	Virtual Single Organisation

1 Research Background

1.1 Introduction

This chapter provides the background information necessary to understand the evolution of the research problem investigated in this PhD study. It presents an outline of the research context and a justification for the need for research. The scope of the study is communicated through specifying its overarching aim and objectives, and the structure of the thesis has been presented.

1.2 The Need for Research

It is widely accepted that for the construction industry to improve its efficiency and value of its outputs a greater degree of learning and knowledge transfer needs to occur from one project to the next (Egan, 1998; Wolstenholme *et al.*, 2009). However, where this is being recognised and acted upon is in isolation within individual organisations due to its connection with overall improvement (Barlow and Jashapara, 1998; López-Nicolás and Meroņo-Cerdán, 2011) and competitive advantage (Carrillo, 2005; Hari *et al.*, 2005; Carrillo and Chinowsky, 2006; Kivrak *et al.*, 2008; Tan *et al.*, 2011; Gavrilova and Andreeva, 2012). This is viewed as drastically limiting the degree to which overall industrial improvements will be realised due to the lack of knowledge sharing across organisational divides. Furthermore, it has been widely acknowledged that the knowledge management (KM) practices currently adopted are largely deficient in enabling the attainment of their key goal; to share worthwhile knowledge. The need for research therefore is twofold. Greater guidance is required firstly in terms of improving KM practices and secondly towards nurturing a project environment which encourages knowledge sharing.

This first need for research is well-trodden in academia; however it is one that is continuously evolving. For instance, a shift has occurred of late away from generating technologically based knowledge stores towards the need to facilitate socialisation and interaction for real tacit knowledge sharing to take place. Originally this interest grew through the desire of organisations to produce a tangible ‘store’ of knowledge that would reduce the extent to which they were vulnerable to knowledge extraction caused by employees leaving their organisation. This led to the increase in investment in technological solutions such as intranets that store knowledge in a codified format such as text. These KM systems still remain to be found as the solutions adopted by the vast majority of construction organisations today.

The problem is that codified knowledge is insufficient in sharing context specific knowledge especially across organisational and discipline divides. To do this socialisation and communication is required so that a fuller understanding of the original context of the experience and learning can be shared. This has resulted in it now being commonly accepted that knowledge is not suited to being captured and transferred from one individual to the next due to it being context specific and embedded in experience.

Therefore there is an evident need to seek to bridge the degree of disparity between practice and theory, as the construction industry continues to invest and pursue technological KM solutions that will not provide the improvements desired. However, as previously stated, if real industry efficiency, quality and value improvements are to materialise, industry needs to be provided with greater clarification on how lessons emerging from a project can be shared more widely than those immediately involved in the original situation.

Work in this area has begun in attempting to guide organisations in terms of the limitations a purely ICT led KM infrastructure possesses. For example, Newell et al. (2006) acknowledge that it is not the case that no knowledge can be transferred across projects using ICT, as some knowledge can be possessed independently of practice; however, other knowledge is more deeply embedded in practice, making social networks a necessity for knowledge sharing. This points towards the ability to compliment two seemingly opposing perspectives of technological versus socialisation approaches (i.e. first generation versus second generation knowledge management thinking: See Section 2.3).

Accordingly, this thesis responds to the call by Newell *et al* (2006) for:

> *"Further research to be undertaken in the area of the interplay between ICT systems, work practices and the development of face-to-face and virtual communities within organisations. The dichotomy between existing approaches to knowledge management clearly fails to address important areas where 'pure' approaches may fail, but 'hybrid' approaches may succeed" (Newell et al., 2006).*

1.2.1 Overarching Research Question

The overarching research question to arise from the above stated inadequacies is:

> *"How can intra-inter project learning instances be leveraged within highly serviced complex construction projects?"*

1.3 Research Aim and Objectives

1.3.1 Overarching Aim of Project

The fundamental aim of this research is to answer its identified overarching research question (see Section 1.2.1). Accordingly, this points toward the need to develop a basis to which knowledge can flow within and across project divides. Therefore it is the aim of this study to:

> *"Develop a theoretical framework that enables knowledge to be transferred across the organisational and discipline divisions of design and construction within highly serviced complex projects"*

Accordingly, this study's contribution is targeted at theory generation through building on and progressing current knowledge in the area of intra- / inter-project learning. The development of a theoretical framework is designed to illustrate the key emergent themes of this study to enhance understanding and provide a coherent foundation for the basis of further work. This could lead to its utilisation to inform and shape practice; however this thesis' main intention is to develop theory in this area.

1.3.2 Research Objectives

To achieve the overarching aim of this study, research objectives have been set in the form of:

- To examine existing literature relating to the need for and barriers against design-construction learning loops;
- To establish the potential and limitations of current knowledge management procedures;
- To establish the potential and limitations of current feedback loops designed to improve design quality;
- Evaluate which technologies/techniques are most effective to assist learning activities; and,
- To improve cross-organisational boundary learning within complex infrastructure projects.

1.4 Outline of Research Methodology

The methodology adopted to satisfy the overarching research aim and objectives of this research (see Section 1.3) consists of the following methods; a detailed and thorough literature review, sequential case study investigations, cross case analysis and a discussion of the findings leading to the development of the theoretical framework (see Figure 1.1). The methodology, although linear in nature, was conducted cyclically. For example, as emerging themes were detected through one in-depth case study, the literature review was revisited once more.

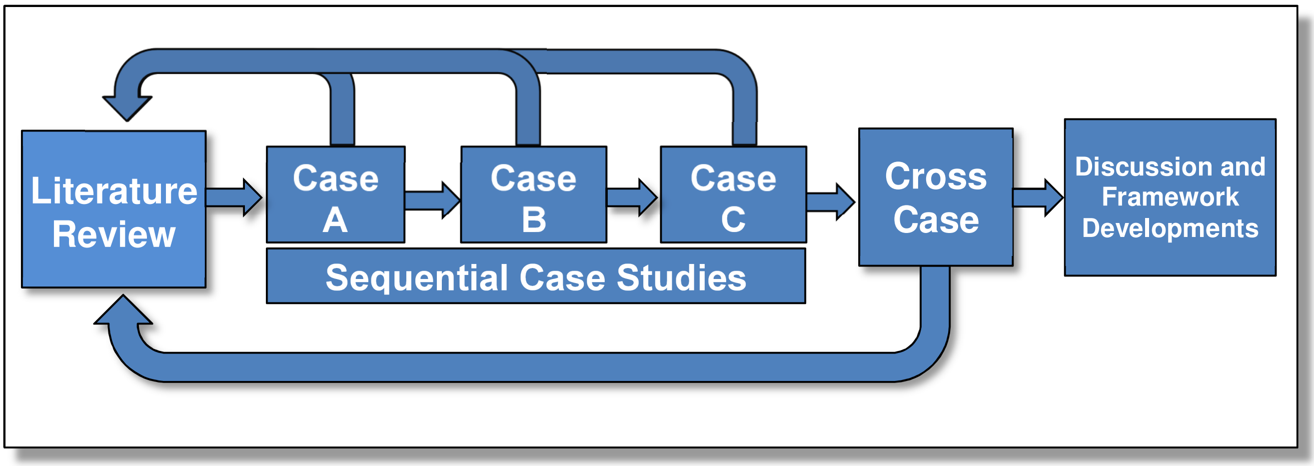


Figure 1.1: Overview of the Undertaken Research Methodology

1.4.1 Literature Review

An extensive literature review which aimed to develop a thorough knowledge base regarding research objectives 1, 2 and 3 (see Section 1.2) was conducted in two stages. The initial review investigated the literary areas of KM and OL. This consisted of developing a detailed understanding of all concepts related to both key areas, the need to improve learning within construction, the benefits of improved learning and means to achieve such. In particular, the need to identify a key learning objective in preference for an unstructured KM initiative was recognised. This was complimented by the identification of the close alignment of the need to improve buildability issues, with that of the need to share lessons learnt and knowledge across organisational and phase divides. As such, a gap in current knowledge was identified in terms of the need to develop a framework which enabled knowledge and information to be captured within the construction phase and be managed so that it can be integrated early on in future projects.

Once this research positioning had been established, a secondary literature review was conducted which focused on investigating the concept of buildability. In addition, a review of complimentary research projects was undertaken to position this study within the wider body of literature and avoid unnecessarily repeating research efforts. This secondary literature review then continued by further investigating means to achieve desired management of knowledge in order to learn and improve (double-loop learning), rather than detect and correct (single-loop learning). This included a detailed analysis of the make-up of the KM life-cycle, supplemented by a review of the techniques and technologies designed to support each phase of the cycle.

1.4.2 Case Studies

The case study approach was adopted due to its ability to generate theory (Eisenhardt, 1989), through an in-depth investigation of current approaches. They consisted of nine semi-structured interviews in total which were used to establish the perspectives of senior personnel and key participants in the process of knowledge sharing between the construction and design phases. The main objective of conducting case studies was to enable a first-hand in-depth understanding of the preceding literature review phase (i.e. research objectives 1, 2 and 3: see Section 1.2). As such, the literature review acted as an effective tool in identifying *what* issues are of importance to observe; whereas case studies enabled answers to *why* and *how* these issues are influential. Accordingly, the case study investigation enabled a much greater knowledge base to be established regarding research objective 4 (see Section 1.2).

Each case study was firstly analysed separately, utilising a method known as within-case analysis. This enabled a rich understanding of the findings of the case to be developed prior to conducting the next case. Consequently, important adaptations could be made to the case study protocol to test emerging or altering propositions from the previous study. Once all three case studies had been completely and individually analysed, cross-case analysis was conducted to establish reoccurring trends or significant differences.

1.5 Research Context

The context of this research is twofold. The overarching context that the research problem is investigated in is the delivery of highly-serviced construction projects. Their complex nature infers that they are highly informed and rich in culminated knowledge from multiple sources. An example case of such is healthcare infrastructure that consists of a magnitude of complex services that have to be housed within a design that often has financial, political and scientific influences relating to their design. Consequently, the complexity of their delivery is increased.

Due to their knowledge richness, the importance for this learning to be shared in order to benefit future developments is heightened further. Alternatively, instances of reinventing previous solutions and unnecessary inefficiencies will inevitably occur. It was decided that it would be beneficial to both the methodology and the communication of findings if the projects chosen for study were comparable and therefore the degree of explanatory variables reduced. For instance, if healthcare, education and industrial power projects were studied, it would be difficult to determine to what extent the differing contexts had influenced the findings observed. Therefore by framing the context to include comparable projects, the findings could be compared more accurately and confidently.

Within this overarching context of healthcare projects, the sub context of buildability has been adopted to concentrate what knowledge is of interest. As will be detailed later in this thesis, attempting to develop a learning culture that attempts to share a magnitude of learning instances is far less likely to be successful (see Section 2.5.3). Instead, adopting a succinct learning objective focuses the KM processes and resources towards heightened levels of success.

Buildability itself is an ideally suited learning objective for this research problem to adopt as it was identified as requiring the sharing of knowledge across organisational divides to occur if buildability problems within the initial project are to be shared to those that can make the greatest impact in future projects. For example, the effects of buildability related problems are experienced within the construction phase of the project; however, they originate from planning and design phases. Therefore if the learning culminating from a project is to benefit future projects, it must be shared between the construction phase and the participants from preceding stages of the process.

1.6 Thesis Structure

The thesis is structured as follows:

Chapter 1: Research Background – This chapter provides an introduction into the research topic area as well as an overview of the how the research originated. The overarching aim and key objectives of the research are outlined, as well as a justification of the need for research in this area being provided. An outline of the research methodology utilised to satisfy the aim and objectives of the research is given as well as a guide to the thesis structure.

Chapter 2: Knowledge Management and Organisational Learning – This chapter consists of the documentation of the first part of a comprehensive literature review. It reports on the identification of the need to conduct research in the area of KM and OL to reduce the extent to which reoccurring inefficiencies affect construction projects. This is realised through investigating the benefits that could materialise on the parts of planners, designers, construction and mutually. The need to focus upon key learning objectives in preference of an overly broad perspective is also established. The difficulties of achieving such are investigated and the barriers to overcome are documented. An analysis of the make-up of the KM lifecycle and a review of KM techniques and technologies designed to support each stage is reported.

Chapter 3: Knowledge Management to Improve Buildability – This chapter forms the second part of the comprehensive literature review. Within this chapter a move towards investigating the concept of buildability is undertaken. This is continued by investigating other related projects in the field of improving buildability and KM frameworks.

Chapter 4: Research Methodology – The documentation of the most critical aspects of a research methodology (ontology, epistemology and methodology) are discussed. A wide array of methodical approaches, both quantitative and qualitative are evaluated so that the most appropriate methods are adopted according to aspects such as the aim and objectives of the project, resource limitations, the context to be investigated, and the data collection and analysis requirements.

Chapter 5: Results – This chapter summarises the key research findings of each case study discussed separately. The findings are structured thematically in a consistent manner to enable cross case analysis to be conducted later (see Chapter 6). As the cases were conducted sequentially, the findings of preceding cases were able to influence the research propositions of the following in order to test their prevalence within other cases. Instances where research propositions were strengthened, weakened, confirmed or dismissed was highlighted throughout each case write up.

Chapter 6: Cross-Case Analysis Findings and Discussion of Findings – A detailed cross case analysis is conducted to produce a synthesis of the key research findings. The aim of this analysis is to substantiate a firm basis for the subsequent development of the learning framework methodology.

Chapter 7: Development of the Research Informed Theoretical Framework – This chapter documents the development of the learning loop methodology proposed by this study. It seeks to examine the effectiveness of the framework within an industrial context through discussing its characteristics with experienced personnel within industry and academia. Consequently, recommendations for further improvements have been integrated into the finalised framework strategy.

Chapter 8: Recommendations and Conclusions – A summary of the research themes discussed throughout this research are made. The key findings, contribution to knowledge, limitations of this study, recommendations for future research and concluding remarks are also provided.

Appendices: A-C – The appendices contain additional documentation that is not integral to the main thesis but is supplementary to further enhance the reader's understanding of the research conducted. An overview of how each research activity satisfied each research objective, development logic of research propositions, case study protocol, and list of publications are all included.

1.7 Research Outputs

Throughout the duration of this study, research outputs in the form of conference and journal papers have been produced. The abstracts of which, and their references are included in Appendix C.

1.8 Chapter Summary

This chapter has provided an introduction into the topic area of interest for this research project. A full justification of the need to address the identified research problem has been discussed, along with the specific demand to achieve such within a healthcare infrastructure context. The overarching aim, as well key research objectives have been outlined to provide further focus and direction. This is followed by an overview of the methodology adopted, which through a thorough review of various methodological considerations has been determined as the best suited to satisfy the aforementioned research aim and objectives. Finally, an overview of the thesis structure has also been provided.

2 Knowledge Management and Organisational Learning

This chapter investigates the key themes of KM and OL. A wide exploratory investigation has been reported pulling on previous research conducted both within healthcare infrastructure and general construction industry contexts. The key terms analysed to establish common definitions to be adopted within this research. The differing types of learning within an individual and organisational context have been documented, followed by an analysis of the main benefits and barriers of improving KM practices within the construction industry.

As such the justification for further research has been substantiated through the identification of key interest areas which have shaped the direction of this study. Such identifications form the basis for a more narrowed and focused review of previous literature, which is thus documented in Chapter 3.

2.1 Introduction

The importance of KM for the purpose of OL has seen an increase in attention in recent years (Kamara *et al.*, 2002). A large degree of construction related OL literature stems from the identification of underperformance within the industry by Egan (1998) and Latham (1994). As cited by Hari *et al.* (2005), these reports acknowledge the need for the construction industry to better manage knowledge that resides in the supply chain, to improve both their efficiency and effectiveness. Although such reports highlighted the necessity for change, it has since been reported that progress towards such targets has been small and in fact fallen considerably short (Wolstenholme *et al.*, 2009).

One of the most significant reasons why it is crucial for construction knowledge to be captured and utilised is that identified by Carrillo and Chinowsky (2006). They acknowledge that construction knowledge is often tied to issues such as buildability, material management, and design intent, each of which are closely related to the design input. Therefore, the capture of construction knowledge is a critical element in improving the design quality of future infrastructure.

Studies from; Kululanga *et al.* (1999), Carrillo *et al.* (2000), Egbu and Botterill (2002), Love *et al.* (2004), Fong (2005), Orange *et al.* (2005) Tan *et al.* (2006), Lee and Egbu (2007), Ruikar *et al.* (2007) and Lopez-Nicolas and Merono-Cerda (2011) have highlighted the potential benefits, challenges and strategies of creating a learning culture. However, construction organisations have been slow to realise the concept of KM as being essential for improving business performance (Graham and Thomas, 2007; Kivrak *et al.*, 2008), and thus implement such procedures (Hari *et al.*2005; Love *et al.* 2004).

This being said, concentrating on improving KM and learning within the construction phase is not viewed as leading to the industry improvements cited by the Egan (1998) and Latham (1994) reports. This was shown through the marginal progression towards such targets detected by the more recent Wolstenholme (2009) report. If true industry efficiency and effectiveness improvements are to be made, knowledge needs to be shared beyond the phase of construction. Accordingly, a greater focus on the interfaces between construction and design is taken, with a deeper investigation into how knowledge can be shared across organisational and disciplinary divides.

2.2 What is Knowledge?

As identified by Martensson (2000), although information is not knowledge, it is an important aspect of knowledge. Blair (2002) delves further by suggesting that just as knowledge is dependent on information, information is equally dependent on data. This indicates an importance to firstly define and separate the terms of data and information before unpacking knowledge.

2.2.1 Data

Blair (2002) states that data is clearly the easiest to describe by offering the definition that they are simply “facts” and “figures” that are meaningful in some way, such as account balances, demographic statistics, or names and addresses. For example, raw data could be in numeric form such as 43, 67, etcetera.

Sanchez (2005) provides the definition that data are qualitative and quantitative representations of events that someone wishes to bring to the attention of other people in the organisation. However, data are always incomplete representations of events as some aspects of an event may be noticed and reported as they are believed to be significant, whilst other aspects are not noticed or reported (Sanchez, 2005). For example, Aamodt and Nygård (1995) state that data are patterns with no meaning, and are therefore the input into an interpretation process ready for decision making.

2.2.2 Information

Information is viewed as data endowed with relevance and a particular purpose (Drucker, 1988). Therefore in the above example of raw numeric data (43, 67 etcetera), Blair (2002) suggests that for this to become information it would need to be given a meaning. This meaning or 'context' could be in the form of the monthly number of rework instances within a certain project.

Sanchez (2005) describes information as being the *significance*, or more precisely, the *meaning,* that is derived from some data when the data are evaluated by an individual using his or her personal interpretive framework (comparing data). When these comparisons of data suggest a significant change in the state of the world or an organisation, that perceived change is the meaning or "information content" (Sanchez, 2005). Conversely, when the comparisons of data suggest that the state of the world or an organisation should not change then the belief to reinforce the status quo is the meaning.

2.2.3 Knowledge

The debate surrounding the question of '*what is knowledge?'* is one that persists without the emergence of a universal definition. Attempts to define knowledge concentrate on differentiating knowledge from information and data (Fernie *et al.*, 2003). For instance, knowledge can be seen as information pooled with experience, context, interpretation and reflection perspective (Martensson, 2000; Jarrar, 2002).

For example, when a site manager's prior experience and beliefs are applied to the information gathered regarding the number of rework instances per month (43, 67 etcetera.), it may be determined that the increasing number of rework instances is acceptable due to a number of factors such as; the project stage and/or its complexity. This accumulated experience has therefore enabled the project manager to interpret and reflect on the information collected within a given context and base decision making upon. In other words, such useful knowledge has been gained through a lesson being learned. This is demonstrated through a lesson being defined as *"an experience from which useful knowledge may be gained"* (Kartam and Flood, 1997). In the case of the above example, a lesson has been learned due to it consisting of a specific problem or situation where a solution and/or explanation have been developed. Accordingly, lessons become embedded in the human mind as 'knowledge'.

It is these generated lessons or experience that organisations attempt to capture to reduce the impact of knowledge extraction if individuals leave as well as to protect competitive advantages

(Swan *et al.*, 1999) (see Section 2.6.3.1). However, it is later criticised in this review that attempts to capture and manage knowledge using a set of tools (i.e. first generation knowledge management) is flawed due to it ignoring the difficulty of applying captured knowledge within different and unique contexts (Swan *et al.*, 1999) (see Section 2.3.1). Therefore, knowledge is further complicated by the notion that it is embedded in the very specific context in which it was shaped and enacted upon (Fernie *et al.*, 2003). This dramatically complicates one's ability to transcribe uncertain and changeable aspects of the situation in which the knowledge was learnt, as they may be too difficult to explain, considered unimportant, too specific, too politically sensitive or too valuable to disclose succinctly (Swan *et al.*, 1999). Accordingly, the differentiation of 'knowledge' falls into two categories; explicit and tacit, which are discussed in the following section.

2.2.4 Types of Knowledge: Explicit and Tacit

In the above adopted stance that knowledge is both individualistic and context specific, it is these two factors which drastically complicate the ability to manage knowledge in the tangible way desired by organisations. This is due to the question of how can the relevant experience, understanding and interpretation of a context specific problem contained in one's head, be captured and stored. In many cases, outlining the initial problem may be straightforward enough, but conveying the process and rationale of overcoming it, whilst defining the relevant context parameters applicable is generally very difficult.

This leads to the separation of types of knowledge into two categories; knowledge that is well suited to being codified and knowledge that is inherently 'impossible' to do so. This separation of knowledge, terming them as explicit and tacit knowledge respectfully, was first distinguished by Polyanyi (1967). 'Explicit' or codified knowledge refers to knowledge that is transmittable in formal, systematic language (Nonaka, 1994), such as grammatical statements, mathematical expressions, specifications, manuals, and thus can be transmitted across individuals formally and easily (Lee and Egbu, 2007). 'Tacit' knowledge has a personal quality, which makes it hard to formalise and communicate as it is deeply rooted in action, commitment, and involvement within a specific context (Nonaka, 1994).

Studies have shown that personal, tacit knowledge is of greater value than explicit knowledge, as it contributes to organisational innovations and competitiveness (Stewart, 1997; Boyd and Belcher, 2002 cf. Boyd *et al.*, 2004; MacVaugh and Auty, 2008; Andreeva and Kianto, 2012). For example, complex construction problems are generally solved by site and project managers using their experience and intuition, which is also known as their tacit knowledge (Boyd *et al.*, 2004). Although seen as of greater value to an organisation, tacit knowledge has also been identified as more difficult to identify and articulate (Nonaka, 1994; Tan *et al.*, 2011) due to it being personal, context-specific, subjective and experience-based (Hari *et al.*, 2005). Consequently, it has been observed that to acquire or transfer tacit knowledge, a learning model which stresses high levels of two-way communication is required (Bessant and Tsekouras, 2001). This therefore hinders the ability to achieve OL due to the difficulties of capturing, storing and disseminating valuable knowledge of individuals.

In comparison, explicit knowledge can be transmitted more easily as it is objective and rational knowledge that can be expressed, formalised, or coded in a natural or artificial language (for example; French, English, Unified Mark-up Language, mathematics, etc.) (Hari *et al.*, 2005). This form of knowledge assists OL due to its ability to be captured, stored and disseminated; however, generally it is of less value.

This compliments two divergent perspectives that are noted within the literature and have seen a shift in focus regarding KM research of late. The first generation knowledge management focus was on knowledge as a mental commodity which can be codified and stored in systems to be exchanged between individuals and systems (i.e. the content perspective) (Visser, 2010). Within this train of thought tacit knowledge must be converted (also known as the codification of knowledge) into explicit knowledge. This is acknowledged by Hari *et al.* (2005), who state that codification of knowledge is vitally important, because without it, the ability to disseminate tacit knowledge is severely limited. The transition between explicit and tacit knowledge is shown in Figure 2.1.

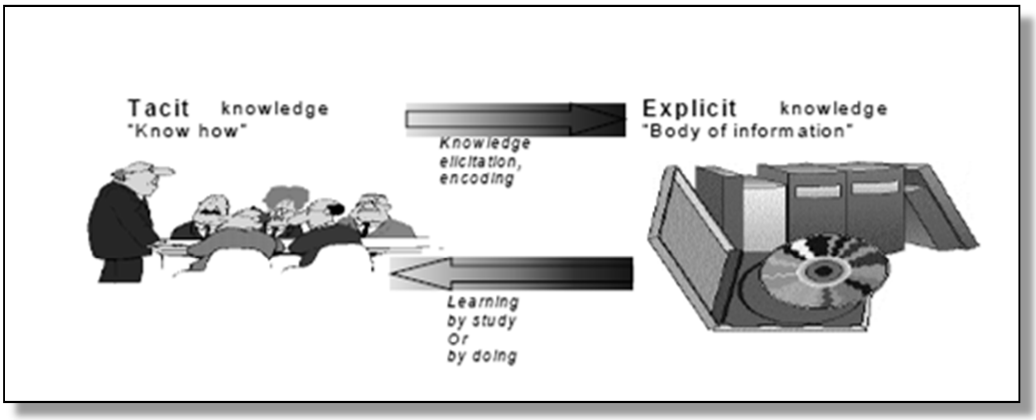


Figure 2.1: The Two Main Types of Knowledge. Source: Patel et al. (2000)

The transfer of knowledge within this perspective ignores the importance of the differing learning styles individuals possess, which stipulates that knowledge is not something that can be codified in a set format. These styles are known by the acronym VARK, which categorises the four physiological learning styles of visual, aural, read-write and kinaesthetic (Drago and Wagner, 2004). For example, audio has characteristics that text lacks, which enhances understanding of information (Panday, 2009). Alternatively, audio in isolation also possesses disadvantages to some learning styles as it may distract the listener's attention and interest (Panday, 2009).

Alternatively, of late there has been a much greater move towards a perspective (termed as the second generation KM perspective) in which knowledge is regarded as a relative, provisional and context-bound phenomenon where knowledge is socially embedded in communities and intimately tied to day-to-day practice (Visser, 2010). It therefore requires humanly possessed skills to reflect, interpret and process the reality at hand (Bell, 1999; Sutton, 2001; Fernie *et al.*, 2003). The above stated need for two-way communication is reminiscent within this perspective; however, it is modernised as 'socialisation'. The fundamental arguments and assumptions underpinning each of these perspectives will now be explored further in the subsequent section.

2.3 Knowledge Management

Within KM literature there are two main theoretical lenses which within this study shall be termed as first and second generation knowledge management. Recent research has seen a shift in towards concentrating efforts on mobilising second-generation KM principles; however, there is an equal degree of consensus that practice continues to conform to a first-generation KM viewpoint. The following sections of this review therefore explore the disparity between academia and practice, by detailing the arguments that underpin each perspective.

2.3.1 First Generation Knowledge Management (FGKM)

A FGKM perspective assumes that knowledge exists within organisations and can be captured and stored (Firestone and McElroy, 2004). Adopting this perspective adheres to definitions of KM that state knowledge can be captured, stored, retrieved and accessed, usually through the aid of information technologies. For example, KM is "*the capture, access, and reuse of information and knowledge using information technology* O'Leary (2001)*"*, or *"a systematic and organised attempt to use knowledge within an organisation to improve performance* KPMG Management Consulting (1998).

Within this perspective, knowledge is seen as a ‘possession’ and an ‘entity’ that can be made explicit and transferred from one person or group to another (Newell *et al.*, 2006). Criticisms of FGKM stem from the opinion that it is overly narrow as it concentrates on explicit knowledge whilst assuming that tacit knowledge cannot be managed because it is in people's heads. Because explicit knowledge is viewed as less useful than tacit knowledge to develop competitor advantage and innovation (Swan *et al.*, 1999), it reduces the worth of the knowledge store, making it less valuable to the organisation and less attractive to utilise. Furthermore, this perspective assumes that the knowledge captured retains its meaning once it is divorced from its original context (Fernie *et al.*, 2003). This implies that once stored, no clarification from the knowledge owner or originator is required surrounding the context in which the experience was created.

A fundamental flaw in the definition offered by O’Leary (2001) is that of the reliance on information technology. As will be discussed in greater detail later (see Section 2.10.1), although information technology is an indispensable tool to assist the function of KM, it should not be solely relied upon. If this is the case then it can result in the function simply becoming ‘information management’ because of the absent element of human interpretation (Robinson *et al.*, 2001) and socialisation (Panday, 2009).

2.3.2 Second Generation Knowledge Management (SGKM)

SGKM differs from FGKM as it views knowledge as situated in social organisational practices and relationships (Newell *et al.,* 2006). In comparison to the FGKM view, knowledge is seen as more socially orientated and therefore values the contribution of socialisation and discussion of a problem in conveying a greater degree of the knowledge context. McElroy’s (2000) typology indicates that FGKM focuses on the supply of knowledge, which includes its dissemination, imitation and exploitation; whereas SGKM focuses on creating and maintaining the conditions required for the production of knowledge.

Thus, when managing organisational knowledge it is essential to not only concentrate on the lessons learnt from a situation, but also on the context in which it occurred, as well as the rationale behind the decision or action taken. As stated in Section 1.5, the research context adopted in this study is highly serviced complex projects. These projects are viewed as having specific intricacies that simultaneously increase the importance in attempting to distil learning from within them, but also the difficulty in doing so. Complex projects tend to be highly serviced and / or present heightened coordination problems during their delivery.

The shared knowledge therefore needs to be as closely representative to the knower's real thinking (contextual information, opinions, stories etc.) as possible. This is due to knowledge being viewed as 'situated' which makes it difficult to transfer to other circumstances (Ruikar *et al.*, 2007). Therefore the greater degree of the consciousness, experience, situation, context or tacitness of the learning opportunity conveyed the more useful and transferable it is likely to be.

A SGKM perspective therefore assumes that knowledge that is codified (i.e. explicit) is little more than information. Instead it focuses on know-how to turn information into 'actionable knowledge' which has consequences for practices and can generate new possibilities for action (Bouwen *et al.*, 2009). This is achieved through socialisation and discussion of the problem so that the 'host' context can be conveyed. This simultaneously alters the emphasis from extracting knowledge from someone in the ambition to later transfer it, towards that of sharing knowledge (Fernie *et al.*, 2003). Where FGKM focuses on a repository approach supported by databases, a SGKM perspective takes a 'network' approach which can utilise technology to connect people and facilitate socialisation (Newell *et al.*, 2006). It is the role of KM therefore to connect two nodes, knowledge owners and knowledge seekers, where the knowledge of one is shared to the mind of another, so that a new decision can be made or situation handled.

This perspective highlights a tension concerning KM implementation, which revolves around how the effectiveness of knowledge transfer can be measured. The FGKM perspective enables organisations to measure aspects of their initiative such as the quantity of knowledge contributions in the system and the degree of use. However, this falls drastically short of being able to measure the effectiveness of knowledge transfer facilitated within this system. In comparison, within a SGKM where all knowing is assumed to be situated and the separation between knowing and doing is not clear, it is much more difficult for organisations to determine the extent to which their investments are being effective. As discussed further in Section 2.6.3 organisations have a high desire towards producing a tangible knowledge resource base to protect competitive advantage and against knowledge extraction (Swan *et al.* 1999). However, the noted inherent difficulty surrounding this critical facet increases the tension towards its mobilisation.

2.3.3 Socialisation and Socio-Technical Systems

The unpacking of what knowledge and KM are, has led to it being stringently evident that the sharing of knowledge is fundamentally dependant on the degree to which the initial 'host' context can be understood and related to. However, it is equally apparent that conveying the contextualised elements of knowledge is enormously difficult as it requires being able to determine the initial context and previous experience of the individuals involved. To heighten the degree to which this may be achieved, two-way communication and socialisation are viewed as essential (Bessant and Tsekouras, 2001; Fernie *et al.*, 2003).

Within a computer science perspective, KM is viewed as requiring knowledge management systems (KMS), which provide technological support to facilitate the creation, access and reuse of knowledge (O'Leary, 1998; Grasic and Podgorelec, 2011). This demonstrates the FGKM perspective. This more directly satisfies organisational demands for a tangible knowledge resource in the attempt to reduce their vulnerability to knowledge extraction when an employee leaves the organisation (Swan *et al.*, 1999), with this desire being heightened within construction due to the inevitable post project break-up of teams (Kamara *et al.*, 2003; Tan *et al.*, 2006; Tan *et al.*, 2011).

However generally, a move towards a SGKM perspective which concentrates on the human aspect of transferring knowledge, supported by IT where applicable has emerged (Graham and Thomas, 2007). This arose because the FGKM perspective led to the development of information stores, rather than a mechanism that is able to share tacit knowledge. An outcome of knowledge being seen as *"bound up with human cognition, and created, used, and disseminated in ways that are inextricably entwined with social activities,"* (Pfaff and Hasan, 2011). Therefore KM must consider organisational and social factors and not be purely technologically focused. Under this perspective a carefully considered combination of KM techniques and technologies is best suited for satisfying the breadth of needs of the proposed feedback loop within this study.

As a result, the development of a knowledge feedback framework between design and construction will require the same design considerations of a socio-technical systems (STS) approach. Socio-technical systems comply with the need to provide integration between *"two types of structure and processes: technical systems, which are engineered to provide anticipatable and reliable interactions between users and systems, and social systems, which are contingent in their interactions and a subject evolution"* (Fischer and Herrmann, 2011). Therefore the process of KM cannot be taken in isolation or assumed to be implemented and utilised in the way it was initially designed. A STS perspective adheres to the need to consider a more holistic view in that social dynamics impact on technical systems as do the reverse.

2.4 Organisational Learning

2.4.1 Connection between Knowledge Management and Organisational Learning

KM is closely related to OL as learning results in the alteration of the beliefs instilled in knowledge (see Section 2.3). Rifkin and Fulop (1997) suggests that it embodies several themes that represent different ways of managerial thinking about what should and should not be done to enable both individual and collective learning in an organisation. They use the following four terms to label these themes; learning organisation (LO), organisational learning (OL), learning environment (LE), and learning space (LS).

Rifkin and Fulop's (1997) descriptions of these themes are as follows:

> A *learning organisation* is an organisation to be created or one that is already learning. Therefore they are the result of successful attempts to facilitate learning within an organisational context.
>
> *Organisational learning* refers to attempted measures to implement 'organisational learning' to create the desired 'learning organisation'.
>
> The *learning environment* is the implementation of particular processes and policies by a manager in order to create a supportive learning environment.
>
> A *learning space* is an arena made available by a release of control by management and by a relaxation of privileging forces in order to facilitate the freedom of people to think and explore and to engage in uninhibited questioning of such things as managerial control.

This study is primarily concerned with how a learning culture can be created within a cross organisational and collective context, where the traditional term of 'organisation' relates to each independent group participating within the project. Therefore this research aims to improve organisational learning within complex construction projects so that the project based learning can be utilised both within that project itself and beyond its lifespan to benefit future projects. In this sense organisational learning refers to the learning generated within the loosely defined boundaries of the temporary multiple organisations (TMOs) involved in completing the construction project.

A unique characteristic of the term ‘project’ within construction in comparison to other industries is that the network of organisations involved in the TMO is connected in a multiplicity of different ways. For example, Dubois and Gadde (2002) identify that projects are made up of short-term tightly coupled organisations within the loose couplings of the permanent industry network. This, they say, has a pertinent impact on learning and innovation as the coordination complexities to do so within such a loosely coupled network is heightened, compared to industries with fewer but more consistent and on-going tight inter-firm couples. Therefore, where longevity and solidity between business to business relationships are desired for on-going cross-organisational learning to take place, the construction industry’s makeup inherently hinders the attainment of this goal. This is a significant reason for such a high degree of the critical learning opportunities apparent in construction projects to not be taken advantage of and consequently important improvements being permanently lost (Latham, 1994; Egan, 1998).

Therefore the themes of interest consist of the overall goal which is to create a learning TMO, measures which can assist in its quest to becoming ‘learning’ (i.e. organisational learning) and what processes and polices support the creation of a cross-organisational learning culture (i.e. learning environment). In regard to the theme of a learning space, in Rifkin and Fulop’s (1997) own words this is an idealised but potentially radical concept. This far-reaching concept is seen as a state that may present the greatest learning potential but one that is impractical in a business sense.

2.4.1.1 Learning Organisation

There have been various attempts to define a ‘learning organisation’ and although there are common ideas connecting the majority of these, a universally accepted definition is absent. For example; a learning organisation has been defined as:

> *“An organisation skilled at creating, acquiring and transferring knowledge and modifying its behaviour to reflect new knowledge insights”* (Garvin, 1993)*;*
>
> *“An organisation that facilitates the learning of all its members and continuously transforms itself”* (Pedler et al., 1996)*; or,*
>
> *“A place where people are continually discovering how they create their reality and how they can change it, requiring a shift of mind from; seeing ourselves as separate from the world to connected to the world; from, seeing problems as caused by someone or something ‘out there’ to seeing how our own actions create*

the problems we experience, as being at the heart of a learning organisation" (Senge, 1993).

The process of learning within an organisation therefore appears to consist of a change or transformation of some sort ultimately being made. However, Garvin (1993) believes that new ways of thinking are enough, which is reflected through Thurbin's (1995) definition that "*a learning organisation is one which improves its knowledge and understanding of itself and its environment over time, by facilitating and making use of learning of its individual members".*

2.4.1.2 Organisational Learning

OL is seen to be the *"process of improving actions through better knowledge and understanding"* (Fiol and Lyles, 1985). However, this definition is so broad that it substantially reduces its use in understanding the concept. The improvement of actions could range from a change in simple individual behaviour to the most advanced organisational process. There is also no indication as to what knowledge is of importance to enable such changes to be made, how this knowledge can be extracted from the day to day normality of working patterns, or, how it can be utilised to determine the positive improvement of actions.

In providing their definition Fiol and Lyles (1985) also acknowledge that individual learning is distinct to OL. Individual learning occurs when an individual acquires new ideas or skills (Keegan and Turner, 2001) and is said to be an on-going process of forming, storing, retrieving and modifying mental models and schemas in response to the dynamics of the situation and environment (Spector and Davidsen, 2006).

Although their apparent differences, the requirement of individual learning to facilitate OL appears unquestionable. Kim (1993) ascertains that "*the importance of individual learning for OL is obvious and subtle – obvious because organisations are composed of individuals; and subtle because organisations can learn independent of any specific individual but not independent of all individuals*". Therefore, individual learning occurs when a person acquires new ideas or skills but OL occurs when an organisation institutionalises new routines or acquires new information (Keegan and Turner, 2001).

Even though this consensus appears to have been reached it must be noted that OL is not as simple as the sum of each member's individual learning (Fiol and Lyles, 1985). For example, Snyder and Cummings (1998) stated that individuals do learn within organisations, but this learning may or may not contribute to OL.

As a consequence of this review, the definition adopted for this research is that by Boer *et al.* (2001), which states that *"an organisation should use tools, methods and techniques that support learning processes, and have mechanisms in place to facilitate and foster different types of learning as well as support the transfer of individual learning into organisational learning"*.

2.4.2 Types of organisational learning

2.4.2.1 Project-based Learning

Construction work is organised as project based (Tan *et al.*, 2011), which incorporates the coordination of a diverse range of organisations to fulfil differing roles within the overall project (Harty, 2005). It is important to consider learning within this context rather than simply visualising learning within the boundaries of one organisation. This is due to the additional challenges such a consolidation of organisations poses. As such, it is the ability to learn from projects that consist of an amalgamation of multiple organisations, and not from projects within a single organisation that is of interest within this study.

Project-based learning in this context is seen as the development of learning capabilities to enable knowledge creation and sharing beyond the individual or team involved, to ensure reasoning beyond the short term project (Ayas and Zeniuk, 2001; Scarbrough *et al.*, 2004).

2.4.2.2 Single-Loop Learning

Single-loop learning is said to be where organisations respond to changes in their internal and external environment by detecting and correcting errors whilst maintaining core organisational norms, behaviours, beliefs, actions or activities (Barlow and Jashapara, 1998). Love *et al.* (2000) state that this type of learning does not encourage or result in any reflection or enquiry as it omits any questioning of current policies or goals. This process of reflection is seen by Wood Daudelin (1996) and more recently by Hart (2005) as a fundamental facilitator for enabling new norms to be established. This is shown through the following statements:

> *"When a person engages in reflection, he or she takes an experience from the outside world, brings it inside the mind, turns it over, makes connections to other experiences, and filters it through personal biases. If this process results in learning, the individual then develops inferences to approach the external world in a way that is different from the approach that would have been used, had reflection not occurred"* (Wood Daudelin, 1996).

> *"The concept of reflection involves criticising one's conjectures, ideas, theories or past actions with a view to invalidating them or, in the case of action, to improve performance by learning from mistakes in previous action"* (Hart, 2005).

Single loop learning focuses on addressing the symptoms of problems (Kululanga *et al.*, 1999). Due to the absence of reflection, this form of 'fire-fighting' symptoms fails to diagnose the root causes of a problem, which could lead to the improvement of organisational practises. For example, within a construction context, Palaneeswaran (2006) views rework as unnecessary and avoidable, but remarks how rework occurrences are rarely monitored in an attempt to reflect and diagnose their root causes. As a result, this lack of reflection has led the industry becoming prone to repeating the same mistakes (Barlow, 2000; Hari *et al.*, 2005; Tan *et al.*, 2011), which is also referred to as the 'reinvention of the wheel' (Keegan and Turner, 2001; Scarbrough *et al.*, 2004; Carrillo, 2005; Palaneeswaran, 2006; Tan *et al.*, 2006; Ruikar *et al.*, 2007).

2.4.2.3 Double-Loop Learning

Double-loop learning is said to be where current organisational norms and assumptions are questioned to establish a new set of norms (Barlow and Jashapara, 1998). It uses symptoms as indicators of problems and focuses on addressing the root causes so that an organisation can detect, uncover, and address the root causes of their underperformance and thus establish new ways of working (Argyris, 1992; Kululanga *et al.*, 1999).

It has been noted by authors such as Barlow and Jashapara (1998) that construction organisations tend to focus on finding pragmatic solutions to problems as they arise rather than double-loop learning. This clearly supports the aforementioned notion that construction organisations are currently viewed as conducting single-loop learning. This repetition of failing strategies is not a healthy course of action, but it is one that the construction industry often tends to follow (Love *et al.*, 2000).

This problem of reinventing the wheel has been an age-old issue within the construction industry (Keegan and Turner, 2001; Scarbrough *et al.*, 2004; Carrillo, 2005). Therefore to become a competitive learning organisation there is a need to move towards the adoption of a double-loop learning culture (Barlow and Jashapara, 1998). This will result in challenging the underlying concepts, paradigms and standpoints that have determined their ways of thinking in the past (Love *et al.*, 2000).

The healthcare infrastructure context is adopting a more double-loop learning approach in terms of design through a move towards evidence-based design. This involves reflecting on information gathered to make educated decisions. However, the construction industry is an area in which single-loop learning is still apparent. Therefore improvements are being made in terms of design for health benefits, but true progress is being restricted in terms of not continuously improving the quality of construction.

The industry in general is well suited to benefitting from the results of effective KM initiatives. For example, it is project based, where experience based knowledge is generated throughout the duration of a project. However, if real improvements are to be made, it is fundamental that designers, and in some cases the client, are included in double-loop learning processes. This is due to designers not having the same opportunity to be aware of design related surface problems as they inevitably arise at subsequent stages of the construction process. Therefore, without the implementation of an effective feedback loop between construction and design, there is no effective means of evaluating some of the root causes of construction inefficiencies.

2.4.2.4 Triple-Loop Learning

Argyris (1993) identified a third type, known as triple-loop learning, also referred to as deuteron-learning (Pedler *et al.*, 1996). This form of learning constitutes the questioning of essential principles on which the organisation is based, and thus challenging its mission, vision, market position and culture (Snell and Chak, 1998). This questioning of the organisation's principles is generally conducted at the highest levels of the organisation and arises when the organisation finds itself unable to take advantage of an opportunity, or when a problem continually resurfaces (Love *et al.*, 2000).

Triple-loop learning relates closely to becoming a 'learning organisation' in which the organisation seeks to become competent in the act of 'learning how to learn' (see Section 2.4.1). However, due to industry specific barriers such as the degree of fragmentation (see 2.7.2), it is apparent that the achievement of such a state is further complicated within the construction industry. This is due to temporary partnerships within projects providing the potential for conflicts of OL goals and therefore inhibiting the extent to which the principles of these organisations can be questioned and challenged simultaneously within a single project.

Triple-loop learning is therefore viewed as an idealistic position to be strived for, but is not a state that can ever be obtained. This is due to continuously evolving nature of learning, as well as organisational personnel and dynamics adapting over time. Furthermore, striving for the status of triple-loop learning requires competency in double-loop learning which has been highlighted as currently not in place (see Section 2.4.2.3).

Therefore whilst triple-loop learning is viewed as beyond the boundaries of this research study, the concepts of double-loop learning and OL within a project setting are highly applicable to this study.

2.5 Knowledge Management Lifecycle

2.5.1 Introduction

It is viewed that the KM lifecycle discussed below refers to the process of institutionalising individual learning into OL. It has been argued by Carrillo *et al.* (2000) that for an IT system to be classified as a KM system one of its key requirements is that it must support the full KM lifecycle. A fundamental reason for this assertion is recognised by Kululanga *et al.* (1999) who suggest that for KM system uptake to improve; all stages of the KM lifecycle should be well supported.

However, due to the need for human and social involvement to facilitate knowledge transfer and absorption (see Section 2.2.4), this argument is seen as too technology centred (i.e. aligning with a first generation KM perspective). Consequently it is viewed that for a KM programme to be classified as a true KM programme, it must support the full KM lifecycle. Accordingly, the KM lifecycle and its constituting stages is now documented.

2.5.2 Stages of the Knowledge Management Lifecycle

There is much variation regarding the makeup of the KM lifecycle, as can be seen in Table 2.1. Some authors have described the differing stages using varying terminology as well as deciding to merge complimentary stages to create a concise process. For example, Tan *et al.* (2006) view the capture stage as comprising the three sub-processes of; identifying / locating knowledge, representing and storing knowledge, and, validating knowledge; stages which other authors have viewed as sufficiently significant to separate. Through observing their differences, it is apparent to this researcher that an amalgamation of the identifications of past researchers' KM lifecycles consists of a need to:

Identify a learning opportunity

Capture this knowledge

Structure / **formulise** or **codify** this knowledge in order to;

Store the knowledge rationally so that it can be

Share / **Access** for others to exploit / benefit from. There is also a need for;

Validate / **Maintain** in order for the knowledge to be kept up-to-date and relevant.

Table 2.1: Knowledge Management Lifecycle Stages

Researcher	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7
Tan *et al.* (2006)	Capture	Reuse	Sharing	Maintain			
Nissen et al. (2000)	Capture	Organise	Formulise	Distribute	Apply		
Barson *et al.* (2000)	Identify	Acquire	Structuring	Generate	Store	Distribute	Assess
Boyd et al. (2004)	Identify	Create	Acquire	Transfer	Share	Exploit	
Tserng and Lin (2005)	Create	Secure	Capture	Coordinate	Combine	Retrieve	Distribute
Carrillo and Chinowsky (2006)	Create	Capture	Sharing	Use			
Carrillo *et al.* (2000)	Generate	Capture	Store	Share	Retire		
Mohamed (2006)	Discover and capture	Organise and Store	Distribution and Sharing	Create and Leverage	Archive and Retire		
Gold *et al.* (2001)	Acquire	Convert	Apply	Protect			
Simone *et al.* (2012)	Collect	Organise	Mobilise				
Horga *et al.* (Horga *et al.*, 2011)	Identify	Capture	Selection	Storage	Transfer	Implement	Create

It should also be noted that some authors argue that the KM lifecycle should not be regarded as a linear process and that the stages may not be completed in sequence (Carrillo *et al.*, 2000; Nissen *et al.*, 2000; Tan *et al.*, 2006). This is supported, as sometimes knowledge is used as it is being constructed in what is referred to as construction-to-use (Demarest, 1997). A more in-depth review of each stage of the knowledge management lifecycle follows.

2.5.3 Knowledge Identification Stage

This stage involves acknowledging that a learning opportunity has occurred or is occurring and that this instance is of significant value to the organisation / project participants to warrant its capture. The decision to identify a learning instance should be human-based and in line with the learning objectives set prior to the project's commencement.

Garvin (1993) contends that organisations need to conduct on-going experiments in the aim to search and test new knowledge. This implies that a learning organisation is one that seeks new knowledge from a broad perspective and does not limit their learning potential by being overly focused. This is supported by Ruikar *et al.* (2007) who found that most organisations were of the opinion that knowledge identification should be unconfined and fluid as this enables new and unexpected knowledge to surface.

Opposition to this perspective is also apparent, with a more focused approach to learning being viewed as presenting greater levels of success. For example, Bordass and Leaman (2005) discovered that in practice, most organisations cannot cope with, or afford overly comprehensive feedback approaches and that it was better to start small, simple and practical with a few focused areas in which there is an interest to improve. This coincides with findings that organisations that implement a KM strategy focused on their specific needs are more successful in capturing tacit knowledge. Such a focus is therefore said to protect against the so called 'paralysis by analysis' syndrome (Nonaka and Takeuchi, 1995).

2.5.4 Knowledge Capture Stage

Hari *et al.* (2005) views effective knowledge capture as being the turning of personal knowledge into corporate knowledge that can be widely shared and applied throughout the organisation. Construction organisations are commonly accepted as being relatively successful in the capture and storage of explicit knowledge; however, industrial barriers such as time, resources and the difficulty in converting tacit knowledge into explicit knowledge, makes tacit knowledge much harder to capture (Kivrak *et al.*, 2008). This is alarming when tacit knowledge is considered to be both the most useful and the most utilised form of knowledge (see Section 2.2.4). For example, a study conducted by Kivrak *et al.* (2008) discovered that the majority of organisations investigated considered 41-60% of their total organisational knowledge was tacit and only exists in the minds of individuals.

It has also been a consistent desire expressed by various authors that the capture of knowledge should be as live as possible to capture a greater extent of the learning opportunity (Kartam and Askar, 1999; Kamara *et al.*, 2003; Tan *et al.*, 2006; Kivrak *et al.*, 2008). Live capture also overcomes the drawbacks of postponing its capture in the form of knowledge deterioration caused by forgetting details and knowledge loss due to post project break-up of teams (Kamara *et al.*, 2003; Tan *et al.*, 2006; Tan *et al.*, 2011).

2.5.5 Knowledge Codification Stage

Knowledge codification is the process of converting knowledge into messages which can be processed as information (Cowan and Foray, 1997). Knowledge codification is subject to a split in opinion regarding its worth, need and beneficial impact. One train of thought views codification as important as it facilitates the transformation of tacit knowledge to explicit knowledge, thus enabling its dissemination (Hari *et al.*, 2005). This is due to converted knowledge being more easily transferred than knowledge that is embedded in organisational principles (Jashapara, 1993; Barlow and Jashapara, 1998).

Those in support of codification suggest it reduces the expense of knowledge acquisition due to it improving the ease by which it can be stored and recalled, as well as improving its overall reliability (Cowan and Foray, 1997). Moreover, the act of codification has been said to be able to reveal strong links between cause and effects as it becomes much easier to compare multiple scenarios and explanations (Prencipe and Tell, 2001).

On the contrary there are those who oppose the codification of knowledge in the belief that over reliance on codified knowledge, to the extent that the results are followed accurately and precisely in the form of rules, leads to rigidity (Prencipe and Tell, 2001). This is supportive of the OL barrier of *'learning leads to over standardisation*' (see section 2.7.2). It is therefore seen as important to investigate to what extent codification can be / should be achieved and in what format knowledge is best captured / stored in.

2.5.6 Knowledge Storage Stage

A failure to capture and store knowledge in a corporate memory causes knowledge loss, which can thus lead to a permanent knowledge void that is difficult to fill (Ruikar *et al.*, 2007). Knowledge loss has been identified as a greater obstacle to overcome within small and medium enterprises (Hari *et al.*, 2005) and therefore may be a greater challenge to overcome within the construction industry due to it being made up predominantly from SME's (Carrillo *et al.*, 2000). As a result, this stage of storing, organising and retrieving knowledge within an organisational memory is a fundamental aspect to an effective organisational KM regime (Starbuck and Hedburg 1977 cf. Chou, 2005). Various techniques and technologies to achieve this function are discussed later in this review (see Sections 2.8 and 2.9).

2.5.7 Sharing and Accessing Knowledge Stage

To attempt to extract the benefits of KM (see Section 2.6), the generation of knowledge alone is insufficient; it must be shared and reused (Patel *et al.*, 2000). Therefore, this stage of sharing and creating access to knowledge will form the basis of the feedback loop between the construction phase (the capturers of knowledge) and future designers, architects and planners (the users of knowledge).

2.5.8 Knowledge Validation and Maintenance

Due to the problem of employees contributing knowledge of variable quality (Robinson *et al.*, 2001), it is seen as essential to validate its accuracy and worth (Tan *et al.*, 2006). Ruikar *et al.* (2007) state that this stage is also necessary to ensure that stored knowledge remains up-to-date.

Although viewed as an essential part of the KM cycle, Goodman and Darr (1998) recognise that due to it requiring human intervention to evaluate each contribution and in some cases, request for additional information, transaction costs are increased. This can exasperate cost related barriers to knowledge management; however, validation and maintenance is said to be critical to avoid the *'development of knowledge landfills'* which can be detrimental to a KM programme (Lawton, 2000 cf. Robinson *et al.*2001). This is shown by the view that knowledge can become obsolete once new techniques or solutions are found (Kivrak *et al.*, 2008), but if old solutions are not removed then confusion may arise.

2.6 Benefits of Organisational Learning and Knowledge Management

This section aims to identify the breadth of benefits attributed to OL and thus assess how this will improve the design and build quality within healthcare infrastructure. Such benefits have been characterised according to which project participant (client, designers, contractors or a combination of participants) is most likely to experience them.

2.6.1 Client Related Benefits

OL benefits identified by Low and Goh (1994) regarding client satisfaction include:

- Improved communications between project parties;
- Enhanced formalisation of responsibilities and lines of authority;
- Improved requirement specification writing; and,
- More regular systematic checking.

In regards to the final point, Low and Goh (1994) suggest that it in turn results in the avoidance or early detection of potentially costly errors, failures and expensive remedial works. These benefits are said to result in reduced costs and time overruns, enhanced quality and more accurate solutions being provided.

In addition, other client related benefits include the increase in active experimentation to evolve processes and products. This leads to potentially supplying added-value solutions (Hari *et al.*, 2005) and a reduction in 'reinventing the wheel,' (Kamara *et al.*, 2003). An example of the occurrence of the latter issue was observed by Hignett and Lu (2009). Within their study it emerged that in the experience of one participant, who had been involved in 15 different hospitals; 15 differing layouts for the same functional area had been developed. It was said that the lack of recording and reflection of past occurrences caused a great deal of repetition of work to conducted, therefore increasing the time and cost of the project.

The possibility of these benefits arising is viewed as potentially being heightened within the construction of new healthcare facilities, as they are said to involve relatively repetitive processes (Abdou *et al.*, 2003). Therefore, through the utilisation of OL mechanisms such as tracking, capture, reflection and feedback of past experiences, it should be possible to put into practise the lessons learnt from historic projects. In the case of clients whose requirements are non-repetitive and unique each time, or the client is simply one-off, there is less opportunity and incentive to improve the level of learning from past project, which therefore makes it more difficult.

2.6.2 Design Related Benefits

The main factors to influence the level of quality of the finalised product were attributed to design in the form of; a lack of coordination of design, unclear and missing documentation, and poor workmanship due to a lack of care and knowledge (NEDO, 1987 cf. Love and Li, 2000). This is more recently supported by Alarcón and Mardones (1998) who state that design quality issues arise from:

- A lack of completeness of the information necessary to complete the project (for example,. inconsistencies, omissions, errors or a lack of clarity);
- A lack of standards in the design for similar projects, thus resulting in lower efficiency; and,
- A lack of buildability which result in a high amount of problems being detected during the construction phase.

It has been suggested by Shammas-Toma *et al.* (1998), Love and Li (2000), Jergeas and Van der Put (2001) and Yang *et al.* (2003) that to overcome the aforementioned design related issues, design-construction integration early on in the project is required. For example, it was observed that in two differing projects, design and construction changes could have been significantly reduced if occupiers and end-users had some input into the design brief, thus leading to a reduction in the critical path (Love and Li, 2000). They continue by proposing that young designers should work onsite to learn the practical aspects of design because computer aided design (CAD) cannot perform miracles or be expected to educate the designer in such matters.

2.6.3 Construction Related Benefits

2.6.3.1 Competitive Advantage

Possibly the most cited benefit of OL within any industry or context is that it can lead to the creation of competitive advantages. Within a construction context alone the following authors are a sample of those who have expressed such assertions: Barlow and Jashapara (1998); Vakola and Rezgui (2000); Kululanga *et al.* (Kululanga *et al.*, 1999); Turner (2001); Robinson *et al.* (2001); Carrillo (2005); Hari *et al.* (2005); Carrillo and Chinowski (2006); Kivrak *et al.* (2008); MacVaugh and Auty (2008); Tan *et al.* (2011); Kale and Karaman (2012) Paranagamage *et al.*

(2012) and Gavrilova and Andreeva (2012). The strength of this perspective can be seen through the following expressions:

> *"The ability to manage and exploit knowledge will be the main source of competitive advantage for the construction industry of the future"* (Boyd et al., 2004)*;*
>
> *"The main motivation for such continuous learning as part of an organisation's culture is to continuously improve thereby ensuring superior performance and competitive advantage"* (Kululanga et al., 1999)*;*
>
> *"Storing innovative ideas/ways of working can result in the development of new products and services and creation of innovations, which is highly critical for the survival and advancement of companies"* (Kivrak et al., 2008)*;*
>
> *"An organisation's only sustainable competitive advantage lies in its ability to learn faster than its competitors"* (Vakola and Rezgui, 2000) *;*
>
> *Lessons learned in projects can be transferred to other projects so that continuous improvement will be provided"* (Kivrak et al., 2008)*;*
>
> *"Knowledge is increasingly recognised as the most powerful asset and a source of competitive advantage to improve business performance"* (Robinson et al., 2001)*;*
>
> *"Results show that both KM strategies (codification and personalisation) impacts on innovation and organisational performance directly and indirectly (through an increase on innovation capability)"* (López-Nicolás and Meroņo-Cerdán, 2011)*; and,*
>
> *"To remain competitive, the critical innovation and ability to respond to customers quickly are also dependent on the amount of knowledge available"* (Tan et al., 2011)*.*

Some competitive advantages such as finding a distinct differential from competing firms (Carrillo, 2005) and thus improving the degree to which they are more employable in the future (Keegan and Turner, 2001), are individually advantageous to the future outcomes of the construction organisation involved. It could be argued that this may be achieved without directly benefiting the healthcare infrastructure project in question. Nevertheless, such competitive advantages and OL as a whole have been linked to the improvement of overall performance

(Barlow and Jashapara, 1998). This is strongly advocated by Vakola and Rezgui (2000) who state that it is needed to facilitate the production of world class construction.

These perspectives are therefore extremely attractive as it suggests that there is a positive relationship between OL and improving built facilities. Consequently, the quality of service provided, as well as the healing potential of patients should be improved according to the findings of studies conducted by De Jager (2007) and Berry *et al.* (2004). These findings discovered that service delivery in the healthcare sector is profoundly affected by the built infrastructure provided to support it and for a hospital environment to function optimally its infrastructure must be fit for purpose. Therefore this moves beyond the purpose of EBD, which aims to create better hospital environments that help patients to recover faster, improve staff performance and retention, and make hospitals safer places to receive medical and surgical care (Stankos and Schwarz, 2007). This in fact suggests that it is not only the design of the hospital that can positively affect the patients' wellbeing but the build quality of the final facility also.

2.6.3.2 Reduction of Reoccurring Problems and Mistakes

Shammas-Toma *et al.* (1998) showed that construction projects are plagued by uncertainty and unpredictability, which causes problems to be tackled as and when they arise. As will be discussed later in this review (see Section 2.7.2) barriers inherent of the industry cause people to search for quick-fix responses to such problems, without facilitating any time for reflection to establish root causes (Lee and Egbu, 2007).

This lack of project-based learning techniques inevitably causes such problems to arise time and time again (Prusak, 1997). Therefore, without a reflection period, the opportunity to discuss, captures or share learning experiences that might yield genuine value for clients through process and product improvement (such as improved design buildability), will be lost (Keegan and Turner, 2001). In comparison, the utilisation of double-loop learning enables the symptoms of reoccurring problems to be diagnosed and their multifaceted deep-rooted causes to be established so that systematic solutions can be developed (Kululanga *et al.*, 1999).

2.6.4 Mutual Benefits

2.6.4.1 Reduced Rework

Rework in construction projects is referred to by Palaneeswaren (2006), as the unnecessary effort of redoing a process or activity that was incorrectly implemented in the first instance. A study conducted by Willis and Willis (1996) identified that on nine industrial projects studied, the average cost of deviation correction exceeded 12 per cent of the total installed facility cost, with this 12 per cent being divided almost evenly (3 per cent each) among four major causes: owner changes, designer errors, constructor errors and other/unknown causes. Similarly, Cnuddle (1991, cf. Love and Li, 2000), found the cost of non-conformance as being between 10% and 20% of the total project cost, with 46% of total deviation costs being created during the design stage, compared with 22% for construction deviations. More recent comparable studies have also observed that such inefficiencies remain apparent with the average cost of rework being 12.4% of the total project cost (cf. Rhodes and Smallwood, 2002) and the cost of design errors being between 6.85% and 7.36% of the contract value (Lopez and Love, 2011).

These complimentary research findings illustrate that rework is a problem that is caused and experienced by the breadth of participating stakeholders and one that can be, and should be, reduced far more than is currently being achieved. However, the consistency of the negative effect of rework suggests that it is one that does not appear to be subsiding as time progresses.

Although the cost of constructing a new healthcare building is said to only constitute 2-3% of the total lifetime costs, the average cost of building a conventional hospital is in the region of £150million (Mills *et al.*, 2009). Therefore the amount of funds exhausted on unnecessary rework could be as high as £18million per project.

The matter of rework has also been cited to stretch far beyond the direct cost implications of the contractor and the client but to also include a range of less tangible costs. This is shown by Burati *et al.* (2000), who suggest that the increase in costs caused by rework may in fact be even higher because it is often the case that schedule delays, litigation costs and other intangible costs of poor quality are not included. Schedule delays in particular, have a detrimental knock-on effect to the end user. For example, during the creation of new facilities, vital healthcare access is unnecessarily being withheld from those that require it. Alternatively, in the case of existing facilities being refurbished, the need for healthcare facilities to remain operational presents specific challenges (Sheth *et al.*, 2010). This is due to the disruption caused through; the reallocation of patients; increased noise; and, disturbance levels, all of which have a detrimental effect on the healing process of patients (Ulrich, 2006; McCullough, 2010; Heft *et al.*, 2012).

The findings of the potential unfavourable impacts of rework emphasises the criticality of reducing such instances as far as possible. This opinion is complemented by Willis and Willis

(1996) who state that doing the job right the first time is the single most important factor for minimising the cost of designing and constructing world-class facilities.

2.6.4.2 Improved Design Buildability

Construction knowledge has the ability to improve the extent to which a building is buildable (Pulaski and Horman, 2005). This goes further than purely concentrating on rework as it also considers a range of other factors which are said to provide the ability to improve efficiency, quality and value (Hyde, 1993; Gambatese *et al.*, 2007; Lam and Wong, 2009). These include; ease of construction, safety, construction resources, construction procedures and environmental concerns (Griffith and Sidwell, 1993; Lam *et al.*, 2007).

Consequently, it is evident that feedback between construction and design is required. However, due to the difficulties facilitating physical knowledge sharing (see Section 2.8.6.2), a framework which facilitates knowledge to be captured during the construction stage so that it can be shared with future designers is proposed. For this to occur, effective KM within the construction stage needs to take place, with this knowledge then being fed back. Subsequent designs can benefit from any learning that has taken place in a process of continuous improvement, rather than simply repeating design strategies which lack buildable attributes.

This feedback will also enable designers to incorporate buildability considerations from the outset of a project in preference for the current procedure of preparing designs and having them reviewed by construction personnel. This results in rework being required, thus causing schedule delays and the possibility for human oversights due to time pressures.

2.6.4.3 Evidence of Fit for Purpose

The capture of learning instances may also provide evidence of the quality of the product being supplied. It is the belief of Pheng and Hwa (1994) that the company providing the service must not only produce the design and product as contracted but also provide evidence that the result is "fit for purpose". Therefore the collection of learning instances throughout the process can not only be used by the contractor to benchmark and improve, but also to provide reassurance to other parties that the end product meets the requirements specified in the first instance.

2.6.5 Summary of Benefits

Although such benefits appear evident, knowledge fails to be captured or transferred and therefore is lost (Carrillo *et al.*, 2000). Nonetheless, a significant amount of valuable information is generated during the construction stage. Therefore a substantiation of the need to apply further efforts in satisfying the goal of this research (see Section 1.3) has been established.

2.7 Barriers to Organisational Learning and Knowledge Management within a Construction Healthcare Context

There are various barriers to OL and KM within the construction industry specifically, in addition to generic barriers. Wunram *et al.* (2000) describe a KM barrier to be everything related to human, organisational and/or technological issues that obstruct inter- and intra-organisational KM. Barson *et al.* (2000) categorise inter- and intra-organisational barriers according to the technical, organisational and people (TOP) socio-technical systems classification. However, it is the opinion of this researcher that the construction industry is so inimitable that a forth category of 'industrial' barriers should be included. This is supported by Orange et al. (1999a) who state that OL within the construction industry involves a much deeper level of complexity. A review of the various OL barriers, according to this TIOP classification will now be conducted.

2.7.1 Technology Barriers

2.7.1.1 Legacy Systems

The presence of non-supportive legacy systems has been quoted as proving a significant barrier to overcome. This is due to the difficulty in achieving compatible systems between multiple departments and/or participating organisations (Schwartz, 1999 cf. Barson *et al.*, 2000). However, a more recent study has identified that this barrier is seeing a decline in prominence (Henderson, 2009). In addition, Kimoto (2005) expresses how the use of technologies such as personal digital assistants (PDAs) are compatible with any operating system, which suggests the potential to further decline as technology continues to advance.

2.7.1.2 Supportive Technology Availability

Schwartz (1999) suggested that the currently available supportive technology for KM is not yet mature enough. However, this observation was provided over a decade ago and technology has improved significantly of late. For example, Kimoto (2005) recognises that PDA technologies are now capable of supporting mobile capture of information and knowledge, with this being further modernised by Chen (2008) and Ruikar (2010) who acknowledge other devices such as smartphones, pocket PCs and tablet computers (such as iPads) as now being applicable. Newell *et al.* (2009) identify that databases can store captured knowledge; Augenbroe *et al.* (2002) suggest that project extranets are capable of supporting high-speed web-based collaboration between dispersed team members; and, intranets can be used to publish or search for information (Newell *et al.*, 2009).

Consequently, the perception that the construction industry has greater barriers to the adoption of advanced computer technologies, due it involving remote field locations and therefore requiring sophisticated telecommunication links (Jergeas and Van der Put, 2001), now appear to be becoming out-dated.

2.7.2 Industrial Barriers

Swan *et al.* (2010) assert that although projects present fertile sites for learning, there is an equal volume of evidence that suggest that construction organisations fail to learn from projects and in fact continuously reinvent the wheel, repeat mistakes or fail to transfer learning from one project to the next. This is fundamentally due to the pressures asserted on projects, which thus form barriers for learning.

2.7.2.1 Project Mentality

A concern expressed by Gieskes and ten Broeke (2000) is that construction companies are strongly oriented towards projects, their contribution to them, and the successful completion of them, with hardly any interest in external issues. Although a structural reality and necessity for survival, this strict short term project focus of the industry is seen to present additional obstacles to learning.

The project orientation of the industry also causes a non-continuous line of production compared to industries such as manufacturing. These divisions of practice create barriers to KM, as the lessons learnt from one project maybe inapplicable to the next (Carrillo *et al.*, 2000). This being said, Anumba *et al.* (2006) view the industry as utilising repetitive processes in the design and production of their products. Therefore although they produce one-off products, the processes employed each time are relatively repetitive and consequently learning from one project can be applied to future projects; though in a less straightforward manner.

Scarbrough *et al.* (2004) view these divisions of practice as enablers of OL, as project tasks generate significant opportunities for learning where they involve overcoming existing divisions in practice to create new practices. New knowledge and learning is created through ‘translating’ cross-divisional differences (where a common language is developed to greater understand meaning) and/or through ‘transforming’ cross-divisional differences (where mutual problem solving between actors results in the creation of new understandings) (Scarbrough *et al.*, 2004).

However it is the transferring of these cross-organisational project-based learning instances back to the wider organisation that is most difficult as the organisational practices are different once more (Newell *et al.* 2003). Consequently, divisions in practice are seen as being double-edged as it has the ability to simultaneously advance and inhibit learning. It should therefore not simply be referred to as a barrier to learning (Scarbrough *et al.*, 2004).

2.7.2.2 Short Term Objectives

Highlighted through studies conducted by Keegan and Turner (2001) are the negative effects of short-term client-driven pressures on longer-term learning objectives. As previously mentioned (see Section 2.6.3), these include; increased time and cost pressures exerted on organisations leading to people to search for quick responses to problems before moving onto the next. This is without reflecting on their experiences, establishing root causes and documenting these to enable future learning (Hari *et al.*, 2005; Lee and Egbu, 2007). It is often the case that construction organisations consider their organisational structures as too lean to exploit KM to the full as there is the desire but not the manpower to capture, store and share knowledge within tight project timescales (Robinson *et al.*, 2001; Tan *et al.*, 2011).

A factor that heightens the negative effect of this short term mentality is the time delay between conducting the action and receiving the benefits of it. For example, Campanella and Corcoran (1999) state that an increase in quality prevention expenditure does not result in the immediate reduction in failure costs due to the time lag between cause and effect. Therefore the short term, 'investment now requires benefit now,' perspective held by many construction organisations is preventing the realisation of greater and possibly more sustainable long term benefits. Carrillo *et al.* (2000) support this by stating that KM is a long term goal.

Furthermore, very few clients have a requirement for lessons learnt (Carrillo, 2005), which heightens the temptation to defer conducting lessons learnt to a future point in time. Although understandable for one off clients; in the case of repeat clients who target progression and improvements (such as within the healthcare sector) lessons learnt should be a high priority. Kartam and Flood (1997) suggest that the rising cost of construction, coupled with the increased time demands placed on contractor schedules means that no members of the construction industry can afford to waste time and resources on ineffective work. In other words, construction organisations that fail to learn will inevitably become uncompetitive.

2.7.2.3 Temporary Project Partnerships and Participants

The UK construction industry is renowned for its fragmented make-up. Each project comprises multiple temporary alliances of independent partners which are in a state of simultaneous cooperation and competition with each other due to being unsure that improvement processes and their results will not be applied in future projects with different partners (Gieskes and ten Broeke, 2000; Ngowi, 2001). Consequently, this inhibits learning as each participant is protective of their own knowledge as the sharing of proprietary information opens the risk of benefitting competitors (Barson *et al.*, 2000). The unstable nature of the industry is therefore leading to a chronic knowledge loss problem compared with other industries (Graham and Thomas, 2007; Orange *et al.*, 2010).

Some smaller participants are of the opinion that only the members employed by the company imposing these procedures, as well as the company itself, will benefit from any learning that may arise (Keegan and Turner, 2001). As a result, external project partners (which can be numerous) feel that the time spent sharing their localised learning experiences is of benefit to others whilst hindering themselves. Consequently, they protect their knowledge and do not contribute to the process, thus dramatically inhibiting project-based learning.

Barlow and Jashapara (1998) also suggest that partnering arrangements may cause inherent tensions and conflicts if the differing parties are driven in different directions due to the nature of their competitive environments. They provide the example that if a client's learning focus is based on innovation whilst a supplier's focus is efficiency, both objectives are unlikely to be fully satisfied.

Where there is a desire to share knowledge across organisational divides, Carlile (2002) identifies three different types of knowledge barriers in which he refers to as "knowledge boundaries." These are:

> Syntactic (language) boundary – where there is a need to establish a stable syntax to allow accurate communication between sender and receiver;
>
> Semantic (meaning) boundary – where even if a stable syntax has been established, a barrier to the sharing of this knowledge is still present in the form of different personnel interpreting it differently from each other; and,
>
> Pragmatic (practice) boundary – where knowledge sharing is constrained by differing practices and interests between the divided groups and/or individuals (Scarbrough *et*

al., 2004) and if knowledge is to be shared effectively, the resistance to change practises and knowledge sets needs to be overcome (Carlile, 2002).

Although this partnership related barriers appear to be apparent, many authors prescribe to the view that partnerships are an effective knowledge sharing technique (Latham, 1994; Barlow and Jashapara, 1998; Kamara *et al.*, 2003). However, the framework within which construction firms acquire and make use of knowledge is said to often be inappropriate or poorly developed (Barlow and Jashapara, 1998). This ultimately leads to the failure of fully reaching the aspirations placed on partnering.

2.7.2.4 Belief that Learning Leads to Over Standardisation

A study conducted by Hignett and Lu (2009) discovered that some designers are of the opinion that increased monitoring and feedback can lead to the standardisation of infrastructure and therefore inhibit future innovation. Within the health sector, Health Building Notes (HBNs) have been collated over the last 50 years to encourage those involved in hospital design to consider the synergy between room layout and the ability to perform a variety of tasks within that working environment (Hignett and Lu, 2009). During that study, they discovered that architects felt that although evidence-based design is of use, design reviews generally resulted in much more timid designs, as non-compliance could have a dramatic impact on the tendering process.

Hamilton (2003) suggests that this worry regarding evidence-based methods limiting creativity is neglecting the challenge of continuously inventing responses to emerging results and facts, which require imaginative and ever-changing interpretations of the design implications. Similarly, Edum-Fotwe *et al.* (2004) disclose how innovation and standardisation although divergent in nature can coincide, with MacVaugh and Auty (2008) asserting that the potential of KM to enhance new product development is undoubted.

It has also been suggested that the lack of standardised work processes is proving to be a barrier of learning as organisations suffer from adopting too many different processes to achieve the same outcome (Robinson *et al.*, 2001). This is once more an example of the construction industry unnecessarily *'re-inventing the wheel'*. This has generated a call from some construction organisations to rationalise and synchronise some of these processes so that reusing knowledge and sharing best-practices can be enabled (Robinson *et al.*, 2001).

These two accounts demonstrate that there is an undoubted desire to incorporate greater understanding and learning within the construction industry. However, the opinions of how successfully standardisation could be used as leverage for such learning outcomes differ dramatically. In respect to the first scenario, a case of over enforcement of the standards is apparent, as the benefits of enabling architectural freedom appear to have evaporated. It appears likely from this account that such imposed restrictions will not produce innovation and progression. For example, Moore (1993) suggests that imposed constraints on design creativity are unlikely to be accepted by a profession whose main form of advertisement is through the buildings that are subsequently produced from their drawings.

In addition, over standardisation may result in organisations ceasing to continually learn due to being satisfied with their current position. Consequently, this position may become the ‘standard’ with no further progress being made. For example, if the evidence base which is used to inform future healthcare infrastructure design is considered to hold true forever more, inappropriate standardisation of these findings will arise. However, if continual learning is sought, it will enable an examination of the effects of shifts in other determining factors, such as how healthcare delivery models adapt over time. This concurs with Hamilton’s (2003) view that research-informed design coincides with the continuous search for truth in the world of science, due to it progressing continuously and therefore not conforming to fixed regulations that will become obsolete by new findings.

As a result it is evident that a complimentary medium has not been reached, where education, guidance and freedom are preferred to the one extreme of overly restrictive criteria or the other of an absence of direction and best practice.

2.7.3 Organisational Barriers

2.7.3.1 Inability to Capture Tacit Knowledge

A significant problem that organisations face is the transferring of specific knowledge (from an individual) to general knowledge so that it can be applied to actual work situations throughout the organisation (Love *et al.*, 2004). This highlights the difficulty of converting ‘tacit’ knowledge (which is personal and complex to communicate), into ‘explicit’ knowledge (which can be transmitted in formal, systematic language and is therefore sharable) (Nonaka, 1994).

Once more, some authors state that this barrier is heightened within the construction industry compared to that of repetitive output industries such as manufacturing (Gieskes and ten Broeke, 2000). This is because when the work characteristics in terms of output differ for each new project, organisations not only have the problem of how to convert tacit individual knowledge into explicit collective knowledge (Carrillo *et al.*, 2000), but also the difficulty of determining what to relate the learning issues to for them to be relevant in future projects (Gieskes and ten Broeke, 2000).

2.7.3.2 Unsupportive Culture

Potentially the most consistently recurring topic in KM literature is the importance of a supportive learning culture within an organisation (Goodman and Darr, 1998; McDermott, 1999; Barson *et al.*, 2000; Patel *et al.*, 2000; Egbu and Botterill, 2002; Koch, 2003; Dainty *et al.*, 2005; Alshawi, 2007; Kivrak *et al.*, 2008; Ruikar *et al.*, 2009; Horga *et al.*, 2011). In fact a 'knowledge-friendly' culture is viewed as the most important factor of OL and KM but also the most difficult to create (Davenport *et al.*, 1998; Horga *et al.*, 2011). Schein (1985) defines organisational culture as *"the basic assumptions and beliefs that are shared by members of an organisation, that operate unconsciously and define in a basic taken-for-granted fashion, an organisation's view of itself and its environment."*

Organisational culture has been blamed by Gieskes and ten Broeke (2000) and Hari *et al.* (2005) for many problems relating to an organisation's ability to learn, including:

- Vertical silos within organisations which lead to a lack of awareness of what others have done;
- Internal competition which inhibits efforts to share knowledge; and,
- Knowledge hoarding.

For example, an overly centralised organisational hierarchy has been viewed as potentially being damaging to project based learning due to it signalling that learning is not the responsibility of everyone but only a few 'enlightened' people within the organisation (Keegan and Turner, 2001). Consequently, this can cause the creation of a strong "us-them" culture between project leaders and subordinates, which is unsupportive to the exchange of knowledge and experiences (Gieskes and ten Broeke, 2000). These studies discovered that many experienced construction professionals:

- See knowledge as power and are therefore reluctant to share it;
- Are reluctant to learn from others in what they describe as the 'not invented here' syndrome; and,
- Are scared to admit to making mistakes.

In comparison, a supportive learning culture is seen as one that enables organisational unlearning, which is the process of selectively forgetting and discarding obsolete or misleading knowledge (Jashapara, 1993) making way for new learning to take place (Huber, 1991). Although an overwhelming strength of consensus towards the importance of a supportive culture, means to achieve such are far less distinguishable. Some advocate that it rarely yields to efforts to change it directly by manipulation (McDermott, 1999). Furthermore each organisation has its own individual and unique culture, which only the organisation in question will be able to deduce what initiatives could encourage change (Carrillo *et al.*, 2000). As such there is no set of homogeneous guidelines that can achieve success across the board. This being said, findings from past research have suggested important facets of nurturing a supportive culture, which include:

- Top management leadership, support, commitment and role models (Robinson *et al.*, 2001; Kivrak *et al.*, 2008; Ruikar *et al.*, 2009)
- Incentives and rewards to encourage knowledge sharing activities (Kivrak *et al.*, 2008)
- Nurturing relationships between people through adequate opportunities for contact so they feel a sense of belonging and free to opening up and asking for / sharing knowledge (McDermott, 1999; Patel *et al.*, 2000; Ruikar *et al.*, 2009)
- Providing motivation for individuals to participate in communities beyond merely creating them (Ruikar *et al.*, 2009)
- Providing adequate mechanisms to capture, store and share knowledge (Ruikar *et al.*, 2009)
- Extending the learning environment to include as many significant people both internal and external to the organisation (i.e. customers, suppliers and other stakeholders) (Barlow and Jashapara, 1998)
- Providing understanding into what insights and information are of important and the reasoning behind them (McDermott, 1999)
- Encourage employees to question their current assumptions and actions (Ayas and Zeniuk, 2001; Love *et al.*, 2004) through experimenting and trying out new ideas due to making mistakes being the finest way to learn (Lee and Egbu, 2007)

2.7.3.3 Limited Resources

An extension to the industrial level barrier of short-term objectives is that of limited resources at an organisational level. The construction industry consists predominantly of SME's (Carrillo *et al.*, 2000), which indicates reduced access to vital resources such as capital, human resources, time and information technology (IT). As the capture and maintenance of knowledge is time-consuming, labour intensive and costly (Hari *et al.*, 2005) these limited resources dramatically reduce the opportunity for small organisations to embark on KM projects, even when the desire is present. For instance, limited human resources hinder an organisation's ability to conduct post project reviews (PPRs) or maintaining knowledge databases once a project is complete. This is because, faced with the ultimatum of reallocating employees to commence a new project or releasing them to update learning related databases, most if not all firms, will opt for the former (Keegan and Turner, 2001).

2.7.3.4 Size of Organisations

The UK construction industry predominantly consists of SMEs (Barlow and Jashapara, 1998; Carrillo *et al.*, 2000). The definition of an SME revolves around the number of employees of an organisation. However, the number of employees to categorise small and medium enterprises, as well as large enterprises differs significantly. For example, Ayyagari et al (2003) cited that the variety of cut-offs for SME classification was great across country divides, with some reporting figures as low as 10-25 and others 100-150. Other authors suggest that SMEs are said to be those organisations that consist of less than 250 employees, whereas large construction organisations have 250 or more employees (McAdam and Reid, 2001).

SMEs are said to have more pressing concerns than knowledge management such as survival; as well as not having the commitment or resources to undertake knowledge management and OL (Carrillo *et al.*, 2000)**.** This is echoed by Egbu (2001, cf. Lee and Egbu 2007), who states that weaknesses attributed to SMEs causing them to be less successful in performing KM practises include; an inability to fund long-term and risky KM programmes; unavailable specialised technological competences; and, an inability to invest in training and education.

2.7.4 Individual / People Related Barriers

The majority of the previously highlighted barriers can also be accredited to being people related, but on a more collective level. This has led to their positioning in an alternative category, whereas barriers stated under this category are more individualistic and personal in nature.

2.7.4.1 Overcoming Existing Habits and Resistance to Change

Resistance to change is a critical obstacle to overcome in any change initiative (Vakola and Rezgui, 2000) as it involves people trying to hold onto old ways of working and thus being uncooperative of the change programme (Burnes, 2004). In such a regime as OL, where change is said to be continuous, it is crucial that learning is integrated with day to day work processes. This is so that lessons learned are disseminated in such a way that the business and its employees can continue to operate whilst responding to the ever changing environment (Love *et al.*, 2004). To achieve this, Hari *et al.* (2005) suggest that wherever possible, drastic changes should not be imposed on people, but through the use of empowerment and ownership, individuals' awareness of the importance of learning and their acceptance of pending changes can be improved.

2.7.4.2 Lack of Faith in the Knowledge Management Regime

The benefits of any quality enhancement programme are not immediately realised due to the time lag between cause and effect (Campanella, 1999). This may lead to employees losing faith with the KM imitative due to its inability to deliver widespread benefits in its infancy until a spread of knowledge can be collated (Carrillo *et al.*, 2000).

2.7.4.3 Idea Theft

In relation to the industrial barrier of '*temporary project partnerships and participants'* where organisations are fearful that the sharing of knowledge will benefit a competitor (see Section 2.7.2), individuals are also fearful that their ideas will be stolen by another employee who will then gain recognition for their idea (Thoben *et al.*, 2002). Consequently individuals become protective of their knowledge and refrain from disclosing it to the wider organisation.

2.8 Knowledge Management Techniques

2.8.1 Introduction

KM techniques and technologies are those that manage OL instances to create a knowledge base and protect against the threat of knowledge loss when an employee leaves the organisation, or is part of a project involving participants external to an organisation (Ruikar *et al.*, 2007; Tan *et al.*, 2011).

KM technologies differ from techniques because KM technologies are viewed as IT KM tools, whereas KM techniques are non-IT KM tools (Ruikar *et al.*, 2007). Kamara *et al.* (2003) also make this distinction, referring to them as 'hard' and 'soft' tools respectively. For the purpose of this research they will be known as KM technologies (IT-based) and KM techniques (non-IT based).

These techniques and technologies are seen as tools that are applied deliberately in the desire to achieve positive outcomes (Kululanga *et al.*, 1999), such as developing new skills, capabilities and ways of thinking, to confront new and different issues in future projects (Ayas and Zeniuk, 2001). They should be capable of handling the richness, content and context of information and not be limited to the capture and storage of the information itself (Gallupe, 2001). Modern technologies enable information collection, analysis and dissemination more easily than ever before (De Jager, 2007; Tan *et al.*, 2011) and are therefore critical to KM success (Egbu and Botterill, 2002; Carrillo *et al.*, 2003; Tan *et al.*, 2011). However, KM is significantly different to information management. KM technologies by themselves, without creating a knowledge-sharing culture will not bring success from a KM initiative (Kivrak *et al.*, 2008; Tan *et al.*, 2011). This is due to KM techniques predominantly focusing on tacit knowledge, whereas KM technologies mainly focus on explicit knowledge (Al-Ghassani *et al.*, 2005). (Al-Ghassani *et al.*, 2005).

A sole focus on delivering KM through technology based systems is viewed as out-dated; however is one that some researchers continue to persist with. For example, Subashini *et al.* (2012) view ICTs as technologies which facilitate the management and sharing of knowledge and information. Therefore, it is clear that although ICTs' efficiency benefits are vitally important to incorporate, it is even more vital for a socio-technical approached to be adopted. As such both techniques and technologies are now evaluated to devise a suitable socio-technical approach to facilitate KM and the required feedback loop.

2.8.2 Collaborative Techniques

Collaborative learning techniques involve multiple enterprises who learn from one another whilst remaining as individual organisations. For example; partnering, alliances, joint-venturing and framework agreements (Kululanga *et al.*, 1999). There are multiple definitions and terms to describe collaborative approaches, however they all fall under the generic umbrella of 'partnering' (Comptroller and Auditor General, 2001).

Barlow and Jashapara (1998) cite evidence that collaborative relationships assist in promoting product and process innovation (Shaw, 1994), with current interest in the construction industry surrounding the role of partnering in enabling the transfer of knowledge between firms. In bringing together differing knowledge bases and skill sets, strategic alliances create unique learning opportunities for the partnering firms involved (Inkpen, 1998).

The Latham Report (1994) suggested that a distinct lack or poor integration between partners and stakeholders is significantly limiting the performance of the UK construction industry. However, improved partnerships can refine and develop new skills and innovations within a lower risk environment at individual, group and organisational levels (Barlow and Jashapara, 1998).

Collaboration cannot ensure that the learning of individual firms participating in the agreement will be shared with other participants. This is due to the barrier of *knowledge protection* in which a firm, although in cooperation within one project may be in competition elsewhere in other projects, thus resulting in the protection of knowledge 'secrets' and competitive advantage (Kamara *et al.*, 2003).

An additional potential barrier to the effectiveness of partnering is that of trust between participants. Building trust and commitment is a key factor in transferring knowledge between organisations and involves the on-going nutrition of a relationship and not one that can be developed through one-off efforts (Barlow and Jashapara, 1998). Therefore, the use of long-standing framework agreements to maintain continuity is beneficial in ensuring learning takes place (Kamara *et al.*, 2003). Figure 2.2 illustrates these knowledge accessibility factors within a partnering agreement (Inkpen, 1998). This framework also suggests that to acquire knowledge effectively the participants of a partnership should:

- Not be rigid in their learning objectives as this could restrict natural learning outcomes from being discovered;
- Ensure leadership commitment in the form of 'champions' (Barlow and Jashapara, 1998; Barlow, 2000; Carrillo and Chinowsky, 2006);
- Be aware of the tendency to believe that just because a partnership is not performing overly effectively, OL is not taking place (performance myopia); and,
- Determine whether there is cultural alignment between the organisations from the outset.

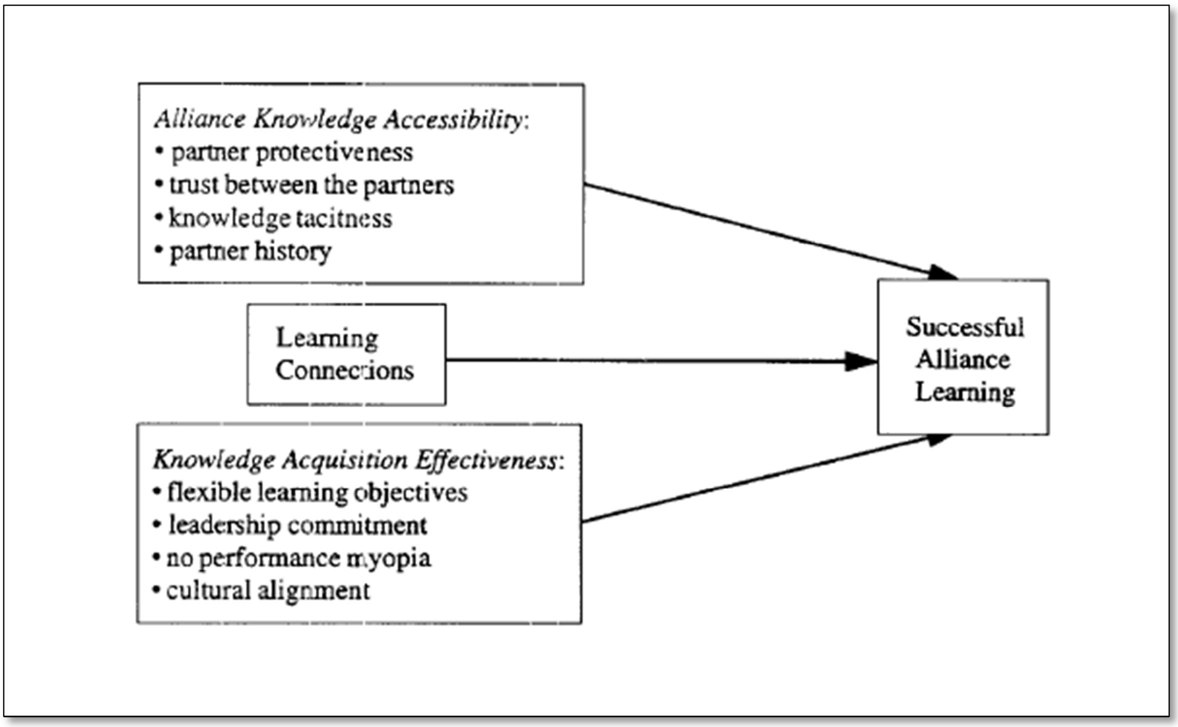


Figure 2.2: Learning Through Alliances. Source: Inkpen (1998)

2.8.3 Non-collaborative Learning Techniques

Non-collaborative learning techniques involve the amalgamation of an organisation into another organisation's operations in the form of mergers or acquisitions (Kululanga *et al.*, 1999). However, unless at least one of the organisations have effective OL regimes in place it is likely to only be a short term solution. It is also the desire of this research to discover ways to improve continual OL and therefore this short-term discontinuous approach is not deemed as appropriate to pursue.

2.8.4 Network Learning Techniques

2.8.4.1 Communities of Practice

Communities of Practice (CoPs) involve people who share work experiences, problem agendas, or similar learning opportunities (Hari *et al.*, 2005). As cited by Zarraga-Oberty and Saa-Perez (2006), as long as there is a sufficient overlap in knowledge (i.e. common understanding) the interaction between individuals with different knowledge bases (heterogeneous and complementary skills) can be facilitated (Nelson and Winter, 1982; Utterback, 1971; Nonaka and Takeuchi, 1995; Ashby, 1956). This is complimented by the definition offered by Ruggles (1997 cf. Ruikar et al. 2009) that CoPs are communities comprising of a group of individuals with differing skill sets, development histories, and experience backgrounds, who work together to achieve commonly shared goals. This technique therefore appears particularly complimentary for the scenario between contractors and designers as they hold sufficient common understanding between each other's knowledge bases.

Furthermore, CoPs enable tacit knowledge to be transferred and are not limited to explicit knowledge, unlike many other techniques. Egbu and Botterill (2002) believe that this is due to 'encultured' knowledge, (which is context specific or otherwise known as tacit knowledge), is learnt through socialisation and immersion in communities of practice.

Another cited benefit is that the membership to these communities is voluntary and based on participation rather than status, so they can span institutional structures, hierarchies and in some cases, organisational boundaries (Ruikar *et al.*, 2009). Membership is usually sought due to people needing to find answers, help and guidance to unknown problems (Ruikar *et al.*, 2009). This collective thinking to solve problems is also attributed by Carrillo and Chinowsky (2006) to obtain benefits such as:

- An improved ability to get in touch with smart people and learn from them;
- Added value brought to clients; and,
- Improved project-based networking leading to jobs being completed more effectively.

Tan *et al.* (2006) state that although a powerful knowledge sharing tool, CoPs are not without their shortcomings. They suggest that it is the passive nature of CoPs which limits its ability to fulfil the knowledge sharing dilemma because if a question is not asked within the community, the knowledge pertaining to the question is less likely to be shared. McDermott (1999) identified that communities of practice are subject to a key 'personal challenge' which involves the necessity for all to be open to the ideas of others, willing to share ideas, and maintain a thirst for new knowledge. In addition however, McDermott (1999) continued to identify further challenges facing the success rate of CoPs in the form of:

- The 'technical challenge' - to design human and information systems that facilitate the availability of knowledge but also assist community members to collectively think together;

- The ‘social challenge’ - to develop communities that actively share knowledge but still contain enough diversity of thought to encourage thinking and problem solving, rather than sophisticated copying; and,
- The ‘management challenge’ - to develop and harness an environment that truly values the sharing of knowledge.

Consequently, Ruikar et al. (2009) view CoPs as an invaluable KM technique; however, they warn that the level of success experienced from this technique ultimately depends on the attitudes of the members within the community. They advocate that it is crucial for questions asked by members to be viewed objectively, no matter how mundane the question appears to be. If this is not the case, such an unconstructive attitude can discourage participation within the community and thus limits its ability to share knowledge.

2.8.5 In-House Learning Techniques

2.8.5.1 After Action Reviews and Lessons Learnt

Post project evaluation (PPE), post-occupancy evaluation (POE), and after action review (AAR), are all mechanisms that provide the potential to learn from buildings, avoid repeating mistakes and supply information to improve the quality of the built environment (De Jager, 2007). PPE is viewed as synonymous with AARs. They are designed to attempt to capture ‘lessons learnt’ within a project, once the project has been completed, so that these lessons made available to other organisational members and future projects (Keegan and Turner, 2001). POE’s however; occur after occupancy and therefore attempt to assess the usability of the facility. As such they aim to enhance areas of learning to improve future performance (Carrillo, 2005).

Although a popular mechanism, this technique has its shortcomings, with the most significant in terms of this research being that it is restricted to the construction phase only. It therefore, rarely, if ever, involves feedback to preceding stages of the overall project, causing vital lessons learnt to not be disseminated to parties that could significantly benefit from them in the future. Furthermore, the lessons learnt within a project are often lost or mismanaged within construction organisations, causing the learning opportunity to be lost altogether (Carrillo, 2005). Furthermore, due to the lack of availability of time and the need to reallocate staff to future projects, the process of AAR is insufficiently completed or deferred entirely (Orange *et al.*, 1999a; Keegan and Turner, 2001; Tan *et al.*, 2011).

Even in the event of AARs being conducted sufficiently, there is the problem of losing potentially important information and insights due to the time lapse between the event itself occurring and it being recalled/captured (Kamara *et al.*, 2003). For example, Keegan and Turner's (2001) study demonstrated that not one single company questioned felt satisfied with how the process was conducted and its outcomes, due to time constraints exerting enormous pressure and thus reducing the effectiveness of the learning practices.

For the effectiveness of learning outcomes to improve, it has been recognised that the point of capture must be brought forward in time to before the completion of the project (Orange *et al.*, 1999a), or more decisively, to the point in which the learning event occurs (i.e. live capture) (Keegan and Turner, 2001; Robinson *et al.*, 2001; Kamara *et al.*, 2003; Carrillo, 2005; Tan *et al.*, 2006).

2.8.5.2 Benchmarking

Barriers, such as limited resources and short term objectives, result in a call for a measurement system capable of assessing the benefits of implementing KM strategies (Robinson *et al.*, 2001). This technique is therefore viewed as a potentially powerful technique to demonstrate the benefits of such a feedback system. As multiple benefits of OL are connected with the reduction of failure costs and improved efficiency (Love and Li, 2000), it has been argued that senior executives will only allocate the significant necessary resources where such economic benefits are evident (Davenport *et al.*, 1998). It is therefore apparent that conducting benchmarking practices are critical to maintain on-going support in the KM regime.

2.8.5.3 Debriefing

Debriefing is seen as the *"purposeful reflection within a social interaction which assists learners to develop generalisations and to transform experience into learning"* (Boyd *et al.*, 2004). The act of debriefing is a form of reflection which is said to:

- Enhance individual learning due to these individual lessons being aggregated, validated and synthesized; and,
- Transform tacit knowledge to explicit knowledge, facilitating its dissemination and thus OL (Lee and Egbu, 2007).

As previously stated (see section 2.2.3), to transfer tacit knowledge requires some degree of social interaction to take place (Nonaka, 1994). Consequently, a study conducted by Boyd *et al.* (2004) discovered that debriefing was a powerful tool in transforming captured tacit knowledge into explicit knowledge so that it can be transferred to a wider audience. For example, their study consisted of the audio capture of learning instances on a construction site, followed by a debriefing discussion so that these instances could be analysed, improved and further reflected upon, than was possible during the instance itself due to time constraints. Debriefing is thus seen as an effective means to extract further knowledge through discussion with others (Boyd *et al.*, 2004).

2.8.6 Individual Learning Techniques

2.8.6.1 Diaries

Diaries provide people the opportunity to reflect and record their experiences, perceptions and feelings regarding their daily operations relatively soon after they have occurred (Lee and Egbu, 2007). This process of reflection is seen as a fundamental facilitator for enabling new norms to be established and therefore to enable learning to occur (Wood Daudelin, 1996). However, this form of written diary keeping is faced with obstacles such as:

- Severe time pressures (Robinson *et al.*, 2001);
- Requirement for writing skills (Lee and Egbu, 2007);
- The viewpoint that they are overly personnel interpretations and therefore non transferrable; and,
- The perspective that they are a waste of resources as they will be buried under other unread reports (Carrillo *et al.*, 2000).

Therefore, Lee and Egbu (2007) suggest that a better construction related medium of diary keeping is that of an oral diary. This breaks down some of the barriers attributed to written diaries as they are relatively quicker to complete and do not require writing skills. Lee and Egbu (2007) have also acknowledged that oral communication has the ability to not only dictate and record tacit knowledge, but also to convert it through the use of metaphors and explanatory communication, which is less possible through written language. This brings into question, which format (text, audio, visual, graphical, video, etc.) is best suited for the transferring of knowledge as it has been proven that within the technique of diary keeping, the output format has had a dramatic effect on its ability to share knowledge. For example, Ruikar (2010) suggests that by incorporating multimedia outputs, such as those facilitated by podcasts, it is possible to accommodate a wide variety of learning abilities and styles, whilst facilitating self-paced learning.

2.8.6.2 Mentoring/Training

Mentoring and training are techniques in which more experienced personnel provide guidance and support for new or less experienced employees (Ruikar *et al.*, 2007). This can be conducted on a one-to-one or one-to-many basis and usually follows a formal format internally, where seniors train juniors within the organisation, or externally, where employees attend courses managed by professional organisations or experts. Keegan and Turner (2001) suggest that this is invaluable if new recipes or actions are to be embedded.

However, as previously noted one-to-one mentoring is resource intensive (see section 2.6.2). Therefore the physical interaction between designers and contractors in the aim of training and educating each other is seen as impractical due to time and cost restraints. Consequently, this KM technique is better suited to succession planning and knowledge retention scenarios within the same organisation or project phase.

2.8.6.3 Reassignment of Employees

A natural technique available to the construction industry due to its project-based nature is the reassignment of successful and knowledgeable employees to other projects. Lord (2000) argues that this technique can assist cross-divisional knowledge transfers and therefore act as a vehicle to pass on knowledge learnt in past projects to similar future projects. However, its success is ultimately dependant on the rate of staff turnover, as this can increase the vulnerability of an organisation, as well as lower individuals' ability to learn from past projects (Kamara *et al.,* 2003).

Michael and Palandjian (2004), assert that care should be taken to ensure that individual learning is fully captured before being reallocated to a subsequent project. Otherwise this learning remains personal, which limits the extent to which it is beneficial to the organisation, as well as heightening the risk that it may be permanently extracted from the organisation if that employee leaves.

In addition, and perhaps more importantly, this technique appears significantly limited for the purpose of satisfying this research's objectives (see Section 1.3), as it involves the redeployment of personnel to roles requiring similar skill sets and/or qualifications. Therefore, similarly to that of mentoring and training (see Section 2.8.6.2), this technique is viewed as incapable of bridging the divide between differing project stages, due to the need for similar skill sets and qualifications to be held by the redeployed employees.

2.8.6.4 Incentives

Many authors have cited the importance of developing an effective incentive and reward structure to support their KM programme (Carrillo *et al.*, 2000; Patel *et al.*, 2000; Robinson *et al.*, 2001; Bordass, 2003; Hari *et al.*, 2005). Carrillo *et al.* (2000) suggest that incentives and rewards can be appropriate strategies for overcoming obstacles such as cultural barriers. This has since been supported by Robinson *et al.* (2001), who state that it is arguably the most important element of a KM strategy in overcoming implementation barriers, with change management programmes and a performance measurement system also being important. Similarly, findings from a study conducted by Kivrak *et al.* (2008) indicate that even if an organisation's culture supports knowledge sharing, top management support in the form of encouragement and rewarding, is seen as a facilitator to encourage such practices.

2.9 Knowledge Management Technologies

2.9.1 Mobile Technology

For the previously identified desire for live capture of learning instances to be satisfied (see Section 2.5.4), there is an evident call for the use of mobile technology. Through a study conducted by Kimoto *et al.* (2005), it was identified that for mobile technology to be applicable within the construction industry it must fulfil the following criteria:

Mobility of Hardware: Construction workers and inspectors require pocket sized hardware to enable convenient mobility around the site / built facility.

Durability of Hardware: Hardware must be strong and resistant to shock, rain, water and dust.

Compatibility of Hardware and OS: The system must be usable on any hardware and operating system (OS)

Compatibility of Data between the Mobile and PC: Construction managers require data that is held on a personal computer (PC) to be accessed on the mobile device and vice versa.

Expressivity of Display: The mobile device must be capable of displaying drawings and pictures both indoors and outdoors.

Stability of System: Total stability of system including OS, memory card and other devices is necessary.

Operability of User Interface: Data input must be easy and intuitive allowing construction workers to input data with gloves on. Easy user interface such as pen-touch is suitable.

Processing Speed: Processes such as start-up, shut down and intermediate processes needs a quick response time. The display speed especially of drawings and pictures is important.

Continuous Computing Environment: Changes in computing environments are subject to quick changes. Therefore a computing environment that assures the long operation of systems is necessary.

They continue by acknowledging that PDAs meet all of these above requirements. They have seen significant developments, with them becoming palm-sized personal computers (PCs), with improved processing speeds, combined with the capability of handing various types of data such as text, audio, pictures, drawings and video (Kimoto *et al.*, 2005). Ruikar (2010) modernises this further by highlighting advances such as the Apple iPod Touch, which houses functions such as; built-in speakers, Bluetooth, presentation software, voice control, microphone, internet and cameras. Smart-phones, Pocket PC phones, and Tablet PCs have also emerged as technologies that are ideal for the mobile capture of knowledge (Chen, 2008).

A benefit of the progression in mobile phone technology in the form of smart-phones is that they incorporate many, if not all, of the features housed in PDA devices. However, they also provide the capability to connect wirelessly to the cellular phone network (Chen, 2008). This has caused other mobile technology devices and Tablets to also start producing options that house subscriber identity module (SIM) cards also. As such, the definition between PDAs, smart-phones and Tablets is increasingly becoming less distinct, with the main differences relating to preferences such as size of screen and weight.

A cited benefit of using mobile technologies for the purpose of remote knowledge capture is their current increase in usage for other purposes including; inventories, snagging, timesheets, RFIs, daily reporting and inspections (Bowden, 2005). This is beneficial due to KM infrastructure components that are capable designed to run on a technology infrastructure that is currently in use is more likely to be initiated (Tan, 2006). This multiple-use of such devices significantly reduces the additional costs that are incurred compared to specialised systems.

Some shortcomings of mobile technologies noted by Bowden (2005) include:

- Being most suited to the collection of structured data compared to the entry of considerable amounts of manual data such as writing;
- Not being suited to tasks that require a big picture view of documents such as drawings (however they are beneficial when there is a need for a close up on small details); and,
- Difficulty in performing tasks that are performed in direct sunlight.

2.9.2 Intranets and Groupware

An intranet is said to be used to store and support information on various knowledge areas, where the capture of best practice and more mature 'explicit' information, as well as communicative facilities such as e-mail, bulletin boards and corporate information newsletters are enabled (Koch, 2003). As cited in Ruikar *et al.* (2007), knowledge captured and stored through technologies such as word processors, knowledge bases and case-based reasoning tools are made available to company employees over the intranet. Such knowledge can be distributed 'passively' (for example, publishing newsletters or populating knowledge repositories for users to browse); or 'actively' (i.e. convening an after action review meeting, or pushing knowledge via electronic alerts to those that may require them) (Markus, 2001).

Intranets are one of the most commonly used technologies for sharing knowledge within the construction industry (Ruikar *et al.*, 2007), with a study conducted by Kivrak *et al.* (2008) discovering that intranets were utilised by all of the organisations questioned. Therefore, the beneficial characteristic of PDAs being multi-use and already in operation within the industry (see Section 2.9.1), also apply to intranets. They have also been praised for their ability to improve efficiency in storage, sharing and access, which should improve decision-making and enhance employee query response efficiency (Bennett and Gabriel, 1999).

However, too much emphasis placed on an information-centric perspective conflicts with the need for a KM system to include users and mechanisms which facilitate locating and interacting with others (Stenmark, 2002). Intranets have been viewed as lacking the ability to contend with face-to-face interactions and discussions (such as in communities of practice), which is seen to result in the absence of reflection; a vital attribute of knowledge generation (Stenmark, 2002).

However, Stenmark (2002) continues to recognise, that when physical meetings are impossible or impractical, virtual meetings through an intranet may provide a viable substitution. Virtual meetings are facilitated using groupware technologies that support collaboration and communication and thus, the coordination of activities distributed by time and geographically (Robertson and Swan, 2001). Specific functionality that groupware offer include; email, conferencing, task scheduling, appointment scheduling and multimedia document management (Rezgui *et al.*, 2000). It can therefore be concluded that this perspective views intranets not as a substitute for other forms of KM techniques, but in fact a supplementary method to improve the efficiency and convenience of the overall system.

2.9.3 Project Extranets

As cited in Kamara *et al.* (2003) project extranets, also known as project websites, are dedicated web hosted spaces for collaboration and information to support design and construction teams (Augenbroe and Verheij, 2002). Extranets share many of the credentials of intranets; however, their most specific difference is that they enable cross organisational links (restricted to those with privileged rights) to access project knowledge, whereas intranets only allow company-wide access to organisational knowledge (Tan *et al.*, 2005).

Various authors recognise that the use of such a web hosted and inter-organisational knowledge base has facilitated the live capture and reuse of project knowledge (Kamara *et al.*, 2003; Tan *et al.*, 2006). This is due to it firstly enabling access and contributions to knowledge remotely and therefore the learning instance can be captured at the point of it occurring no matter how distributed the occurrences are (Kamara *et al.*, 2003). Secondly, extranets enable access and contribution to the knowledge base through multiple organisations, thus facilitating knowledge from multiple stakeholders to be collated and shared in the attempt to benefit the overall project. The widespread availability and use of the internet makes it possible for most firms within a project's supply chain to utilise and contribute to the knowledge base (Kamara *et al.*, 2003). It should be noted however; that an extranet's effectiveness for this purpose is ultimately dependent on project participants overcoming barriers such as trust, competition, resource limitations and time pressures.

2.9.4 Data and Text Mining

Data and text mining is a technology capable of extracting meaningful knowledge from masses of data and text (Ruikar *et al.*, 2007). According to Egbu and Botterill (2002) data and text mining tools such as neural networks, artificial intelligence and conventional statistical analysis are accomplished by classifying data, as well as identifying and matching patterns of data. This is supported by Ruikar *et al.* (2007), who continue to highlight that such tools are capable of identifying hidden or unknown relationships that can create new knowledge.

As cited by Tan (2006) data and text mining's main purpose is to support the knowledge identification stage of the knowledge life cycle (Karanikas and Theodoulidis, 2002). However, in addition to the limitation that they are purely data and text based, the appeal of such mining technology is reduced due to computers' inability to understand text as humans do. This is due to them bypassing grammatical structures so that words and phrases are taken as indicators of meaning, causing difficulty when sorting ambiguous words (Leong *et al.*, 2004). This is supported by Egbu and Botterill (2002) who counteract the argument offered by other authors that such pattern identifying and matching tools can eliminate human intervention, by stating that an intelligent human is still required to:

- Structure the data in the first place;
- Interpret the data and understand identified patterns; and,
- Make decisions based on the knowledge generated.

2.9.5 Building Information Modelling

It is recognised that there is currently an increasing amount of interest within the industry towards the adoption of building information modelling (BIM) (Succar, 2009). Suermann and Issa (2009) attribute this surge in focus to the many professionals who have labelled BIM as the answer to the construction industry's poor interoperability and data management, which is stated as costing the industry billions of pounds a year.

It is viewed as vital that this research not only compliments current project delivery approaches but also aligns with the future direction of the industry. Therefore it is important to consider the potential of BIM in supporting such a proposed feedback framework. This review therefore sets out to expand the understanding of what BIM is to arise at a common understanding or definition. Furthermore, the benefits attributed to BIM are outlined and a review of its potential to satisfy or assist this research's objectives is undertaken.

BIM is said to be "*an IT enabled approach that involves applying and maintaining an integral digital representation of all building information for different phases of the project lifecycle in the form of a data repository*" (Gu and London, 2010). It is more than 3D CAD modelling as this is limited to collections of points, lines, 2D shapes and 3D volumes, whereas BIM not only consists of such geometric entities but can also comprise of quantitative and qualitative data to apply 'meaning' (Yan and Damian, 2008). This is achieved through it being a digital model in which information about a project can be stored in 3D, 4D (integrating time), 5D (incorporating cost), or even 'nD' (a term covering any other information that is included) (Nisbet and Dinesen, 2010). However, such definitions are limited to simply describing the attributes and capabilities of BIM; with a common definition to what BIM actually is currently eluding the industry (Holzer, 2007).

Eastman *et al.* (2008) comply with this opinion but offer an understanding of BIM as being "*an intelligent simulation of architecture*" which must exhibit the six key characteristics shown in Figure 2.3.

A building Information Model must be:

- **Digital**
- **Spatial** (3D)
- **Measurable** (quantifiable, dimension-able, and query-able),
- **Comprehensive** (encapsulating and communicating design intent, building performance, constructability, and include sequential and financial aspects of means and methods),
- **Accessible** (to the entire AEC/ owner team through an interoperable and intuitive interface), and
- **Durable** (usable through all phases of a facilities life).

Figure 2.3: Six Key Characteristics of Building Information Modelling Technology

They continue by stating that no current implementations of BIM software actually meet all of the above criteria needed to be formally classed as BIM technology, but they believe that those characteristics are essential for reaching the goal of integrated practice (Eastman *et al.*, 2008). Therefore within this study, BIM will be referred to as meaning the *intelligent simulation of architecture*. Furthermore, the BIM approaches mentioned in this review consist of the advancing technologies that are progressing towards the goal of true BIM technology status, even if they cannot be strictly classed as BIM technologies in their current form.

2.9.5.1 Benefits of BIM

Numerous benefits have been attributed to BIM such as the improved integration between the multiple disciplines comprising a project, as well as between plans, sections, details, graphics and data in ways that are not possible in 2D (Yan and Damian, 2008). Clash detection, reducing the cost of changes, clearer scheduling and more efficient fabrication utilising data from the project BIM can also be achieved (Nisbet and Dinesen, 2010). Increased opportunities for owners, designers and builders to collaboratively coordinate the supply chain of the building process are also facilitated (Manning and Messner, 2008).

As such, the UK government have acknowledged the potential of BIM through advocating its use on virtually all government projects within the next five years (i.e. by 2016); an increase in adoption compared to the current recommended level being only on projects over £50m (Withers and Matthews, 2011).

The disciplines suggested to be possible beneficiaries is also extensive including; clients, architects, engineers, estimators, contractors, lawyers, sub-contractors, fabricators, code officials and operators, to name a few (National Institute of Building Science cf.Holzer, 2007). BIM solutions are not more applicable to one type of building than another (Becerik-Gerber and Rice, 2010), which is why Eastman *et al.* (2008) illustrate the breadth of potential benefits of BIM according to the project stage in which they materialise rather than specific disciplines (see Figure 2.4).

2.9.5.2 Adoption of BIM

At present, the widespread adoption of BIM technologies is yet to be seen (Tse *et al.*, 2005; Gu and London, 2010; Sheth *et al.*, 2010). This is said to be attributed to the significant investment needed in the technology, processes and organisations themselves; combined with the difficulty in evaluating IT expenditure benefits in monetary terms (Becerik-Gerber and Rice, 2010).

Some view the infancy of BIM as a barrier to its adoption due to the opinion that a time frame of 5 to 8 years is needed for the more conservative participants of the industry to note its apparent benefits (Becerik-Gerber and Rice, 2010). Consequently it is viewed that BIM implementation is and will continue to gather momentum within the architectural, engineering and construction (AEC) industry as and when industry confidence in the cost-benefit ratio improves. (Manning and Messner, 2008; Sheth *et al.*, 2010).

Preconstruction Benefits

Concept, Feasibility and Design Benefits

- Early awareness of cost and time feasibility
- Reduction of unexpected cost escalations

Increased Building Performance and Quality

- Early evaluation of design alternatives using analysis / simulation tools
- Evaluate proposal to determine whether it meets functional and sustainable requirements

Design Benefits

Earlier and More Accurate Visualisations of a Design

- Early generation of 3D model for visualisation
- Dimensionally consistent model in every view

Automatic Low-Level Corrections When Changes Are Made to Design

- Use of parametric rules to automatically update the 3D model when changes are made

Generate Accurate and Consistent 2D Drawings at Any Stage of the Design

- Accurate/ consistent drawings can be extracted for any set of objects or view of a project
- When changes are made, fully consistent drawings can be generated immediately

Earlier Collaboration of Multiple Design Disciplines

- Enables simultaneous work by multiple design disciplines on a coordinated 3D model

Easily Check against the Design Intent

- Earlier and more accurate cost estimations

Extract Cost Estimates during the design stage

- Extract an accurate bill of quantities and spaces for cost estimates at any stage
- Enables better informed design decisions to be made

Improve Energy Efficiency and Sustainability

- Enables energy analysis early on making modifications easier to implement

Construction and Fabrication Benefits

Synchronise Design and Construction Planning

- 4D allows simulation of the construction process at any point in time
- Reveals sources of potential problems and opportunities for improvements

Discover Design Errors and Omissions before Construction (Clash Detection)

- Inconsistencies between 2D drawings are eliminated
- Speeds construction process, reduces costs and minimises legal disputes

React Quickly to Design and Site Problems

- Design changes made easily with other objects in the design being automatically updated
- Consequences of changes can be visualised, estimated and resolved much quicker than the error prone paper-based system.

Use Design Model as Basis for Fabricated Components

- Facilitates off-site fabrication, reduces cost and time
- Larger components of design to be fabricated off-site than would previously be attempted

Better Implementation and Lean Construction Techniques

- Accurate model of design and materials allows for improved planning and scheduling to ensure just-in-time arrival of people, equipment and materials.

Synchronise Procurement with Design and Construction

- Procurement from the vendors and subcontractors is simplified.

Post Construction Benefits

Better Manage and Operate Facilities

- Information of all systems used to check that they work appropriately after completion

Figure 2.4: Benefits of Building Information Modelling. Source: Adapted from Eastman *et al.* (2008)

2.9.5.3 Suitability of BIM to this Study

BIM technology appears to complement the objectives of this research (see Section 1.3) in the form of enabling information to be shared to improve the integration between varying disciplines within projects. BIM therefore appears capable of reducing the fragmentation of the industry through improving project participant integration. Furthermore BIM eliminates elements of the design stage which are subject to higher levels of human error. As such, BIM is viewed as a means to improve design buildability, as well as the cooperation between differing disciplines within each project.

However, it is not viewed as satisfying the entire range of objectives that this research seeks to satisfy (see Section 1.3). For example, BIM does not appear to be able to satisfy the ability to capture buildability related knowledge residing in the construction stage of projects in its current format or methods of use. It assists in minimising buildability issues in the first instance through means such as clash detection. However, it does not appear to be utilised to capture knowledge relating to buildability issues that do arise, or that of design changes that need to be made. Therefore the feedback of such knowledge to designers and/or to update the underlining rules behind the model itself cannot be achieved.

Although the above limitations of BIM restrict the extent to which it can satisfy this study's objectives (see Section 1.3), it is evident that the future evolution of BIM technology will have a significant impact on the AEC industry (Eastman *et al.*, 2008). Therefore a framework which integrates with such would be highly beneficial due to it reducing the duplication of effort evident between incompatible solutions, as well as enhancing this research's potential longevity. Consequently, the potential of BIM must be considered in regards to providing a prospective platform to deliver the proposed feedback platform.

2.10 Knowledge Management Technique/Technology Selection

2.10.1 Need for a Multiple KM Technique/Technology Approach

Kululanga *et al.* (1999) acknowledge that the wide range of KM techniques/technologies discussed previously are capable of extracting learning outcomes from a variety of internal and external domains, including individual, group, organisational and cross-organisational; however not one solitary technique/technology satisfies all levels entirely. For example, the use of partnering may be suitable in the attempt to capture knowledge across organisational divides, but it is not effective in capturing learning instances on an individual basis. In some cases these techniques are simply enablers of OL in which they offer a vehicle for learning to arise, but they make no attempt to fulfil other stages of the KM process. It is therefore evident that the use of a sole technique is insufficient in addressing the entire KM requirements of an organisation's generated learning (Kululanga *et al.*, 2001).

Table 2.2 illustrates this view through an overview of the aforementioned techniques and technologies, categorised according to which stage of the KM lifecycle they best support.

Table 2.2: Knowledge Management Techniques and Technologies. Adapted from: Prencipe and Tell (2001); Ruikar et al. (2007)

KM Lifecycle Stage	KM Technologies	KM Techniques
Identification	Data mining Text mining Knowledge mapping	Brainstorming Face-to-face meetings Benchmarking Communities of Practice Post project review
Capture	Word processors Spread sheets Case based reasoning / expert systems Knowledge mapping Mobile technologies (PDAs)	Post project review Recruitment Discussion Forums Mentoring Training Diaries
Codification	Mind mapping technologies Knowledge mapping Web based publishing Virtual reality tools Word processors CAD Spread-sheets	Meeting minutes Milestones / deadlines Case writing Project history files Drawings Notes Diagrams Debriefing
Storage	Data Warehouse Lessons learnt Databases	Documentation Filing Libraries
Share / Access	Intranets Extranets Communities of practice Web publishing E-mail Groupware Video conferencing	Communities of practice Discussions Mentoring Training Seminars / Conferences Job rotation

It is also not the case that an increase in the number of techniques/technologies used results in a greater quality of captured knowledge. This is shown through Keegan and Turner's (2001) findings that a greater quantity of practices (particularly in the area of retention) did not equate to higher quality project-based learning. This is because they suggest that some practices actually have the ability to impede the sharing of knowledge. It is therefore suggested that a realistic objective would be in line with Gieskes and ten Broeke's (2000) call for a better insight into the makeup and arrangements of these techniques/technologies.

2.11 Chapter Summary

This chapter has documented a thorough review of OL and KM literature. There is significant evidence surrounding the need for learning to take place within construction if the multifaceted benefits analysed in this review are to materialise. At present the construction industry is falling behind that of comparative industries such as the automotive industry in terms of learning. Some of this failure to learn can be attributed to the prominence of some of the identified industry specific barriers to learning; however, it remains apparent that there remains a lack of desire to overcome the integration issues facing the industry.

As discussed in section 2.5.3, for KM to be successful it is important to focus on the key learning objectives that present the potential to offer the most beneficial return, in preference for applying an overly broad knowledge initiative. A specific area of improvement to become known, facilitated through improved KM and in particular the development of the proposed design-construction feedback loop, is that of enhanced buildability. This is of specific interest within construction due to the recognition that the built environment directly impacts on the quality of service / wellbeing provided within it (Berry *et al.*, 2004; De Jager, 2007). Therefore buildability improvements are linked to enhanced quality, efficiency (both in its eventual functionality and its initial construction) and value.

Consequently, this chapter has facilitated a key learning objective to materialise that is appropriate to focus this research upon. This is in the form of enhancing buildability through improved KM. Accordingly, the subsequent chapter will conduct a more in-depth review of buildability literature, whilst also investigating comparative studies aimed at improving buildability and/or KM within construction.

3 Knowledge Management to Improve Buildability

3.1 Introduction: The Adoption of Buildability as the Key Learning Objective

The preceding chapter reviewed general KM and OL literature. A key identification was made in the form of recognising that to succeed it is best to focus efforts on narrower and more targeted learning objectives rather than breadth and variation (see Section 2.5.3). Consequently, the objective of improving buildability was highlighted as potentially attaining the greatly sought after efficiency and quality improvements demanded by Latham (1994), Egan (1998) and Wolstenholme (2009). In particular, buildability issues present an opportunity in which their reduction can benefit a wide variety of project participants, improve integration and enhance the quality and value achieved.

The logic behind the adoption of buildability to represent the key learning objective of this study also extends further than being suited to current industry performance improvement targets. As this study is predominantly concerned with improving cross organisational learning achieved within construction projects, it is critical that the learning objective compliments this aim. Therefore a KM objective that requires cross-organisational learning is fundamental if means to improve it are to be explored. Alternatively, if a learning objective was adopted that simply required the feedback of knowledge within the same phase or organisation (for example, construction rework instances) it would not enable the complexities involved in achieving cross-organisational learning to be examined.

Furthermore, the adopted context of this study focusing on highly serviced complex construction projects are subject to heightened complexities relating to their buildability and coordination during design and planning. The project context and the learning objective are therefore seen as complimentary and well aligned. Accordingly, it has been recognised that the construction stage possesses significant buildability expertise which can contribute to the design process (Pulaski and Horman, 2005). Therefore, a clear link can be made between improving KM through the feedback of relevant knowledge, to that of enhancing buildability. The logic connecting the adoption of buildability in facilitating the main aim and objectives of this research to be examined are summarised in Figure 3.1.

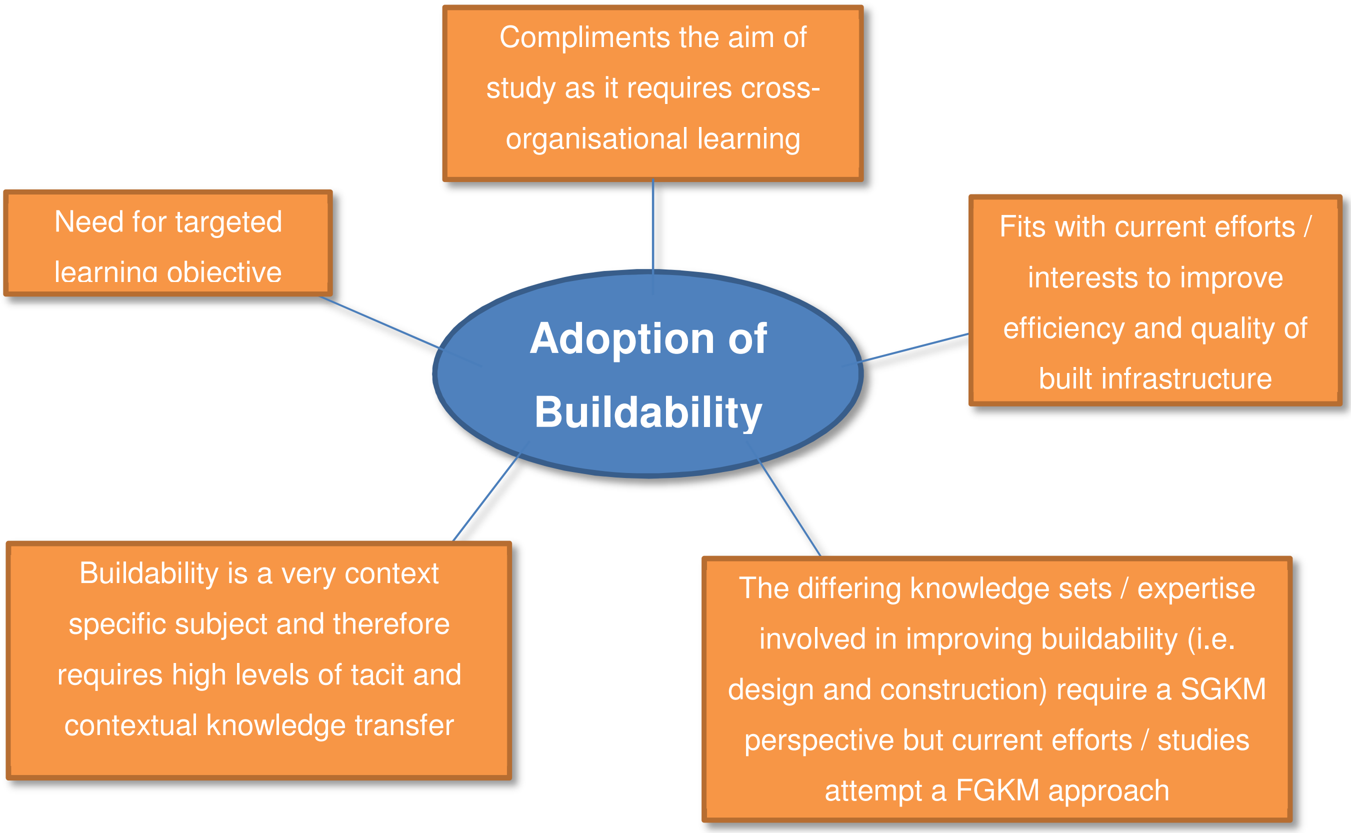


Figure 3.1: Logic of Adopting Buildability as the Learning Objective of this Study

As such, this chapter further investigates the concept of buildability including; the benefits of improving the extent to which designs are buildable; the barriers against achieving such; and, the main methods/factors that need to be considered. This is followed by a review of complimentary research projects to position this work in the wider body of literature and simultaneously avoid repeating research unnecessarily.

3.2 Buildability

3.2.1 Defining Buildability

There has been much debate surrounding the terminology of buildability and constructability. For instance, buildability has been defined as:

> *"The extent to which a building design facilitates efficient use of construction resources and enhances ease and safety of construction onsite, whilst the client's requirements are met"* (Lam et al., 2006).

Whereas, constructability has been defined as:

> *"The integration of construction knowledge in the delivery process, whilst balancing the various project and environment constraints to achieve goals and building performance at an optimal level"* (CIIA, 1983 cf. Ma et al., 2001).

Low (2001) suggests that these concepts can in fact be used interchangeably, due to them being taken as synonymous (Al-Ghamdi, 2000). This is supported through other authors, such as Thabet (2000), believing that the only difference between the terminology is that buildability originates from the United Kingdom, whereas constructability has its origins in the United States. A closer examination of the differences in terminology has been undertaken and illustrated in Figure 3.2.

Some of these definitions have received criticism. For example, the definition of buildability provided by the Construction Industry Research and Information Association (CIRIA) is seen as too narrow as it essentially confines buildability to being a design process issue, whereas subsequent definitions of buildability and constructability have been unable to provide complete consensus of their constituent parts (Wong *et al.*, 2007). As can be seen from the variation apparent within the definitions a consensus regarding the essential elements of buildability or constructability in the form of a concise definition has not been reached.

One set of commentators argue a specific difference between these two terms by suggesting that constructability differs markedly from buildability in terms of it consisting of much wider boundaries (Griffith and Sidwell, 1993). These authors suggest that this difference is due to buildability being a concept which focuses predominantly on the influence of the designer regarding the ease of construction onsite, whereas constructability takes a more holistic perspective, focusing on the contribution of all stages of the building process. Chen *et al.* (1993) also identified the inadequateness of the CIRIA definition and addressed them through the reassessment of the definition to read:

> *"Buildability is the extent to which decisions, made during the whole building procurement process, ultimately facilitate the ease of construction and the quality of the completed project"* (Chen et al., 1993).

Consequently, the terminology of buildability has been brought in line with that of constructability. This is through engaging the entire procurement process. It also highlights the need to consider the performance of the completed project instead of limiting it to just its ease of construction (Chen *et al.*, 1993). For example, the assembly of a project could be planned and designed for ease of construction; however if it is costly and difficult to access for maintenance then the extent to which is was easily buildable has been reduced from the viewpoint of this definition (Chen *et al.*, 1993).

Constructability is…

- …the integration of construction knowledge in the project delivery process and balancing the various project delivery and environment constraints to achieve project goals and building performance at an optimal level (CIIA, 1983 cf. Ma *et al.*, 2001).
- …the application of a disciplined, systematic optimisation of the construction-related aspects of a project during the planning, design, procurement, construction, test, and start-up phases by knowledgeable, experienced construction personnel who are part of a project team (Ardery, 1991)
- …a system for achieving optimum integration of construction knowledge in the building process and balancing the various project and environmental constraints to achieve maximisation of project goals and building performance (CII Australia 1993).
- …the extent to which decisions made during the whole building procurement process, in response to factors influencing the project and other project goals, ultimately facilitate the ease of construction and the quality of the completed project (Griffith and Sidwell, 1993)
- …referred to as the extent to which a design facilitates efficient use of construction resources and enhances ease and safety of construction on site while the client's requirements are met (Lam *et al.*, 2007).

Buildability is…

- …the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building (CIRIA, 1983).
- …a problem of managing the transfer of appropriate knowledge about the construction process to the design process worker. It is not solely about the technicalities of the construction process (Moore, 1993).
- …the extent to which a building design facilitates efficient use of construction resources and enhances ease and safety of construction on site whilst the client's requirements are met (Lam et al., 2006).
- …the extent to which decisions, made during the whole building procurement process, ultimately facilitate the ease of construction and the quality of the completed project (Chen *et al.*, 1993).
- …design and detailing which recognise the problems of the assembly process in achieving the desired result safely and at least cost to the client (Illingworth, 2000).
- …the extent to which the design of the building facilitates ease of construction, subject to the overall requirements for the completed building (Fischer and Tatum, 1997).
- …the ability to construct a building efficiently, economically and to agreed quality levels from its constituent materials, components and sub-assemblies (Ferguson, 1989)

Interchangeable

- Constructability, or buildability (UK), is a major factor in measuring the success or failure of construction projects (Thabet, 2000).
- The concept of "constructability" in the United States, or "buildability" in the United Kingdom, emerged in the late 1970s (Gambatese *et al.*, 2007).
- Buildability (or constructability), is the integration of design and construction to improve the chances of achieving a better-quality project, completed in a safe manner, on schedule, and for the least cost (Yang *et al.*, 2003).
- Fischer and Tatum (1997) use a modified U.K buildability definition to define their view that; constructability is the extent to which the design of the building facilitates ease of construction, subject to the requirements of construction methods.
- Buildability, known in the North American construction industry as constructability, can be considered as a major factor in measuring the success or failure of a project (Ganah, 2003).

Figure 3.2: Definitions and Quotations Surrounding the Concept of Constructability and Buildability

It has therefore been deduced from this review that although in the past there may have been limitations surrounding the terminology of buildability, these issues have been eliminated and the terms can now be used interchangeably. Consequently, the preferred option of buildability, due to its UK origins will be used hereafter, except for direct quotes from other authors using the term constructability specifically. The definition adopted for this research has been adapted from those supplied by CIIA (2006, cf. Ma *et al.*, 2001) and Chen *et al.* (1993) to read:

> *"Buildability is the extent to which construction knowledge is integrated throughout the entire building procurement process in order to optimise the ease of construction and the quality of the completed project."*

3.2.2 Factors of Buildability

Differing studies have attempted to categorise the most common factors that affect buildability. Such studies include; Hanlon (1995), Fischer and Tatum (1997), Arditi *et al.* (2002) and Lam *et al.* (2007). There is however a high degree of variation arising from such studies, which indicates the difficulty in categorising buildability factors. This is due to its subjectivity. For example, Lam *et al.* (2007) provide greater degrees of prescription, such as; allowing economic use of contractor's resources; enabling contractors to develop and adopt alternative construction details; and, enabling standardisation and repetition, to name a few. In comparison, Arditi *et al.* (2002) are less prescriptive and provide the most common characteristics of projects that can influence buildability, such as; project complexity, design practices adopted, project delivery/size/type, and project location to name a few. Results to Arditi *et al.'s* (2002) study into what the most significant factors influencing buildability are illustrated in Figure 3.3.

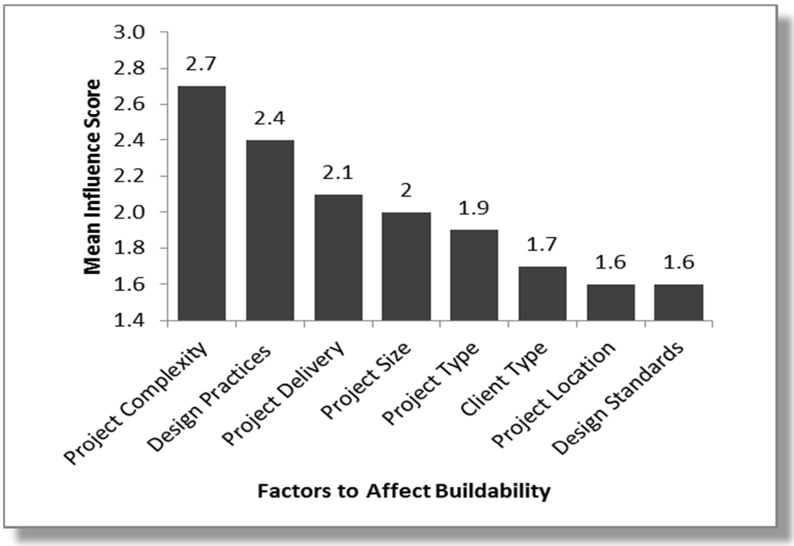


Figure 3.3: Factors Affecting Constructability. Source: Arditi *et al.* (2002)

In a similar non-restrictive method, Fischer and Tatum (1997) classify buildability knowledge into five groups according to the broad design decision on which they have the greatest impact. These groupings and a brief explanation of the knowledge classification are shown in Figure 3.4.

Buildability Knowledge Classifications

- **Application heuristics** – knowledge terms that relate to overall project variables to the applicability of a given construction method.
- **Layout Knowledge** – buildability knowledge that constrains the vertical and horizontal layout of structural elements.
- **Dimensioning knowledge** – knowledge which constrains the dimensions of structural elements.
- **Detailing knowledge** – knowledge which affects the detailed design of the structure such as sizing and layout.
- **Exogenous knowledge** – knowledge which describes the requirements of construction methods in terms of factors that are not under the control of the designer.

Figure 3.4: Classification of Buildability Knowledge. Source: Adapted from Fischer and Tatum (1997)

3.2.3 Drivers to Improve Buildability

Improvements in buildability are said to enhance the extent to which clients are able to obtain the best possible value from the construction process (Hyde, 1993). This is due to them being linked to benefits such as:

- Improved construction efficiency (Kartam and Askar, 1999; Lam and Wong, 2009);
- Enhanced construction quality (due to construction difficulties being taken into consideration during the design stage and therefore reducing the number of mistakes made during construction) (Lam and Wong, 2009):
- Reduced construction costs for clients, designers and contractors due to increased simplicity and standardisation of designs (Gambatese *et al.*, 2007; Lam and Wong, 2009);
- More effective teamwork, better conceptual planning and more accustomed site management (Griffith and Sidwell, 1993); and,

- A reduction in delays, contract change orders and legal claims due to the greater degree of consideration paid during the design stages with regards to construction delivery methods (Nima and Abdul-Kadir, 1999).

A greater buildability focus is also said to encourage continuous learning practices by identifying problems occurring in previous projects so that they can be taken into consideration and therefore mitigated rather than repeated. Similarly, the feedback of best practise and effective solutions can be facilitated. Therefore knowledge from a construction perspective can supplement that gained through post occupancy evaluations and project reviews; thus benefitting future projects due to establishing a much more substantial and complete knowledge base.

Furthermore, buildability measures can result in significant cost savings that are not simply restricted to efficiency and quality related. Construction costs are also seen to be reduced due to the ability to procure more effectively (Griffith and Sidwell, 1993), in terms of materials, equipment and labour (Russell *et al.*, 1994). Such cost benefits have been suggested to be in the region of savings of more than 10% in project time and 7% in project costs, with an overall return on investment being reported as 10:1 (Pulaski and Horman, 2005). This is supported by Griffith and Sidwell (1993) and later by Pocock *et al.* (2006) who both suggest that the benefits of 'good' buildability throughout the project are approximately ten to twenty times the cost of achieving it.

Russell *et al.* (1994) contends that such direct value adding benefits are not the only benefits of buildability. They argue that qualitative benefits, which may be too difficult to attribute an exact value for, are by no means less important. This difficulty in accurately assigning a value for such intrinsic benefits is demonstrated through the ambiguity in the estimates provided above. This is supported by Griffith and Sidwell (1993) who suggest that benefits can also be quite pragmatic, which means it is not only important to attempt to measure them in terms of cost, time and quality, but also the physiological and psychological gains for the building team members. The multitude of additional qualitative benefits is demonstrated in Figure 3.5.

3.2.4 Barriers against Improving Buildability

Section 2.7 outlined the significant barriers to general KM and OL. These are also applicable to improving buildability due to the chosen strategy to obtain such being in the form of a knowledge feedback loop. Therefore, this section analyses further barriers to such a feedback loop due to the buildability focus of this research.

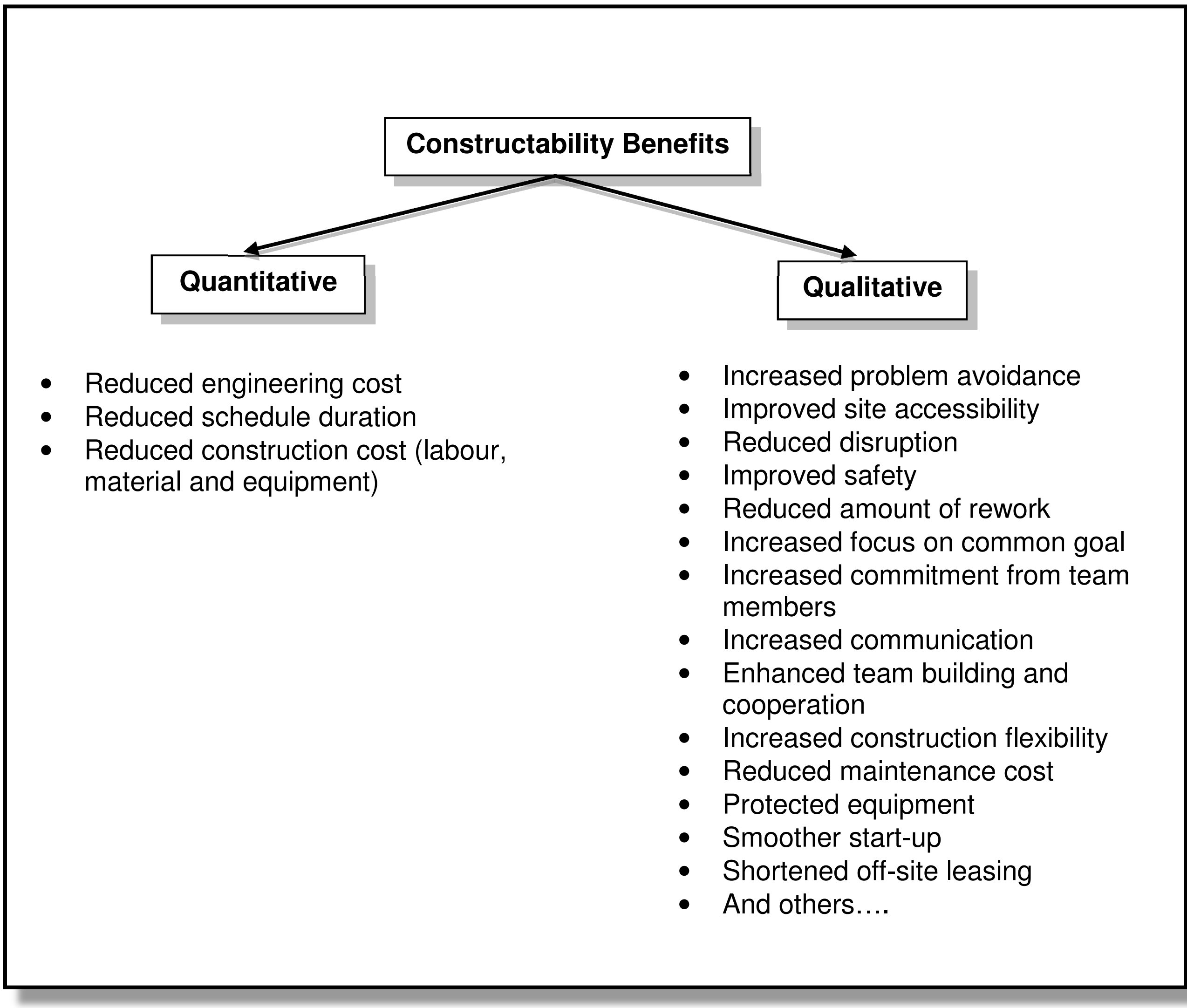


Figure 3.5: Quantitative and Qualitative Constructability Benefits. Source: Russell *et al.* (1994)

3.2.4.1 Lack of Integration Causing Buildability to be a Low Priority

A study conducted by Uhlik and Lores (1998) found that the greatest barrier to enhanced buildability was the lack of integration involved in the traditional form of contracting. This was shown through their reference to this form of contracting as being *"design (without construction input) – bid – build".* However, to improve buildability, there is a call to integrate construction knowledge earlier in the project life cycle than simply during the construction stage. For instance, Ganah (2003) suggests that through the integration of construction knowledge and experience into each phase of the project delivery process the benefits of buildability can be achieved.

This was followed by the second most prominent barrier being designers' lack of construction experience and knowledge of construction technologies. Lam *et al.* (2006) concur with this opinion by suggesting that due to the continued fragmented characteristics of the industry, designers become deficient in construction knowledge, thus causing the production of inefficient designs.

Griffith and Sidwell (1995) suggest that this low priority to buildability practices and the continuation of the causes of such problems is due to further specific implementation barriers, which stem from, or reinforce the unsupportive fragmentation of the industry. These include:

- Client resistance due to the lack of knowledge and understanding to the benefits of enhanced buildability;
- Project priorities being orientated around cost and time and therefore clients are more aware of the increase in costs that closer integration in the early stages of a project cause without realising how improved buildability may in fact reduce overall costs and time in the long run;
- Resistance to change from the traditional building process;
- Professional separation due to construction professionals being unaccustomed to close integration with other professional parameters or contributing their full expertise at the earliest stages of the process; and,
- Little incentives for project participants to change their traditional remit.

3.2.4.2 Fear that Enhanced Buildability Leads to Over Standardisation

As with general KM (see Section 2.7.2), there is an argument that improved integration of construction knowledge to enhance buildability, can lead to the over standardisation of designs. This is because in attempting to produce designs which are more simple to build, variations in elements such as building systems, material types, construction details, dimensions and elevations tend to be minimised (Nima and Abdul-Kadir, 1999). For example, Moore (1993) states that standardisation is viewed by designers as imposing repetition and rationalisation of the design process which therefore restricts designer's natural creativity.

This being said, it is by no means the intention of this research to facilitate the feedback of knowledge to standardise design unnecessarily and to the detriment of the facility's overall effectiveness. The formulation of the proposed feedback loop aims to supplement the information gained through EBD research and POEs such as Achieving Excellence Design Evaluation Toolkit (AEDET) and A Staff and Patient Environment Calibration Tool (ASPECT), so designers can produce the most idealistic designs possible. This is supported by Trigunarsyah *et al.* (2007), MacVaugh and Auty (2008) and Andries and Wastyn (2012) who suggest that the act of learning can result in greater innovation. This is perceived as the act of introducing and using new ideas, technologies, products and/or processes aimed at solving problems, viewing things differently and improving efficiency and effectiveness (CERF, 2000).

This is said to be the difference between knowledge resulting in over standardisation and knowledge enabling simplification. Simplification is the minimisation of complexity within a design or project other than that which is actually essential (Moore, 1993). Moore (1993) views simplification and standardisation as not being mutually exclusive. This facilitates a high degree of educated control on the designers' part to incorporate simplicity and standardisation only where appropriate. This aligns with Mcculloch's (2010) definition of an evidence based designer which states that they make decisions based on the best information available from research, previous evaluations and evidence gathered to demonstrate improvements in the organisation's utilisation of resources. The differences between simplification and standardisation are shown in Table 3.1.

Table 3.1: Suggested Natures of Standardisation and Simplification. Source: Moore (1993)

Standardisation	***Simplification***
• Generally seen as being applicable at task level only	• Applicable at project level and task level
• Minimises component variety	• No deliberate minimising of component variety
• Avoids complexity by adopting a position of maximum opportunity for its occurrence	• Seeks to identify non-essential complexity
• Preference for prefabricated, factory produced components	• No explicit preference for prefabricated components
• Maximises operative skill development in narrow areas of expertise	• Considers the level of operative skill required over wide areas of expertise
• Requires specific consideration as to how nonstandard aesthetic requirements can be included	• Places no aesthetic restrictions on the process of design
• May force innovation in minimizing component variations, but restricts creativity	• Does not restrict innovation and seeks to encourage design creativity

3.2.4.3 Need for Enhanced Buildability Currently Unrecognised

In an attempt to reduce time and costs, clients put undue pressure on designers to complete the task quickly (Griffith and Sidwell, 1995). This problem could be heightened within public sector projects as it was discovered that substantial pressure is put on public owners to reduce costs at every stage of the capital project (Pocock *et al.*, 2006). This ultimately leads to squeezing designers to such an extent that they inevitably cut out further buildability considerations (Pocock *et al.*, 2006). This is with little appreciation for the schedule and monetary savings that may result from a smooth project delivery if more time and consideration is given to the practical issues arising downstream (Lam *et al.*, 2006). This is shown through a respondent's statement in the study conducted by Pocock *et al.* (2006) that:

> *"Some client's require constructability input in their projects, but most must be sold on the benefit".*

For construction knowledge to be integrated into earlier stages of the delivery process, contractors also need to recognise the importance and benefits to be extracted as a result of improved buildability of designs. Contractors need to overcome barriers to knowledge sharing such as 'short term project objectives', 'temporary project participants' and 'knowledge protection' (see Section 2.7.2) through sharing buildability related knowledge with designers so that improvements can be made. The incentives identified by Griffith and Sidwell (1995) of doing so on the part of the contractor include:

- Enhanced reputation;
- Minimisation of wasted resources;
- Improved finished product quality;
- Fewer delays, disruptions and rework;
- Fewer disputes; and,
- Lower production costs.

This multifaceted requirement for improved buildability is demonstrated through the findings of a study conducted by Pocock *et al.* (2006). When asked *"who usually requires buildability?"* 83% of the respondents (who consisted of design, construction and client based personnel) stated contractors, construction managers or subcontractors, 73% said owners or owners' representatives, 55% said architects, engineers or design consultants, whilst only 6% said 'other'.

The need to feedback knowledge is further demonstrated through Figure 3.6, which illustrates the ability of each phase to influence overall project cost (Lam *et al.*, 2006). As such, if knowledge is integrated early on in the process, the opportunity to take into consideration the factors that can affect buildability is heightened and thus enables project costs to be reduced. In comparison, the opportunity of the construction stage to individually extract the buildability benefits is somewhat reduced. This is a demonstration of the *Pareto*

Principle where decisions taken early on in the project have a greater potential to influence the final outcome of the project (Griffith and Sidwell, 1993), with this potential diminishing as the project progresses (Pulaski and Horman, 2005). For instance, 80 per cent of a project's overall value can be affected within the first 20 per cent of effort, with this degree of influence diminishing as time progresses.

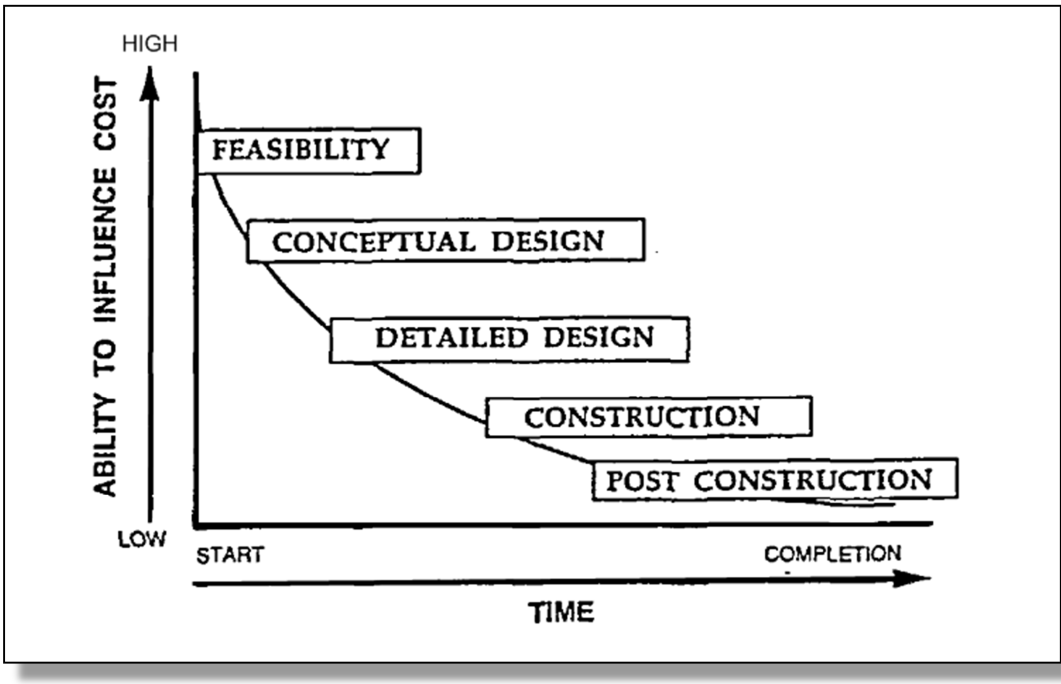


Figure 3.6: Cost Influence Curve. Source: Lam *et al.* (2006)

3.2.5 Need for Cross-Organisational and Phase Feedback Loops

De Jager (2007) states the mechanisms of systematic assessments and feedback loops in which knowledge is fed back to those who can utilise and benefit from it, are very powerful for learning from new facility developments, avoiding repeating mistakes, and using information to improve the quality of the built environment.

However, this review has demonstrated that improving KM and OL within the construction stage specifically is highly unlikely to reap the forecasted benefits specified. The construction stage is only a relatively small contributor to the problem, which is also limited in terms of its opportunity to influence project performance (see Section 3.2.4). For instance, Kartam and Askar (1999) contend that lessons learned during the construction of facilities may be applicable in one or more phases of the project life cycle. Therefore a construction specific feedback loop would only address the needs of the value engineering loop indicated as feedback loop 1 in Figure 3.7. It is therefore clear that a coordinated feed-back loop originating from the construction phase, feeding back knowledge to designers in particular, and when necessary those involved in the planning of future healthcare projects, is required. This would in turn address the needs of the buildability feedback loops 2 in Figure 3.7.

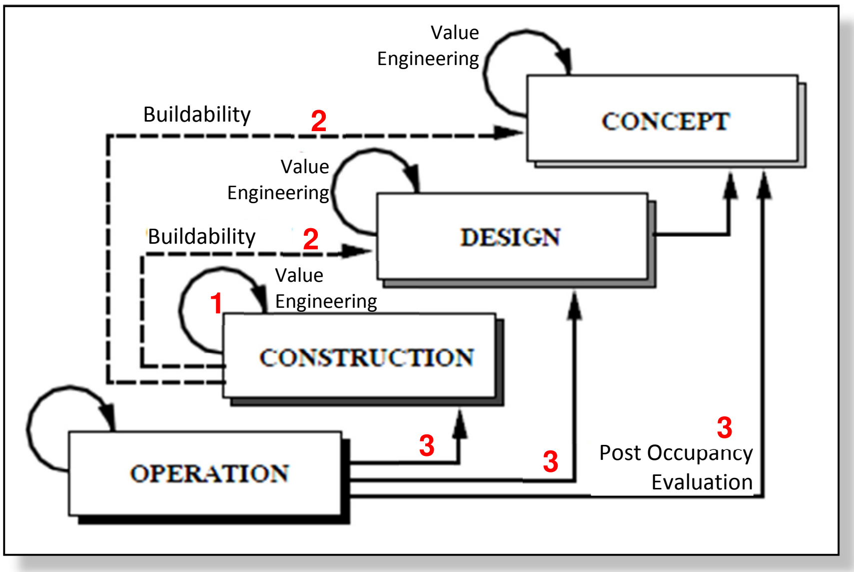


Figure 3.7: Feedback Loops in the Project Lifecycle. Source: Adapted from Kartam and Askar (1999).

At present the only systematic feedback loops adopted are in the form of POEs. These aim to evaluate buildings in use and feedback the collated knowledge into the planning of future projects. In terms of Kartam and Askar's (1999) diagram this form of feedback loop only satisfies the needs of feedback loop 3 indicated in Figure 3.7. This demonstrates a distinct lack of learning currently being undertaken, as the knowledge rich stage of construction is not being utilised. Such post occupancy feedback loops can be illustrated in the form of Figure 3.8.

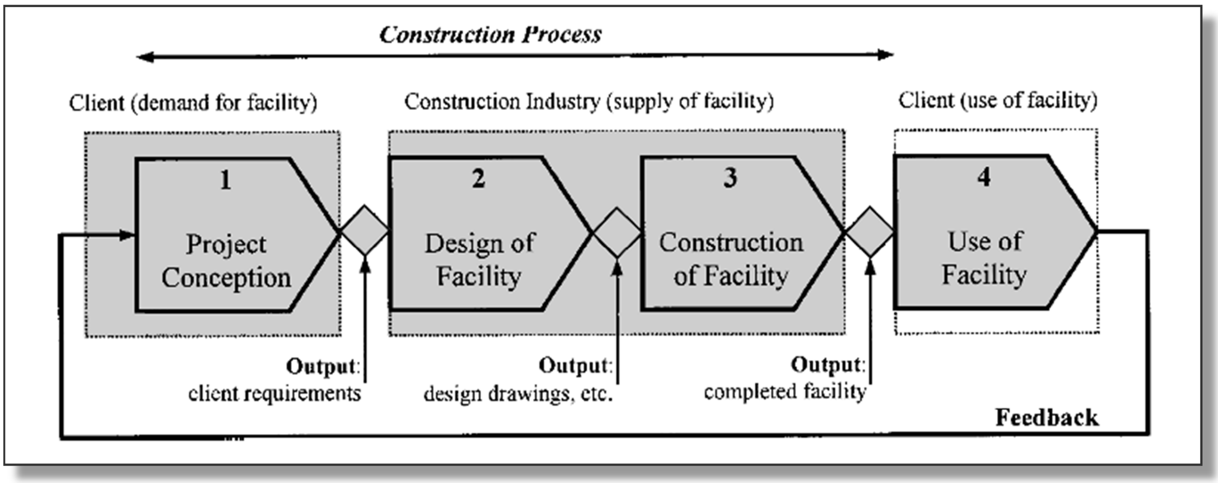


Figure 3.8: Post Occupancy Evaluation Feedback Loop. Source: Kamara *et al.* (2002)

This literature review therefore highlights the need to address the distinct lack of a capture and feedback. The addition of such a feedback loop is illustrated in Figure 3.9.

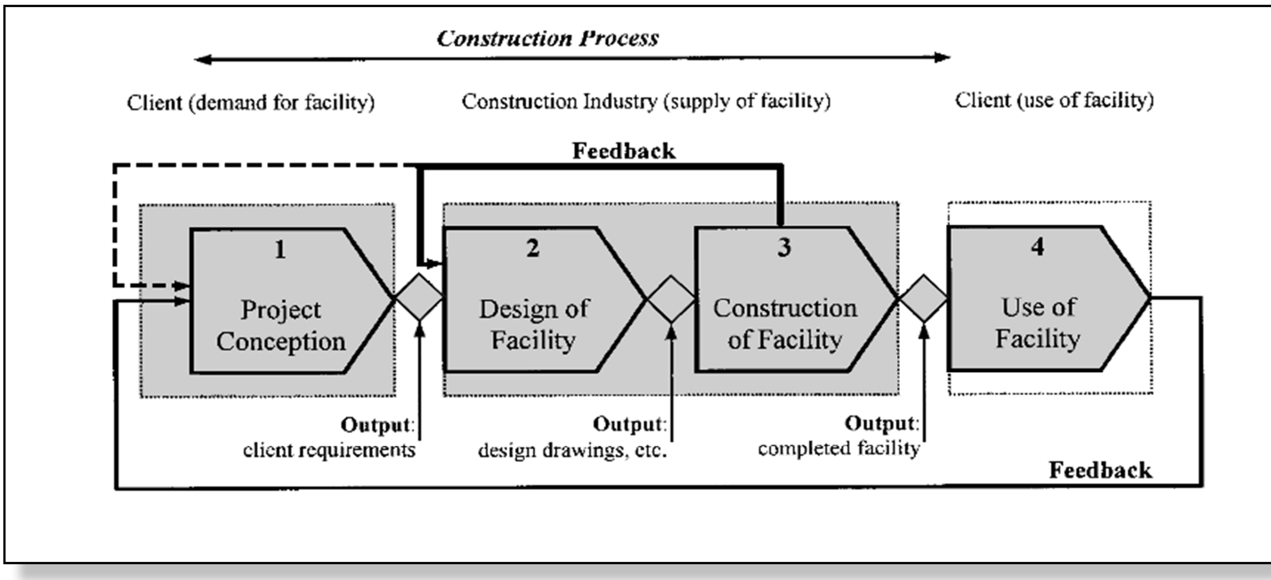


Figure 3.9: Construction Stage Feedback Loop. Source: Adapted from Kamara et al. (2002)

3.3 Comparative Studies for Improving Buildability

This section presents a review of comparative studies of mechanisms designed to improve buildability. In addition, reviews of alternative means of knowledge capture and feedback that may not have been developed specifically to improve buildability, but have the potential to be adapted to do so, are also documented.

3.3.1 Buildability-Specific Knowledge Management Research

3.3.1.1 Construction Knowledge Expert (COKE)

Fischer (1993) developed a system known as a Construction Knowledge Expert (COKE) which was designed to provide automated buildability feedback for the layout and dimensioning of reinforced concrete structural elements. This was achieved through linking the computer representation of a building using (CAD) software such as AutoCAD, to an expert system containing the knowledge base collated. The designer is then provided feedback to its buildability, which thus guides them towards designing structures that are more buildable (Thabet, 2000).

A drawback of this system is the significant reliance on the knowledge engineer's programmatic skills, which ultimately alienates domain experts from the system's development process and causes 'knowledge acquisition bottlenecks' (Ugwu *et al.*, 2004). It also requires the designer to create a design, export the design to a format that the expert system can understand, educate the expert system to which lines represent what parts of the structure, for example; walls, beams, slabs etc., and then perform the constructability check. This will then indicate what elements of the design conflict with the rules inserted into the expert system (such as maximum slab thickness).

This process appears flawed as it relies on designers to commit additional time in programming the system in terms of; specifying what construction methods will be used and indicating what lines represent what elements. The designer then has to run the buildability check, which also takes time, before identifying buildability conflicts. Ultimately this results in rework for the designer. It is beneficial in terms of it facilitating designers with the ability to conduct more rigorous buildability checks prior to the designs actually being developed; however, such a buildability check needs to be conducted in real time.

This system concentrates on the structural conflict element of buildability. This element is applicable to computer modelling to a much greater extent than is the case with more subtle buildability factors such as project complexity, site restrictions and material choices etc. Such factors are more subjective and may not necessarily result in a ‘true’ or ‘false’ response. Therefore, this system appears limited regarding the degree to which it could provide a holistic solution to improving the buildability of designs.

3.3.1.2 Buildability Information Framework

This framework incorporates a visualisation and communication system (VISCON) which aims to model graphical buildability related information which is used by both designers and contractors (Ganah, 2003). For instances where there is insufficient clear information to assemble building components, or information has been misinterpreted by the site team, the VISCON system would be utilised. Through using visualisation and communication tools the understanding of the design is improved further. If the design elements are then adjudged to be buildable construction can commence; however, if this is not the case then a return to the detailed design phase is undertaken.

This framework highlights the importance of improved integration prior to the construction phase, which in particular points towards the need for contractors to be able to visualise the design effectively before proceeding. In particular it shows that visual aids are more useful in communicating and understanding concepts, which is formulated concisely through the quote *“a picture is better than a thousand words”* (Ganah, 2003).

Advances have been made since this study such as the increase in interest surrounding BIM technologies. Therefore it is likely that this important step will become mandatory, even if the VISCON framework is not incorporated specifically. Furthermore, whilst acknowledging its importance, this buildability framework does not adequately satisfy the objectives set out in this research (see Section 1.3). Due to this framework acting in the form of checking the understanding and buildability of the detailed design, it inevitably results in an increased amount of rework if a return to the detailed design stage is required.

3.3.1.3 Constructability Information Classification Scheme

This research developed and tested a generic model that classifies buildability information for reinforced-concrete structural elements (Hanlon and Sanvido, 1995). It builds upon the groupings identified by Fischer (1993), to enable database entry and retrieval by keyword searches of buildability related knowledge (Pulaski and Horman, 2005). Such groupings include; design rules, lessons learned, external constraints, resources constraints, and performance information (Hanlon and Sanvido, 1995).

Pulaski and Horman (2005) continue by drawing attention to the main shortcoming of this system in the form of its failure to link the stored knowledge to any preceding stage in the process or indicate the input timing. Consequently, the use of this system to track root causes of buildability instances, to continuously improve and reduce their future occurrences is somewhat limited. It is therefore recommended that to increase the effectiveness of using stored buildability knowledge; the knowledge must be linked to the phase that is most likely to benefit from it, in preference of the expectation that that phase will intuitively search for such knowledge themselves (Pulaski and Horman, 2005).

3.3.1.4 The Constructability Lessons Learned Database (CLLD)

The Constructability Lessons Learned Database (CLLD) was developed by Katam and Flood (1997) to provide a repository for previous lessons learnt which are verified by domain experts before being stored in a database (Yu *et al.*, 2008). Similarly to that identified through this study, Kartam and Flood (1997) recognised that the construction industry does not possess a reliable method for capturing knowledge and information generated from daily construction activities. Therefore, the CLLD aimed to provide a means to record, organise and transfer such knowledge. This was achieved through the development of a tool which enables contractors to enhance their daily decision making through utilising proven solutions to similar problems (Kartam and Flood, 1997).

The system design consists of a shared stored lessons learnt database which is accessible remotely through Lotus Notes. Through this, documents can be accessed, stored and shared with others on the network (Kartam and Flood, 1997). Although it is noted that graphics, fonts, colour, tables, spread sheets and file attachments can be incorporated into the inputs of the system (Kartam and Flood, 1997), the primary format for the captured knowledge to be presented in is text. This system is therefore viewed as adopting a first generation KM perspective, with it being suited to the capture of explicit knowledge at best, or even being classed as an information management system (see Section 2.8.6),.

3.3.1.5 Characteristics of Design-Relevant Constructability Knowledge

Fischer and Tatum's (1997) study appears to be the most closely aligned study with the objectives of this research (see Section 1.3). They also highlight the need for construction knowledge to be integrated into design decisions as early as possible to improve designers' understanding of construction requirements. A lack of understanding is said to be caused by the; fragmented delivery process, contracting practices, diverging goals between design and construction professionals, and changes in construction methods and materials (Fischer and Tatum, 1997).

This study demonstrates that if feedback loops are established so that construction knowledge can be collected and made available to designers for consideration during future decisions, then important buildability benefits can be experienced. This is due to the finding that significant design-relevant buildability knowledge exists and that it can be related to design variables (Fischer and Tatum, 1997). To achieve such, they formulated a template which involved categorising buildability knowledge into five different groups depending on which broad design decision the knowledge related to. The knowledge collected was specifically focused on cast-in-place reinforced concrete, which produced an expert system which could therefore guide design decisions relating to its use.

Fischer and Tatum (1997) in their own words, *"formulised specific constructability design rules that directly assists a designer in designing a structure."* Design rules consisting of "*precise constraints*," such as "*do not use round columns for office buildings because it is hard to connect partition walls to round columns,"* were outcomes of this collated knowledge base (Fischer and Tatum, 1997). Such strict rules were preferred due to the researchers' criticism of other examples of buildability knowledge in the form of guidelines being difficult to relate specific design variables to (Fischer and Tatum, 1997).

However, this is viewed as being fraught with resistance on the part of designers as they may envisage their creativity being hindered due to design rules being imposed upon them (see Section 2.7.2). It is also believed that attempting to produce such rigid sets of rules considering the degree of potential variables apparent in construction projects is an arduous proposition. This was acknowledged by the researchers themselves through stating that "*such rules are a brittle representation of constructability knowledge because it is unclear how to proceed if a project variable falls short of the constructability requirement*" (Fischer and Tatum, 1997). Their resolution to this consisted of acquiring additional knowledge. However, this is viewed as potentially resulting in the system's demise due to the difficulty it would cause in locating appropriate information, especially if such a system was developed to incorporate a much wider range of structural elements, materials, phases, etc.

3.3.2 Non-Buildability Specific Knowledge Management Research

3.3.2.1 Cross-Organisational Learning Approach (COLA)

The 'Building a Higher Value Construction Environment' (B-Hive) project's aim was to enhance OL between construction partners through the development of a system or process (Tan *et al.*, 2006). It developed a conceptual IT supported model that facilitates a course of reflection and discussion of processes for review, learning and knowledge generation (Orange *et al.*, 1999b). This is in the form of the Cross-Organisational Learning Approach (COLA). This approach aims to identify and review both incidents and successes, to generate key learning outcomes that can be fed back to both present and future project partners (Franco *et al.*, 2004).

This approach is applicable, as even though it was not directly developed to improve buildability, it is recognised as being able to accommodate such an aim. This is due to its design being focused on cross-organisational relationships. Therefore, efforts to encourage knowledge transfer within such a partnering arrangement are subject to the same obstacles.

This approach does however have limitations. The framework comprises of knowledge collection and sharing through the process of reviews, which results in an output of agreed learning outcomes. As such, the drawbacks of AARs (see section 2.8.5) are clearly evident. In addition, this framework is not seen to incorporate the necessary technologies that would support distributed teams (Kamara *et al.*, 2002). Consequently, a fundamental downfall is its inability to support the live capture of learning instances and experiences. Even though the framework supports cross-organisational sharing of knowledge, the knowledge that is shared is viewed as less valuable due to the time lapse between the event occurring and the capture of the experience-based knowledge.

3.3.2.2 Extending Knowledge Management across Supply Chains in the Construction Industry: Knowledge Sharing in Construction Supply Chains

Through identifying and providing evidence of the benefits of each stage of the supply chain sharing knowledge effectively this study's aim is to argue the case for extending the current scope of KM beyond the organisation to across the entire supply chain (Maqsood *et al.*, 2010). As such, this study aims to improve the awareness of this need rather than providing a means for achieving it.

3.3.2.3 Knowledge and Learning In CONstruction (KLICON)

The KLICON project investigates the role of IT in capturing and managing knowledge for OL on construction projects (Patel *et al.*, 2000). Although of significant value in assessing appropriate technologies to support a feedback framework, it is not directed at the formulation of such itself. Furthermore, due to the identification of the need for the utilisation of multiple techniques and technologies within a socio-technical systems (STS) approach (see Section 2.10.1) the sole concentration on a technology based solution is limited.

3.3.2.4 Cross-sectorial LEarning in the Virtual EnteRprise (CLEVER)

This project is based in the context of project management, specifically investigating how best practice knowledge can be shared across industrial sectors (CLEVER, 1999). Consequently, the CLEVER project does not satisfy the same aims of this research as it attempts to share knowledge across sector boundaries. Although bridging industrial divides, the knowledge sharing in question involves similar stages in the supply chain. Therefore, the identification and feedback of critical knowledge to benefit other stages in the supply chain is not satisfied. The project remains of interest however, due to it contending with similar barriers to the sharing of knowledge, such as; cultural differences, organisational divides, and the difficulty in relating knowledge to relevant scenarios.

3.3.2.5 Improving Management PerformAnce through Knowledge Transformation (IMPaKT)

This project stresses the need for KM strategies to not only facilitate the transformation of knowledge within an organisation but to also be capable of evaluating its effectiveness and efficiency (Carrillo *et al.*, 2003). Complimentary to the recognition cited in this review (see Section 2.5.3), Carrillo *et al.* (2003) acknowledge the need for KM initiatives to be aligned with an organisation's strategic objectives. Consequently, this research produces a framework which enables organisations to link their KM initiatives to improved business performance through the use of the developed software tool.

Although, the framework appears robust and effective, it does not satisfy the needs of this project in terms of enabling knowledge capture and dissemination across organisational and discipline divides. However, this framework may be a valuable addition to a KM strategy as an evaluative tool regarding the effectiveness and efficiency of a framework. It is not seen as a tool that could be used to evaluate such a framework at the conclusion of this research as it requires a strategy to have been implemented and matured over time before the evaluation is conducted.

3.3.2.6 Creating, Sustaining and Disseminating Knowledge for Sustainable Construction: Tools, Methods and Architecture (C-SanD)

The C-SanD project aims to develop tools, methods and an architecture that is capable of capturing and sharing sustainability related knowledge (C-SanD, 2001). The main related tool to emerge from this research is the 'Sustainability Management Activity Zone' (SMAZ).

This zone is a portal which enables contractors, clients and consultants to input or access sustainability related knowledge.

This tool therefore facilitates the medium to contribute and access knowledge regarding the move towards achieving sustainability standards within projects. This is a potential mechanism of interest as it facilitates the capture and sharing of knowledge (in this case sustainability related only).

3.3.2.7 Capture and Reuse of Project Knowledge in Construction (CAPRIKON)

The CAPRIKON project, and more specifically the research conducted by Tan (2006), identifies the need for knowledge capture to be as live as possible to avoid knowledge deterioration and/or loss. Tan (2006) developed a database methodology that supports the input of knowledge either by individuals, groups (meetings), or the rationale for making changes to documents. The system supports the full range of the KM process including capture, storage, validation, and sharing.

This system is aimed at capturing lessons learnt within a construction organisation context for the application of lessons within the same setting. As such, this system is not designed to overcome the barriers inherent in sharing knowledge across organisational and discipline divides. Furthermore, the knowledge captured is predominantly textual with the option to attach photographs separately, which ultimately makes it more suitable to the transfer of explicit knowledge. It may also make it difficult for designers to fully understand the problems due to it being a less effective knowledge sharing format compared to visual, audio and in particular, two-way communication (see Section 2.8.6.1). It is viewed that the system's ability to attach photographs and other visual attachments could assist in this issue; however, the process of input makes this a laborious task.

Furthermore, the extent to which the knowledge captured is in fact achieved 'live' is debatable. This is due to knowledge input being designed in such a way that the event occurs, thus triggering a knowledge capture opportunity in the mind of an employee, who then needs to log onto the system to input the knowledge. This is likely to involve a time lapse between the event occurring and it being captured, especially if the system does not incorporate mobile technology and remote connectivity to capture onsite experiences. Therefore, if the person inputting the knowledge must return to the site office, login, and then input the knowledge, this is a process that is likely to be subject to the types of time related barriers to outline previously (see Section 2.7).

The only true live capture element of this system appears to lie in the capture of knowledge arising from group meetings and reviews. This is due to the system enabling the documentation of knowledge to be conducted during the activity itself. However, such post project reviews or periodic reviews involve the recall of events after they have happened, which subsequently results in knowledge deterioration once more (see Section 2.8.5).

3.3.3 Summary of Related Research Projects

This review has revealed that although there has been a substantial recognition for the need to improve knowledge sharing within the construction industry, none of the research to date appears to satisfy these demands entirely.

For instance, the areas in which previous research has fallen short include:

- An inability to capture learning instances live;
- The need for designs to be checked by an expert system rather than facilitating real-time knowledge transfer to the designer (thus causing rework);
- An inability to indicate which phases need to be aware of the knowledge (therefore difficult to trace root causes / achieve efficient feedback of knowledge);
- Being overly concentrated on isolated techniques (such as reviews, or communities of practice) instead of adopting a multi-pronged approach to bridge the shortcomings of each technique; and,
- Being overly IT focused and thus ignoring the need for social interaction to share tacit knowledge.

Ultimately, efforts to improve knowledge sharing in this area adopt a predominantly FGKM approach, where attempts are made to codify knowledge from those with specific expertise, store it in some form of database for it to be made available to other audiences. Very little facilitation of two-way communication and socialisation has been made, despite the evident requirement for this aspect as outlined in Section 2.3.3. This directs towards a gap in current research efforts that can be filled through the development of a learning environment that enables inter- and intra-organisational learning to take place. Through a move away from purely FGKM approaches, towards that of the incorporation of SGKM fundamentals it appears that a greater degree of success can be obtained.

3.4 Summary of Literature Review Chapters

The review of a vast array of literature has led to many themes of interest to emerge, which both shape and impact on the direction of this study going forward. This section therefore encapsulates the key themes in relation to the research objectives and shows how they aid in the moulding of the research methodology going forward.

3.4.1 Summary of Emerging Literature Review Themes

Objective 1: To examine existing literature relating to the need for and barriers against design-construction learning loops

The need for improved learning between differing phases is distinct, if true efficiency, quality and value improvements are to arise. The support for a move towards more open communication is indisputable from an academic perspective and agreed with from an industry one. Although industry appears to agree that it will have undoubted benefits, scepticism remains regarding its true achievability due to barriers such as protection of competitive advantages, short term pressures and a lack of natural integration to name but a few.

Where the literature furthered this objective was the finding that current approaches to KM follow a predominantly FGKM perspective, where knowledge is codified and stored. However, due to the differing knowledge sets and expertise apparent within the differing phases of design and construction, the communication of context specific information is of even greater need than when the participants have similar knowledge and experience. Therefore of great importance is the investigation of how the lack of integration between the parties can be overcome, as two-way communication and socialisation is undoubtedly necessary for cross-organisational learning to take place within the construction industry.

This objective therefore calls for the research context to consist of the temporary multiple organisation (TMO) outlined in Section 2.4.1.1. This will more readily facilitate a thorough investigation into the environment facilitating or hindering cross-organisational learning to be obtained. As such investigating construction and design organisations in isolation will not enable this knowledge sharing environment to be investigated, especially if the organisations are active in separate projects. Instead the literature has pointed towards the need to observe the learning environment between design and construction within the same project to be conducted so that the intricacies of this relationship can be investigated more deeply.

Objective 2: To establish the potential and limitations of current knowledge management procedure; and, Objective 3: To establish the potential and limitations of current feedback loops designed to improve design quality.

Current feedback loops mainly consist of knowledge gained through conducting POEs or AARs. This can be used to inform other phases such as design within the planning stage of future projects, but are rarely used to feedback knowledge to the design teams of the current project. POE's suffer from the drawbacks of conducting retrospective KM activities, which include the risk of members of the project no longer being available and their inevitable reduced ability to recall the circumstances of events even if they are.

Current KM procedures revolve around a technologically supported FGKM approach where attempts to codify and store knowledge are made so that it can be accessed by others at a later date. This removes the risk of relying on knowledgeable individuals sharing knowledge or knowledge loss when they leave the organisation. However, this is viewed to only concentrate on the less valuable explicit knowledge, whereas tacit knowledge remains in the heads of those that experienced the situation itself.

This review was therefore invaluable in directing attention away from overly concentrating on attempting to create a knowledge depositary and instead on nurturing an environment that enables socialisation and communication to take place. These techniques were identified as critical if tacit knowledge sharing is to take place. Conversely, the evident investment put into developing such tangible stores of knowledge demonstrates the need for organisations to be able to see a return for such efforts. This directs towards investigating the aspects that are critical in gaining the commitment and buy-in of organisations.

Objective 4: Evaluate which technologies/techniques are most effective to assist learning activities

Clear indication has been established that not one KM related technique or technology is capable of supporting the multiple stages of the KM process. More importantly however, it has also been identified that a simply technologically focused approach, which has been the temptation in the past due to the cost and efficiency benefits that it presents, will not facilitate effective KM. This is due to it being more suited to information management or at best the management of codified explicit knowledge rather than the more valuable tacit knowledge.

To share tacit knowledge it is evident that socialisation is required as knowledge is context specific and therefore if the recipient is to benefit from the knowledge shared they need to understand as much of the origin's context as possible.

Preceding studies have therefore started a move away from purely technological solutions which relate to FGKM approaches towards that of socio-technical solutions. This points towards the development of a methodology that enables the effectiveness and appropriateness of differing KM techniques and technologies to be more readily established. This includes the necessity to investigate current KM practices and identify the extent to which true KM is taking place, or whether it is more reminiscent of information management. In establishing this distinction and investigating the value of current practices, further insights of the formulation of an effective framework that enables cross-organisational learning to take place can be developed. These areas of interest also have implications for the following research objective which is discussed further below.

Objective 5: To improve cross-organisational boundary learning within infrastructure projects

All themes discussed in this review will inevitably impact on further research undertaken. In particular the need for high degrees of socialisation, live knowledge sharing / capture where possible and improved opportunities for cross-organisational learning / knowledge sharing all need to be incorporated.

Accordingly, this impacts on the methodological considerations made in the subsequent chapter of this thesis as the data collection strategy and its eventual analysis need to compliment the ability to extract what aspects of current practice are effective, which are not, and most importantly, establishing the rationale behind the reasoning for these conclusions. Without such, the development of the theoretical framework will not have a sound theoretical basis and therefore the achievement of this objective will not be possible.

4 Research Methodology

4.1 Introduction

Research is said to be the systematic process of collecting and analysing information (data) to increase our understanding of the phenomenon about which we are concerned or interested (Leedy and Ormrod, 2001). Allison *et al.* (1996) state that research is more than "*a systematic enquiry*" designed to develop or contribute to generalizable knowledge, as it must also be *"reported in a form which allows the research methods and the outcomes to be accessible to others."* As a result, this chapter will outline the most applicable methodological considerations that need to be made, detail the most suitable research methods and justify those that were adopted in addressing the research problem at hand.

4.2 Methodological Considerations

This research has been determined as theoretical in nature, resulting from the desire to establish causal processes and explanations to the research questions outlined in the objectives of the project (Hakim, 1987) (see Section 1.3). It is therefore important to establish whether this research is to be guided by current theories (deductive), or, used to guide the creation of new theory (inductive).

Guba and Lincoln (1994) identify that inquiry paradigms define for inquirers what it is they are about and what falls within and outside the limits of legitimate inquiry. They suggest that such an inquiry paradigm is one that is made up of three fundamental questions which are interconnected in such a way that the answer to one question, taken in any order, constrains how the others may be answered.

The three questions proposed by Guba and Lincoln (1994) are; the ontological question (reality – i.e. what is assumed to exist and what can be known about it); the epistemological question (the nature of the relationship between the knowledge seeker and what can be known); and, the methodological question (the rules of inquiry). Fleetwood (2005) attempts to simplify this by suggesting that *"the way we think the world is (ontology) influences: what we think can be known about it (epistemology); how we think it can be investigated (methodology and research techniques); the kinds of theories we think can be constructed about it; and the political and policy stances we are prepared to take."* This interdependency demonstrates the importance of detailed consideration into the differing alternatives of each question to perform the act of inquiry most effectively. Such methodological considerations will now be discussed further.

4.2.1 Deductive, Inductive and Abductive Theory

Bryman (2008) recognises that there is a distinct relationship between theory and research. This is due to research either being guided and influenced by questions posed by theoretical considerations (deductive theory), or alternatively, theory is the result of research (inductive theory) (see Figure 4.1).

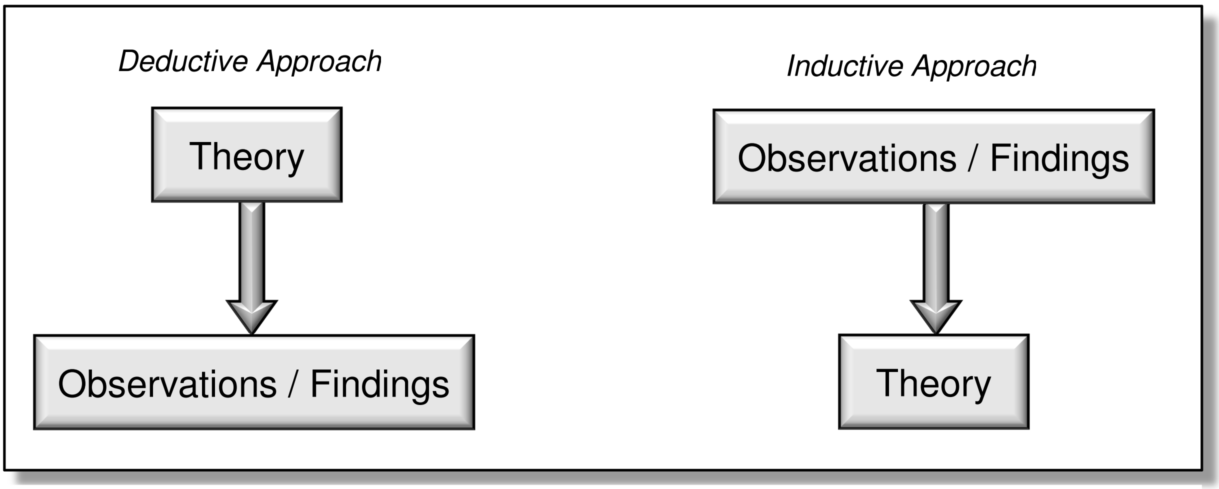


Figure 4.1: Deductive and Inductive Approaches to the Relationship between Theory and Research. Source: Bryman (2008)

This research originated from the recognition of the need, previously identified by many authors such as Latham (1994) and Egan (1998), that the construction industry in general could significantly benefit from better KM and OL. It has been further defined to concentrate specifically within a healthcare infrastructure context due to their desire to continuously improve the quality of their built facilities (Berry *et al.*, 2004; De Jager, 2007). Furthermore this sector is viewed as being well related to continuous improvement due to the degree of relatively repetitive projects.

Accordingly, it could be incorrectly viewed that this research is based upon existing theories; however, this is only true to the extent that, without such, the knowledge collated would have been insufficient in identifying the theoretical area to address. This aligns with Yin's (2009) viewpoint that all investigators should make the effort to develop a theoretical framework, no matter whether the study is to be explanatory, or descriptive as the use of theory is an immense aid in defining the research design and data collection, as well as being a vehicle for generalising results.

This therefore aligns with a third approach of abduction. Abduction more closely aligns with an inductive approach than deductive; however, it differs in that it involves constantly going 'back and forth' from one research activity to another and between empirical observations and theory (Dubois and Gadde, 2002). It stems from the view that theory cannot be understood without empirical observation and vice versa, due to the evolution of the theoretical framework directing the search for empirical data, whilst empirical observations highlight previously unidentified issues that require further exploration (Dubois and Gadde, 2002). As such, the abductive approach understands that the analytical framework shapes the empirical investigation, which in turns shapes the analytical framework for future activities and so on. This is particularly useful in the development of theory (Dubois and Gadde, 2002).

Accordingly, an abductive approach has been adopted because it enables the on-going development of theory through remaining flexible and continuously adapting research activities according to previous findings. This form of redirection is viewed as enabling the underlining research question of this study (see Section 1.3) to be answered. This is because it is concerned with investigating the best way to overcome the problem (i.e. theory development), rather than testing previously developed theory. How the abductive approach is incorporated into the study's methodological design is further discussed later in this chapter (see Section 4.5.2).

4.2.2 Ontology

Ontology can be described as the 'reality' that researchers investigate (Healy and Perry, 2000). It is about the theory of social entities and is concerned with what exists to be investigated (Walliman, 2006). According to Guba and Lincoln (1994) there are two extremes regarding a researcher's ontological position; realism and relativism.

Realism takes the view that certain entities, be they objects, forces, social structures, or ideas, exist independent of human beings, but it is possible to gain reliable knowledge of them (Mingers, 2004). That is, these entities are born of people's minds but exist independently of any one person (Healy and Perry, 2000). Therefore the external world consists of pre-existing hard, tangible structures which exist independently of an individual's cognition and is one which can be investigated (Fitzgerald and Howcroft, 1998).

A relativist view is one which views reality as being able to be apprehended in the form of multiple, intangible mental constructions, socially and experientially based, local and specific in nature (Guba and Lincoln, 1994). Fitzgerald and Howcroft (1998) envisage relativism as the belief that multiple realities exist as subjective constructions of the mind, in which socially-transmitted terms direct how reality is perceived and therefore will inevitably vary across different languages and cultures.

Mingers (2004) recognises that there has been a distinct move away from what has been termed as ‘naïve’ realism. This is due to it receiving substantial criticism as, pure and unmediated observation of empirical facts is viewed as impossible. Fleetwood (2005) suggests that this ontological view acknowledges that there is *no* unmediated access to the world, as access is always mediated. This is due to whenever an entity (or state of affairs) is reflected upon, our sense data are always mediated by a pre-existing stock of conceptual resources which we use to interpret, make sense of and take appropriate action (Fleetwood, 2005).

Within this study, an inherent tension lies between the two views of knowledge held within each perspective of KM (i.e. FGKM and SGKM). As discussed within the literature review (see Section 2.3.1), the FGKM perspective views knowledge as being extractable from its original context so that it can be codified and stored. However, adopting a SGKM viewpoint adheres to the notion that knowledge is situated and context specific (see Section 2.3.2). It is therefore embedded in experience and practice.

The reality to be examined consists of organisations, projects and knowledge. The need to manage knowledge within this reality is viewed as being improvable through its study. Therefore ontologically this thesis identifies that the above reality is out there to explore, which is coherent with a realist perspective. However, it is also acknowledged that the question surrounding ‘what is useful knowledge and how can knowledge be best managed?’ is dependent on which perspective is adopted. Mutch (2002) argues that this perspective gives the potential to not only give a better account of the information gathered but also forge a better integration between worlds of organisational and information theory.

This thesis therefore aligns with a critical realist perspective as it prescribes to the view that there is a distinction between the ‘real’ world and the ‘social’ world, due to the social world (unlike the ‘natural’ world) being dependent on human action for its existence (Fairclough, 2005). However, whilst an ontological reality exists, this thesis gives credence to the relativist view that multiple realities exist as subjective constructions of the mind based on the interpretation of language (i.e. which definition of knowledge is adopted).

4.2.3 Epistemology

Epistemology is concerned with what we can regard as acceptable knowledge and how we know things, with their being a choice between two distinct forms of acquiring knowledge within the study of social sciences; empiricism and rationalism (Walliman, 2006). Empiricism is knowledge gained through sensory experience using inductive reasoning, whilst rationalism is knowledge gained by reasoning using a deductive approach (Walliman, 2006).

As identified in Section 4.2.1, this research takes an abductive approach which relies upon induction and thus conforms towards an empiricist method of acquiring knowledge.

Furthermore, most commentators distinguish two common forms of epistemology; positivism and interpretivism (Mingers, 2001). Bryman and Bell (2007) assert that a central issue concerning the decision into which epistemological stance is most appropriate is the question of whether or not the social world can and should be studied according to the same principles, procedure and ethos as the natural sciences. Positivism has predominantly emerged from natural science roots (Orlikowski and Baroudi, 1991) and is applied successfully within this context to extract knowledge. This is due to its emphasis on generating hypothesises that can be tested to establish explanations of universal laws (Bryman and Bell, 2007).

Interpretivism however, is an epistemological view which is critical of the application of a scientific model to the study of the social world due to the view that the subject matter of the social sciences – people and their institutions – is fundamentally different from that of the natural sciences (Bryman and Bell, 2007). It differs from positivism through the researcher's perspective being interested in becoming more fully involved with stakeholders and subject matter to achieve a better understanding of the stakeholder's world (Guo and Sheffield, 2006). Where positivists attempt to reduce the area of investigation to a few variables (to be able to make reliable predictions and explanations), interpretivists are concerned with making a reading of the situation (to gain an understanding of the meanings people use to make sense of their lives through gaining their viewpoints and even becoming an insider themselves) (Braa and Vidgen, 1999).

Gibbons *et al.* (1994, cf. Bryman and Bell, 2007) identify that the way knowledge is produced falls into two distinct categories, which they term as mode 1 and mode 2. Bryman and Bell (2007) summarise these contrasting modes as follows:

- *Mode 1 is particularly driven by an academic agenda which relies on discoveries building upon existing knowledge in a linear fashion. Within this model a distinction is made between theoretically pure and applied knowledge. However, due to this type of knowledge production being academically driven, academics are seen as the most important audience of such knowledge and therefore only limited emphasis is placed on the practical dissemination of knowledge.*
- *Mode 2 however, involves academics, policy makers and practitioners whose combined experiences and skill sets aim to address a shared problem. As a result, knowledge is disseminated more swiftly and with much more emphasis on practical*

adoption. Due to this model being trans-disciplinary, the findings of such knowledge are seen to be closely related to its context and difficult to replicate. Within this model, knowledge production is therefore not seen as a linear process.

This thesis aligns with an interpretivist approach, with the intention to produce knowledge according to Gibbons *et al's* (1994) Mode 2 model. This is due to interpretivism seeing a growth in popularity recently; especially in the domain of information systems research (Mingers, 2001). Due to this research investigating the potential for a socio-technical approach to KM and OL, as well as being interested in the discovery of as wide a spectrum as possible of the variables affecting the success of such, an interpretivist viewpoint is seen as beneficial. Similarly, due to knowledge being produced through a combination of trans-disciplinary actors (i.e. academics, contractors, designers etc.), as well as attempting to produce knowledge that can be disseminated outside the limits of academia, a Mode 2 model of knowledge production has been adopted.

4.2.4 Methodology

The term methodology refers to a set of structured guidelines for activities to undertake to improve the effectiveness of an intervention (Mingers, 1997). In scholarly terms, this intervention is the act of inquiry and consequently the methodology is the means employed which aims to increase the levels of confidence that the inferences made into the social world are valid (Hall, 2003).

Fellows and Liu (2008) state that regardless to whether anything is actually discovered or not, research should be considered as the 'voyage of discovery'. They continue to assert that what is discovered in due course ultimately depends on the patterns and techniques of searching. This signifies the importance of establishing the most complimentary set of research techniques to the problem, as the value of the findings ultimately depends on their compatibility.

4.2.4.1 Quantitative Vs. Qualitative Methods

Newman and Benz (1998) separate research methods into two distinct approaches; quantitative and qualitative. The quantitative paradigm is based on a positivist perspective whereby science can be characterised by empirical research and all phenomena can be reduced to empirical indicators which represent the truth, without the investigator influencing or being influenced by it (Tashakkori and Teddlie, 1998).

Qualitative research, places emphasis on meanings, experiences and descriptions which are usually gathered by means of verbal communication (Naoum, 2007). The qualitative paradigm is based on interpretivism and assumes that the investigator and the object of study are interactively linked so that findings are mutually created within the context of the situation which shapes the inquiry (Tashakkori and Teddlie, 1998). Table 4.1 illustrates the main differences between the nature of each research method approach.

4.2.4.2 Quantitative methods

Surveys

Surveys are a commonly used data collection method for social research which can be in the form of verbal interviews or pencil-and-paper questionnaires (McQueen and Knussen, 2002). There are many recognised trade-offs when deciding which is the most beneficial technique to adopt for social research. For instance, Berg (2007) draws attention to the fact that interviews are more commonly utilised due to their ability to provide the maximum opportunity for complete and accurate communication of ideas between the researcher and the respondent. However, McQueen and Knussen (2002) argue that questionnaires are not only a potentially quick, cheap and straightforward method of obtaining information, but they are also capable of demonstrating relationships, explore differences and test hypothesis.

Table 4.1: Differences between Quantitative and Qualitative Research. (Source: Adapted from Bryman, 1988 and Bryman and Bell, 2007)

	Quantitative	Qualitative
Role	Fact-finding based on evidence or records	Attitude measurement based on opinions, views and perceptions measurement
Relationship between researcher and subject	Distant	Close
Scope of findings	Nomothetic	Idiographic
Relationship between theory / concepts and research	Testing / confirmation	Emergent / development
Nature of data	Hard and Reliable	Rich and Deep
Nature of findings	Generalisation	Contextual understanding

4.2.4.3 Qualitative Methods

Literature Review

Conducting a literature review is a critical element for any research project. It provides thorough knowledge of the area in which the research is to be carried out, as well as a familiarity with other complementary research (McQueen and Knussen, 2002). It also enables an assessment to be made into where the research will fit in the wider body of work (Walliman, 2006). This further frames the research problem with subsequent research questions, as well as ensuring that complimentary work is built upon rather than unnecessarily repeated (Berg, 2007).

Observation

Observation is a research method which facilitates a researcher to systematically observe and record people's behaviour, actions and interactions (Hennink *et al.*, 2011). This method is particularly prevalent within studies which aim to view behaviour in a naturalistic setting (Barbour, 2007). However, Neuman (2003) warns of a potential moral-ethical dilemma present in such research due to the need to decide whether to conduct informed observation (participants are aware of the observation) or covert observation (participants are unaware). By gaining consent it is viewed as potentially harming the study by disturbing the participants or location and therefore gaining distorted and unnatural findings; however, by not informing participants it is viewed as being unethical and against the people's right to personal privacy (Neuman, 2003).

Focus Groups

Focus groups are a qualitative technique in which participants are informally interviewed within a group-discussion setting (Neuman, 2007). A focus-group remains an interview and not a discussion, but unlike a series of one-on-one interviews, focus group participants are able to hear each other's responses and make additional comments (Patton, 2002). However, members of the focus group need not agree or even disagree with others; the objective is to get high-quality data within a social context (Patton, 2002).

Interviews

An interview is a one-on-one data collection method in which an interviewer and interviewee discuss specific topics in depth (Hennink *et al.*, 2011). Three alternatives of interviewing are apparent, each with their strengths and weaknesses over the others (Patton, 2002). Patton (2002) describes these as;

- The informal conversational interview (spontaneous question generation in-line with the natural flow of interaction);
- The general interview guide approach (producing a checklist of issues to be explored without a rigid set of questions); and,
- The standardised open-ended interview (taking each interviewee through the sat sequence of carefully worded and intentional questions).

Case Studies

Case study approaches have frequently been defined in many different ways. However, emerging commonalities revolve around the scope of case study research. For example, case studies are said to facilitate an in-depth investigation of a phenomenon or process to gain new theoretical interpretations or to gain more exhaustive knowledge pertaining to existing theoretical insights (Fellows and Liu, 2008). Furthermore, they are the study of an issue explored through one or more cases within a bounded system (i.e. a setting or a context) (Creswell, 2007). The most comprehensive definition regarding the scope of a case study is that supplied by Yin (2009), which states:

> *"A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident."*

They typically combine data collection methods such as archives, interviews, questionnaires and observations to produce evidence qualitatively, quantitatively or sometimes a mixture of both (Eisenhardt, 1989). The most common application is in scenarios where existing knowledge is limited, as well as when the contextual variables are so numerous and qualitatively different that no single survey or data collection approach can be appropriately used (Fellows and Liu, 2008). Consequently, the case study inquiry copes with such variation through relying on multiple sources of evidence (data collection methods) to facilitate a convergence in data in a triangulating fashion to emerge (Yin, 2009).

Creswell (2007) outlines the case study approach as follows:

> *"It is predominantly a qualitative approach, (however it can consist of quantitative components also) in which the investigator explores singular or multiple bounded systems (cases) through a process of detailed, in-depth data collection involving multiple sources (such as; observations, interviews, audio-visual material, documents, or reports) and then reports a case description and case based themes that have emerged."*

4.2.4.4 Triangulation

Mingers (2001) asserts that no one paradigm is superior and that their different approaches may be more or less appropriate for particular situations or topics. This is complimentary of a pluralist approach in which different methodologies, methods and/or techniques are used in combination to achieve a more successful intervention (Jackson, 1999). This 'multi-methodological' approach stems from the argument that different research methods (especially from different paradigms) focus on different aspects of reality and therefore through combining these, the opportunity to gain a richer understanding of a research topic will be presented (Mingers, 2001) (see Figure 4.2).

The success of a triangulation approach is dependent on the identification of the most appropriate method(s) or technique(s) to each specific research question. This is shown through the view of Berg (2007) that the methods used to conduct a research study depends largely on what the research questions are. Therefore careful consideration has been given to determining the aims and objectives of this study to establish what the resultant research questions are. As a result, the most suitable research method(s) to extract the desired knowledge to answer each research question can be determined. The tabulation of this analysis is included in Appendix A (see Table 10.1).

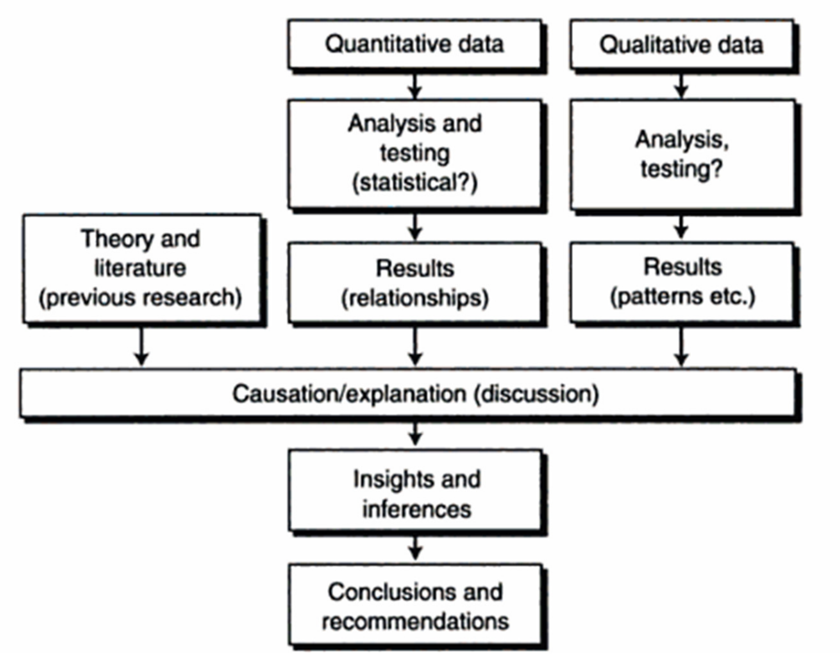


Figure 4.2: Quantitative and Qualitative Research Triangulation. Source: Fellows and Liu (2008)

4.3 Selection of Appropriate Research Methods

The review of each research method's credentials reported in section 4.2.4.1 is summarised in Table 4.2 in terms of the types of research question that each is most suited to. As such an evaluation of each method's ability to satisfy, not only each research objective, but also the questions they provoked has been conducted (see Appendix A: Table 10.1). This consisted of analysing to what extent knowledge relating to each research question had already been gathered through the literature review. As such, it could be determined what data, information or knowledge was still required to sufficiently answer the questions provoked and accordingly what methods were most suited to satisfy them.

Table 4.2: Relevant Situations for Different Research Methods. Source: Yin (2009)

Method	Form of Research Question	Requires Control of Behavioural Events?	Focuses on Contemporary Events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival Analysis	Who, what, where, how many, how much?	No	Yes/no
History	How, why?	No	No
Case Study	How, why?	No	Yes

The initial research activity of conducting a thorough literature was ideally suited to identifying the key trends and interest areas concerning the breadth of research questions. This was due to it indicating answers to *who, what, where, how many* and *how much* type questions according to preceding research studies. Subsequently, it was evident that a further data collection phase attempting to answer *how* and *why* such trends and areas of interest exist would need to be conducted. Accordingly, case studies were viewed as enabling the research objectives (see Section 1.3) to be fully satisfied.

4.4 Overall Research Methodology Design

The aforementioned research approaches were incorporated in a multiple-methodological research design. Figure 4.3 illustrates how each research inquiry approach contributed to satisfying certain research objectives, as well as narrowing the scope of inquiry. Figure 4.4 illustrates further how each research approach combines with other adopted approaches to generate the overall research methodology.

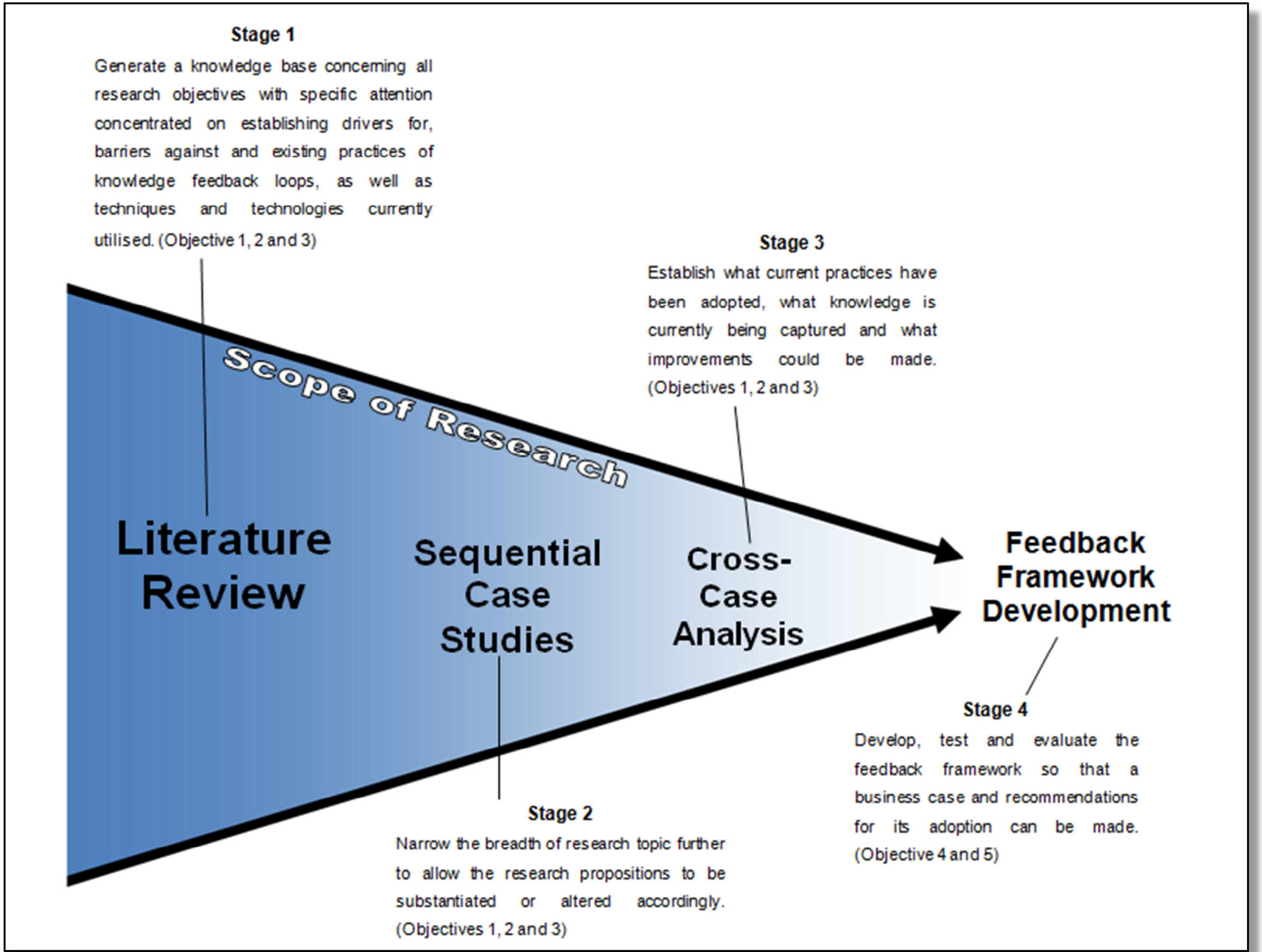


Figure 4.3: High Level Research Methodology

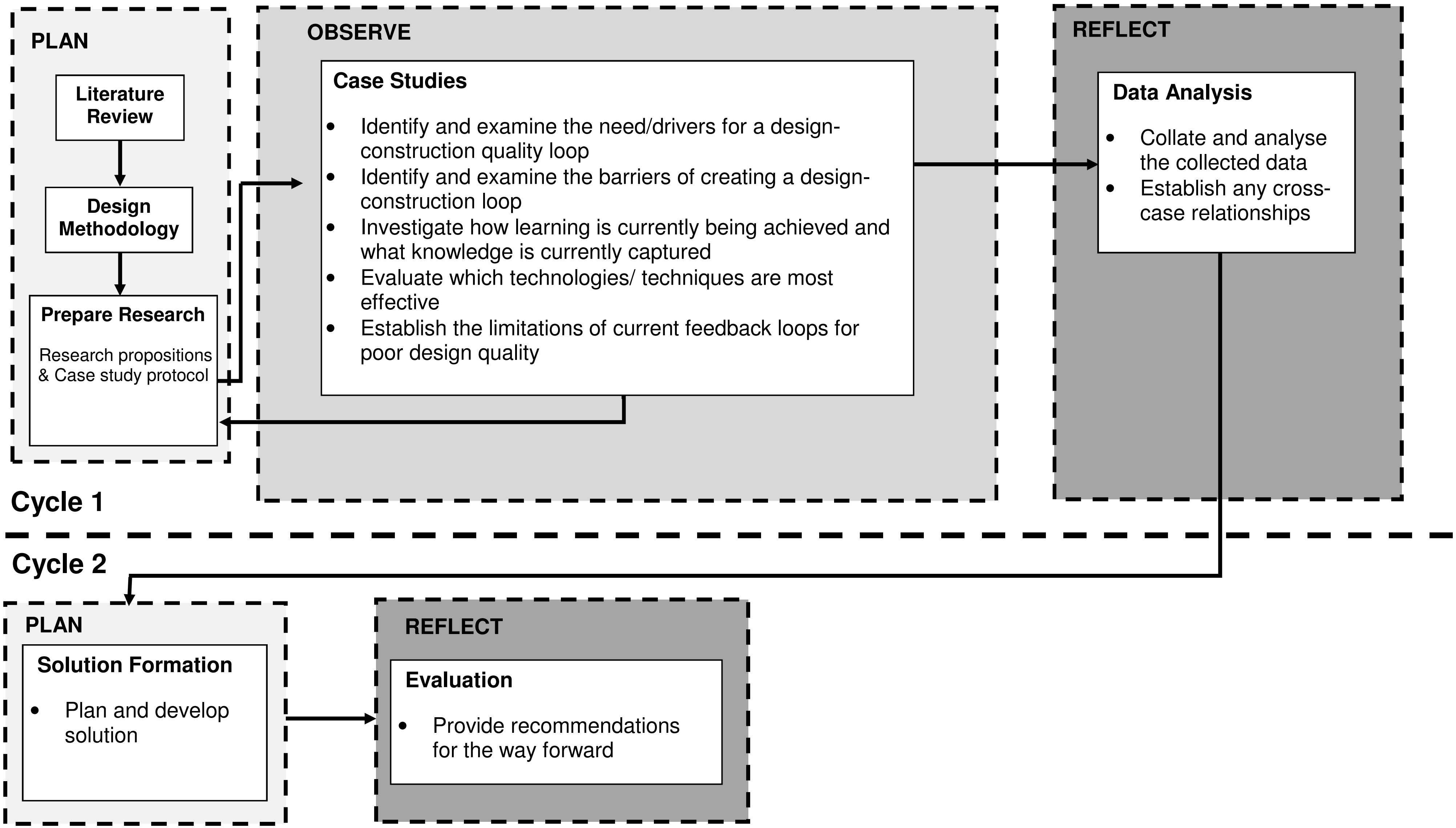


Figure 4.4: Research Methodology Design

This is once more summarised through Figure 4.5, which will be utilised as an overview figure at the beginning of each section of this thesis from hereon in. This is designed to provide guidance and understanding to the reader as to which stage is being discussed in relation to the overall study.

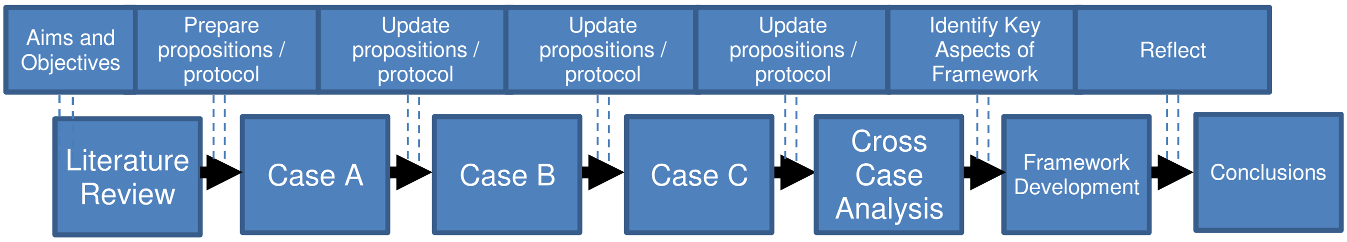


Figure 4.5: Research Activity Process Diagram

4.5 Research Methods Utilised

4.5.1 Literature Review

Due to the breadth of this research topic a ‘whole to parts’ approach (see Figure 4.6) has been adopted.

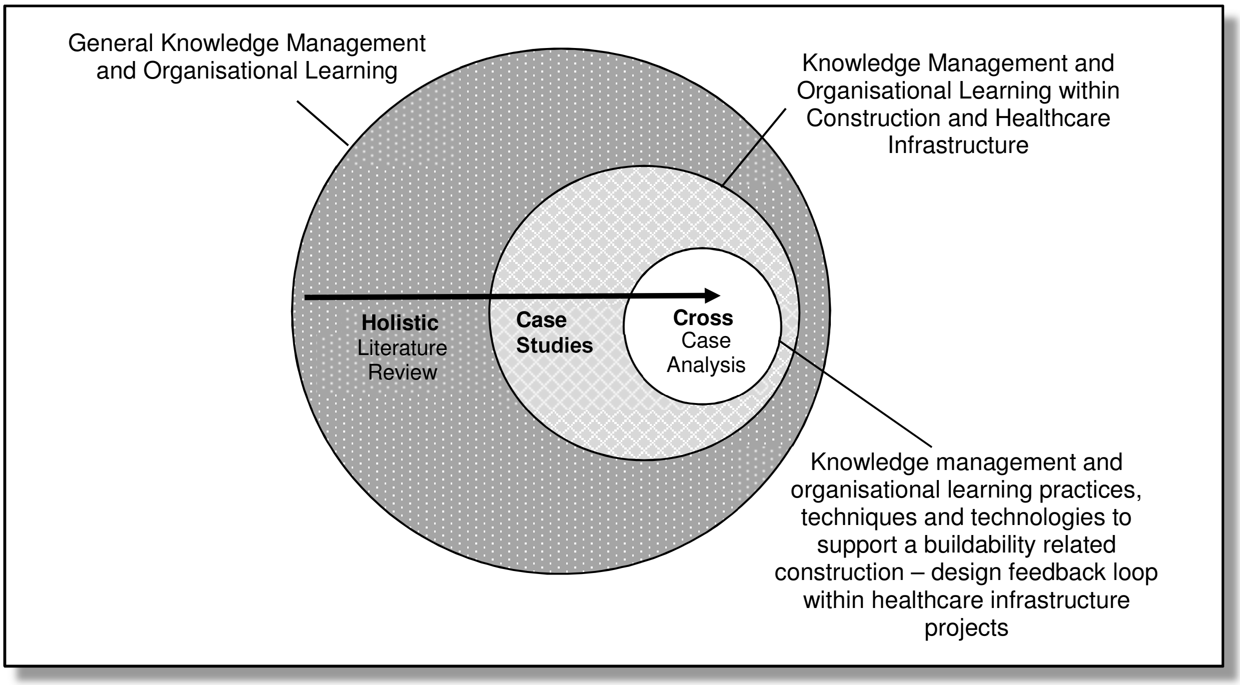


Figure 4.6: 'Whole to parts' literature review approach. Source: Adapted from Ruikar (2006)

This enables a two-pronged literature review strategy to be implemented. Firstly, insights into general KM and OL processes, their benefits, and their challenges were gained. A more specific focus on the need to improve such practices within the construction industry in general and within healthcare infrastructure projects in particular was then applied (see Chapter 2). This initial narrowing in focus is illustrated in Figure 4.7.

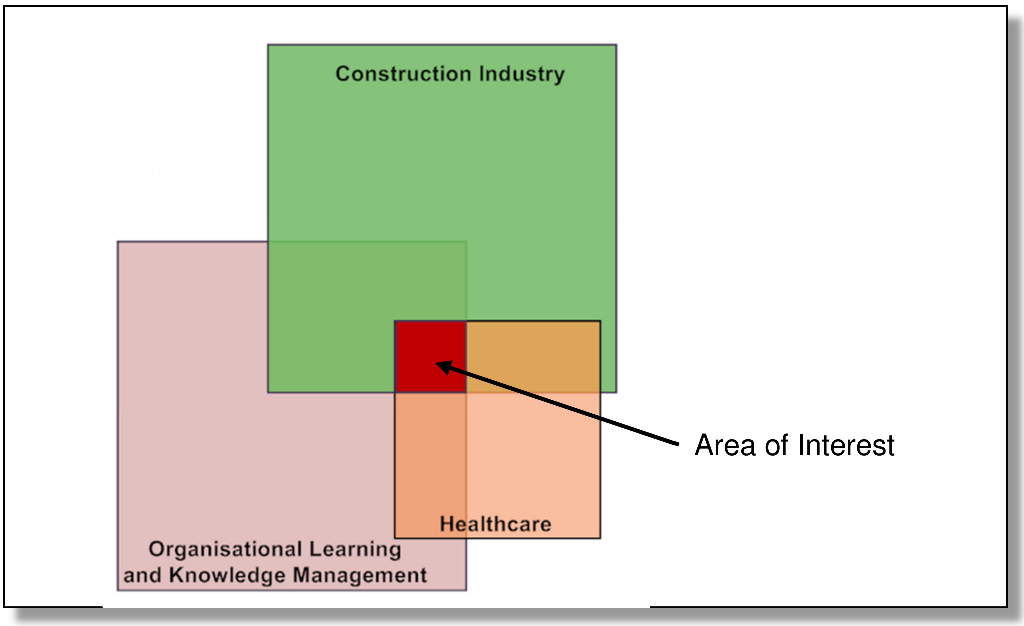


Figure 4.7: Initial Literature Review's Narrowing Focus

Key elements to arise during this stage were; the need to improve buildability, the need for a social-technical systems approach, the differences between KM techniques and technologies, and, other related studies. This shaped the subsequent stage in the literature review strategy. The overlaps of the six main literature areas and consequently the area of interest for this research are illustrated in Figure 4.8.

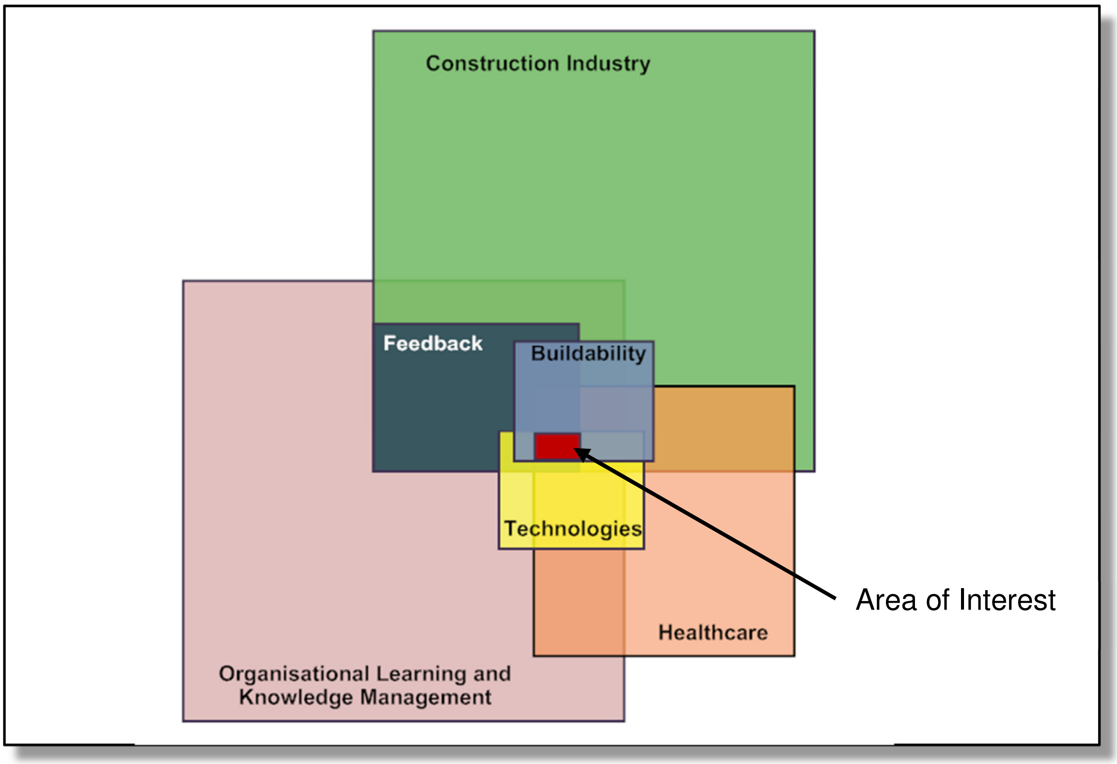


Figure 4.8: Narrowing in Focus of Areas of Interest

This two part literature review strategy enabled the partial achievement of the entire breadth of research questions (see Appendix A: Table 10.1). More crucially, it formed the basis for the development of further stages of this research in the form of the sequential case studies. It is also important to note that on-going literature reviews were undertaken throughout the duration of this study. This was to keep up to date with research conducted within the areas of interest, as well as to further develop knowledge within areas whose importance became evident through further investigation.

The function and value of the literature review process therefore contributed to a wide range of aspects of this research. These are summarised below:

- Increasing the degree of knowledge in areas of interest;
- Gaining an insight into developments within related and non-related industries;
- Discovering complementary research projects;
- Focusing the research project effectively;
- Enabling the research to be framed within the wider body of research work;
- Avoiding unnecessarily repeating research; and,
- Forming a foundation to base further research upon.

4.5.2 Case Studies

Eisenhardt (1989) suggests that case study investigation can be used to; provide description, test theory, or, generate theory. As this research is interested in generating 'theory' or at least empirical generalisations (see Section 4.2.1) it is the latter aim in which is of interest. The theory generative case study approach is illustrated in Figure 4.9.

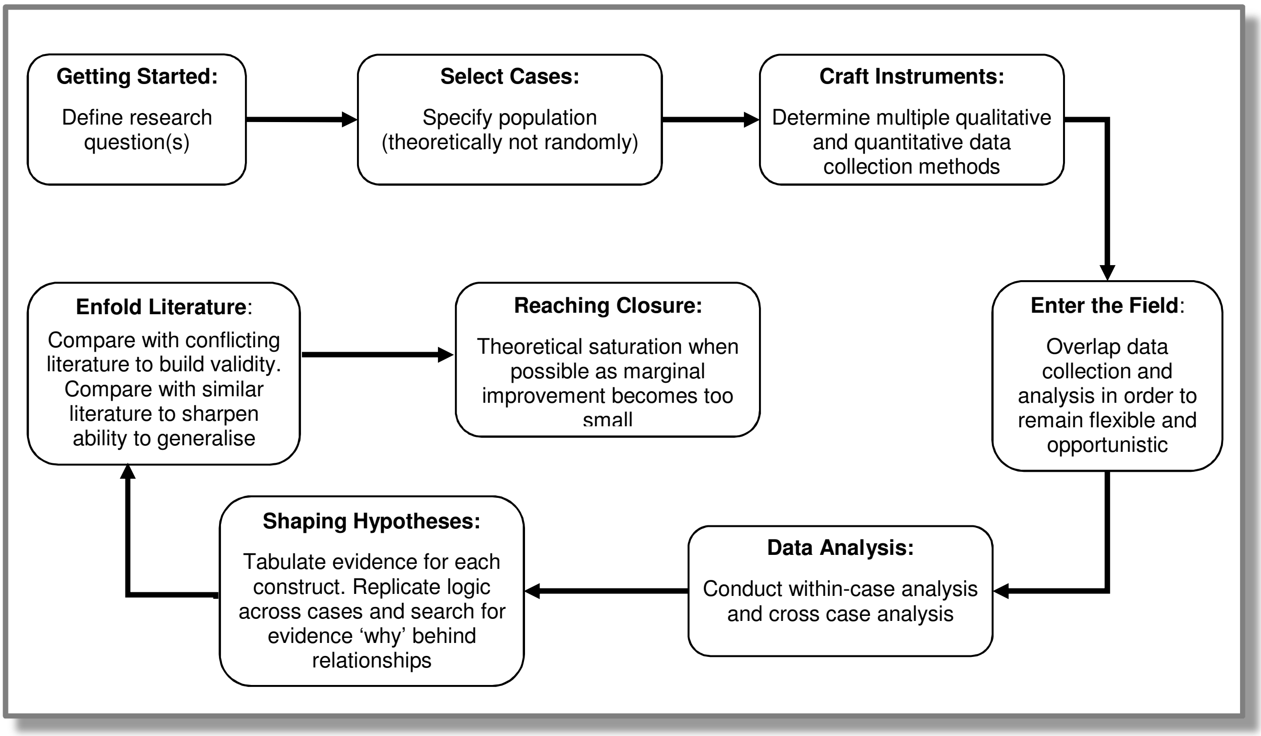


Figure 4.9: Process of Building Theory from Case Study Research. Source: Adapted from Eisenhardt (1989)

In agreement with the main attributes of Eisenhardt's (1989) case study process, Yin (2009) opposes the view that case studies are conducted in a linear fashion. Instead they must be done in an iterative manner to continually refine and improve the investigative process. Consequently, the broader iterative steps of case study research are shown in Figure 4.10.

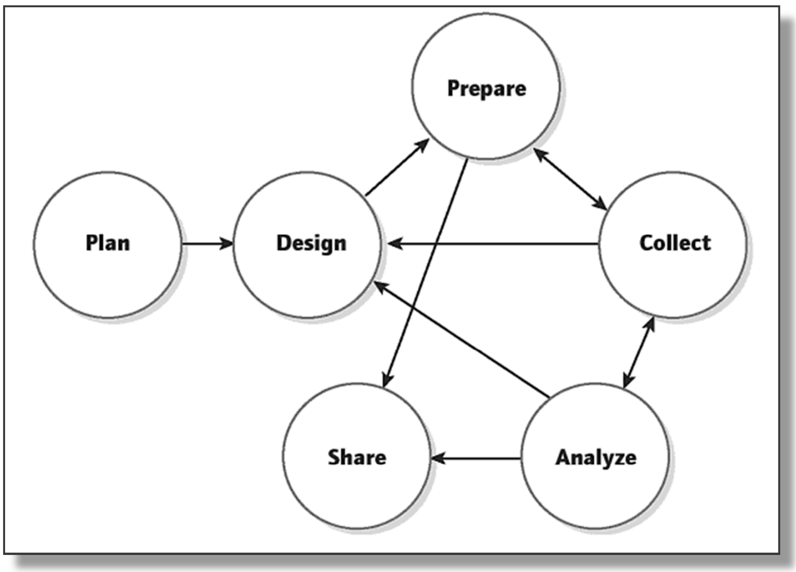


Figure 4.10: The Case Study Method as a Linear and Iterative Process. Source: Yin (2009)

Dubois and Gadd (2002) confirm this stance by stating that the iterative process of moving between research activities (i.e. empirical work and theory) gives the ability to discover new dimensions to the research problem. This is achieved through the previously discussed abductive approach (see Section 4.2.1) by a technique they term as 'systematic combining'. This stresses an integrated approach to case study research where each activity is intertwined, thus influencing and being influenced by other activities. For instance, the evolving analytical framework (methodology) guides the search for empirical data, with these observations potentially resulting in unexpected but related issues that may need to be explored in further research activities. This process can thus change the theoretical framework being produced (Dubois and Gadde, 2002) (see Figure 4.11).

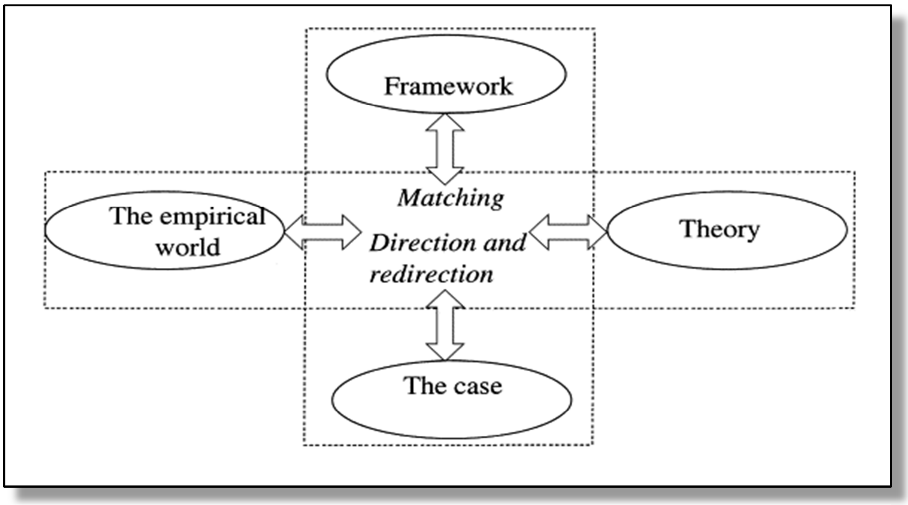


Figure 4.11: Systematic Combining. Source: Dubois and Gadd (2002)

Therefore where triangulation aims to verify the accuracy of data, the use of multiple techniques and sources may contribute to revealing aspects unknown to the researcher and thus discover new dimensions to the research problem. (Dubois and Gadde, 2002). For this reason an abductive, systematic combining approach to the case study phase of the methodology has been adopted.

It is however acknowledged that case study research is not without limitations. Yin (2009) notes that other investigators view case study research as less desirable than other forms such as surveys and experiments. This is attributed to the concern over the lack of rigour that is sometimes evident as the investigator fails to follow systematic procedures, accepts equivocal evidence, or exercises bias to influence the findings and conclusions, in addition to them providing little basis for scientific generalisation (Yin, 2009).

Due to the evident in-depth nature of case studies a further consideration is time limitations, as potentially only a small number of cases can be studied (Fellows and Liu, 2008). This limitation has been primarily overcome by conducting a thorough and in-depth literature review so that key trends and interest areas can be established prior to conducting case studies. Consequently, the in depth case studies focused on more specific issues, which ultimately reduced the time required to conduct them.

4.6 Case Study Methodology Considerations

As case study investigation was the main research method adopted within this study it is crucial to outline the multiple considerations that were made in developing its underlining design. This section also demonstrates how the supplementary method of the literature review was utilised to support the development of this core theory generating approach.

As a result of a review into comparative case study methodologies including Eisenhardt (1989), Gerring (2007) and Yin (2009) it was decided that the process illustrated by Yin (2009) is the most robust and therefore was rigorously followed. Such a process involves the following five important components:

- A study's questions;
- Its propositions, if any;
- Its unit(s) of analysis;
- The logic linking the data to the propositions; and,
- The criteria for interpreting the findings.

4.6.1 Case Study Question Generation

The preceding research activity of the literature review enabled the question of *'what'* areas and problems are most vital to be addressed to be answered in preparation for the case study investigation design. Such research questions are outlined below. The following case study design considerations therefore aim design case study investigation that can provide answers in terms of *'how'* and *'why'* these issues are so prevalent and *'how'* can they be improved.

- How can key barriers (particularly those on a personal level) be reduced?
- What are the most critical issues of buildability to feedback to designers?
- To what extent can BIM be utilised within the feedback loop?
- What feedback between designers and contractors is currently in place and how effective is it?
- How can knowledge be shared with other members in the supply chain?

4.6.2 Research Proposition Development

Research propositions direct attention to aspects that should be examined within the scope of the study, whereas preparation work point towards what questions the project is interested in answering (Yin, 2009). Simply put such preparation work details the area of interest and specific research questions for a project, whereas research propositions force the researcher to identify and therefore target the key areas that should be studied to obtain answers to them. Yin (2009) warns that without such it is tempting to attempt to gather information on 'everything'. Therefore the defining of general topics represents a vast narrowing of relevant data which ultimately enables the study to remain within feasible limits (Yin, 2009).

This issue of stating research propositions before conducting the research itself is one of the most contentious aspects of the Yin (2009) methodology. Other authors contend that theory-building research should begin as close as feasibly possible to the idealistic position of no theory being under consideration and no hypothesis to test (Eisenhardt, 1989). This is to attempt to reduce, although impossible to achieve in its entirety, the possibility of formulating preordained theoretical perspectives that may cause bias and thus limit the findings (Eisenhardt, 1989).

Eisenhardt (1989) suggests that researchers should avoid considering specific relationships between variables and theories (as is the case with propositions) and instead formulate a research problem and simply specify the important variables to focus upon. In contrast, Gerring (2007) supports Yin's (2009) perspective that case study research should be based on the generation of an initial hypothesis, preconceptions or propositions arising from a theoretical evidence base such as a literature review.

It is therefore apparent that both perspectives are consistent in the fact that they recognise the need to identify the key areas (i.e. variables) that must be studied to obtain answers for the main research questions. They differ in terms of whether the generation of research propositions should precede the act of data collection.

Gerring (2007) defends his method by suggesting that until such preconceptions are formulated, the details of further research cannot be determined. Yin (2009) supports this view whilst elevating the areas in which such research propositions can benefit a researcher by stating that they not only narrow the focus of the study but also simplify the identification of appropriate cases and analytical techniques. The advantages of doing so early on in the process is said to be twofold. Firstly, it heightens the likelihood that the necessary data will be obtained. This will therefore prevent the scenarios of:

- Collecting too much data which would ultimately become unused and/or cause data overload; or,
- Collecting too little relevant data thus resulting in a return to the data collection phase if the possibility remains (Yin, 2009).

Secondly, it provides the potential to generalise case study results much more easily during the data analysis stage. This is due to it being possible to associate the results of each proposition (either in support or discrediting them) back to the causal links made from the literature review.

It is therefore apparent that the need to consider the variables involved in answering the research questions plays a critical role in the development of case study research design. This is regardless of whether it is in the form of theory propositions or attempting to identify the variables apparent to investigate. It is the view of this researcher however, that the act of formulating research propositions benefits its design to a greater extent to that of attempting to identify the study's variables without formulating predetermined theoretical perspectives. This is due to the cited multifaceted advantages that such propositions facilitate, which include:

- Identifying the areas of interest during the design stage;
- Determining the necessary data to be collected;
- Signifying the most appropriate analytical methods; and,
- Enabling theory generalisation during analysis.

Consequently, this research continued to follow the case study methodology outlined by Yin (2009), but also benefited from the advice outlined by other authors. For instance, Eisenhardt (1989) recommends avoiding becoming captivated in thinking about specific relationships between variables and theories at this stage, which has the potential to artificially shape the findings. To achieve this Gerring (2007) advises that a researcher's initial hypothesis may change in the course of their research. Therefore, by remaining flexible and open to the prospect that such hypothesis are likely to alter throughout the course of the project, it increases the probability that the trap of artificially shaping the findings to suit the initially formed hypotheses will be avoided. Accordingly, a further technique that was adopted where appropriate was to develop rival propositions so that the tendency to attempt to prove the accuracy of initial beliefs was avoided (Eisenhardt, 1989).

Assurance of avoiding such bias is achieved further by conducting sequential case study investigations which enable hypothesis to be altered in-between each case study, whilst actively encouraging research proposition fluidity throughout the project. This is an example of the adopted abductive approach to research (see 4.2.1). The credentials of adopting such a sequential form of data collection are discussed further in Section 4.6.6.

The research propositions developed as a consequence of the initial literature review are shown below:

Proposition 1 - a feedback loop between the phases of design and construction could improve the level of vital learning conducted within healthcare infrastructure projects

Proposition 2 – the capture and feedback of buildability instances to designers can improve design quality, reduce costs and time.

Proposition 2a – the usefulness of the knowledge captured is improved the nearer to the learning event occurring the eventual capture takes place.

Proposition 2b –vital tacit knowledge can be captured and fed back to designers if a variety of capture formats are utilised.

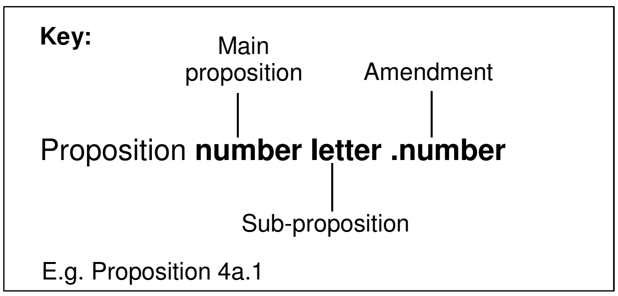
Proposition 3 – a socio-technical systems approach can overcome the downfalls of a purely technique or technology centred KM approach.

Proposition 4 - mobile technologies can be utilised to assist the live capture of learning instances onsite

Proposition 4a – BIM provides a potential platform for the proposed feedback loop

Proposition 5 – Healthcare infrastructure is inimitable compared to other large complex projects

Proposition 5 (rival) – Healthcare infrastructure does not demonstrate significant signs of inimitability compared with other large complex projects



The logic connecting the theory framework derived from the literature review and preceding case studies (in the instances of the second and third case studies) with the resulting emergent research propositions has been tabulated (see Table 10.2: Appendices B.1). This table demonstrates how the propositions remained flexible and were adapted over time depending on the outcomes of various research activities. This table therefore acts as a map of the changes in direction taken throughout this study depending on the variation between the expected findings (i.e. anticipated direction) and the eventual findings (i.e. direction taken).

4.6.3 Unit of Analysis

A case study's unit of analysis is related to defining what the actual 'case' is (Yin, 2009). In some cases this could be an individual with which information is to be gathered about; however, in this case the unit of analysis was less straight forward to define. This is due to the case in question not only involving groups of individuals but also the fact that they were from differing organisations and disciplines. Consequently, Yin (2009) advises that in such instances it is not easy to define the beginning or end points of the case and therefore care must be taken in making sure that the information gathered does not reach beyond its ill-defined extremities.

This is an additional reason for the need to state research propositions before undertaking data collection. For example, if a clear unit of analysis could have been set, such as the study being interested in a certain individual, the boundaries of the data collection would be much clearer. However, in this case, research propositions act to narrow the focus.

The unit of analysis was initially loosely defined as *'the knowledge flow between the construction and design stages of healthcare infrastructure projects'*. Yin (2009) continues to state that once a tentative unit of analysis has been defined, further clarification through questioning what the subject of the case study includes should be conducted. This is achieved through posing study specific questions such as; which persons of this cross-organisational group are important, what knowledge is being observed, and what time boundaries are to be defined regarding the beginning and end of the case (Yin, 2009).

Consequently, the literature review was utilised to answer these questions, with the unit of analysis for this study becoming:

> *"The flow of buildability related knowledge between construction personnel and designers of healthcare infrastructure projects."*

4.6.4 Criteria for Interpreting Study Findings

During the design phase of case studies it is vital that consideration is given to the various choices of analytic techniques so that assurances can be made that the case study methodology collects the necessary data to suit the desired analysis method (Yin, 2009). For this to be achieved, a general analytic strategy consisting of the fourth and fifth components of the methodology design (see Section 4.6) must firstly be prepared (Yin, 2009). This section will therefore:

- Discuss the analytic strategy adopted;
- Review the five main analytical methods outlined by Yin (2009);
- Discuss the reasoning why the method(s) selected were deemed the most suitable for this research project; and,
- Discuss the implications of such regarding the necessary data collection methods.

4.6.4.1 Analytical Strategy

A recurring theme is that of the generation of theoretical propositions to form a fundamental ingredient to both data collection and analysis components. As such, the primary analytical strategy adopted is known as *relying on theoretical propositions.* This approach revolves around the notion that due to the data collection strategy being based on the same theoretical propositions, it will assist in; focusing attention on the most critical data whilst ignoring that which is insignificant, organising the case study, and helping to define alternative explanations to be examined (Yin, 2009).

4.6.4.2 Analytical Techniques

Eisenhardt (1989) precedes Yin's (2009) consideration of appropriate analytical methods by bringing attention to the differences between within-case analysis and cross-case analysis. Within-case analysis involves detailed case study write-ups, which then become central to the generation of insights because they assist in the analysis process of a typically large volume of data (Eisenhardt, 1989). Only once detailed descriptions of each case study have been developed can cross-case analysis be conducted (Eisenhardt, 1989). This involves searching for patterns between the cases to make confounded conclusions (Eisenhardt, 1989), through analytic techniques such as; pattern matching, time-series analysis, cross-case synthesis, logic models and explanation building (Yin, 2009).

This two-tiered method is said to benefit a researcher in coping with the staggering amount of data collected through case study research by enabling them to become intimately familiar with each case and its unique patterns separately before attempting to generalise across cases (Eisenhardt, 1989). Consequently, such an approach was adopted. A summary of the above five main analytical techniques is given below, followed by the rationale of the selected approaches.

- **Pattern matching** compares an empirically based pattern with a predicted one (for example the research propositions and initial theory building) and if the patterns coincide then the case study's internal validity is strengthened (Yin, 2009).
- **Time-series analysis** is an analytical approach which involves tracing events over time in detail and with precision. This is to identify changes between the observed and either a theoretically significant trend specified before the investigation; or some rival trend also specified earlier (Yin, 2009). Time-series is therefore used when data has been obtained from observations sequentially over time to understand the mechanism that gives rise to the observed series in order to predict or forecast the future values of a series (Cryer and Chan, 2008).
- **Cross-case synthesis** involves treating each case study as separate and aggregating findings across a series of individual studies (Yin, 2009). This aligns with the advice given by Eisenhardt (1989) that within-case analysis should precede cross-case analysis.
- **Explanation building** is a special type of pattern matching where the goal is to analyse a case's data by building an explanation about the case (Yin, 2009). In an iterative process, the evidence is examined and theoretical positions revised. This is then followed by the evidence being examined once more from a new perspective, with its goal not being to conclude a study but develop ideas for further study (Yin, 2009).
- **Logic Models** are another type of pattern matching whereby empirically observed events are matched to theoretically predicted events; however they differ by deliberately stipulating a complex chain of events over an extended period of time (Yin, 2009). The chain of events consist of repeating cause-effect-cause-effect patterns to determine what the initial intervention's immediate outcomes (effects) were, what these effects subsequently caused (intermediate outcomes) and what the intermediate outcomes finally resulted in (ultimate outcomes) (Yin, 2009).

Accordingly, the cross-case analysis technique(s) that were adopted for this study were pattern matching and cross-case synthesis. Pattern matching was viewed as being beneficial as it presented the ability to rule out potential threats to validity. This was due to the process of firstly identifying such threats and then detecting patterns between cases that do not harbour the same characteristics (Yin, 2009). The process undertaken to action these techniques will now be discussed in the following section.

4.6.4.3 Analytical Process

This section details how the mass quantity of qualitative data obtained was managed and consequently analysed. Each case study consisted of at least two verbal one-to-one interviews being conducted, background research to the case and supplementary evidence such as knowledge repository example being obtained.

The initial case study protocol was based on questions arising from the initial literature review in regards to answering the founding aim and objectives of this study. There is therefore a direct link between the logic surrounding the development of the propositions and the case study questions (see Section 3.4.1). To improve the responses obtained, a copy of the case study protocol (see Appendix B.2) was sent to each participant prior to their interview taking place. This allowed them to consider the key aspects surrounding each question in more detail than if they were delivered impromptu. The case study protocol was organised according to the intended analytical themes (see Figure 5.3), which aided the questions to naturally flow from one interest area to the next and simultaneously aided managing the response data obtained.

Once the interviews had been conducted, they were fully transcribed individually. This highlighted any gaps in the data, which enabled follow-on questions of interest to be put to the interviewee whilst the topics remained prevalent in their minds. The next stage of the analysis was to organise the data across sources so that it could be analysed as a whole. This was achieved by coding the data according to the question that it answered so that answers to the same questions could be compared. Further coding was necessary due to the nature of the semi-structured interview adopted (see Section 4.5.2), in which some answers crossed the boundaries of certain questions and topics and therefore had to be included in the analysis of multiple areas. This management of data was aided through the utilisation of a software package called Audio Note Taker which is designed to manage audio data sources so that they can be broken down into desired segments (i.e. common headings / propositions). Once the data had been fully coded and managed it allowed for a second revisit to the data sources if any further data gaps or the requirement for clarification was identified.

An analysis of any consensus or contentions between the primary data could then be established, with this then being compared to that established through the literature review (Chapters 2 and 3). The initial research aim and objectives (Chapter 1) led to the identification of key interest areas to examine within previous literature. In turn this led to identifying key research propositions (Chapter 4), which formed the basis for the case study protocol development (Appendix B.2). Through this a vast amount of qualitative data was generated and analysed (Chapters 5 and 6). This detailed and planned process therefore provided a high degree of rigour (Yin, 2009), which guarded against Eisenhardt's (1989) warning towards the difficulty of coping with a staggering amount of data that would inevitably be obtained.

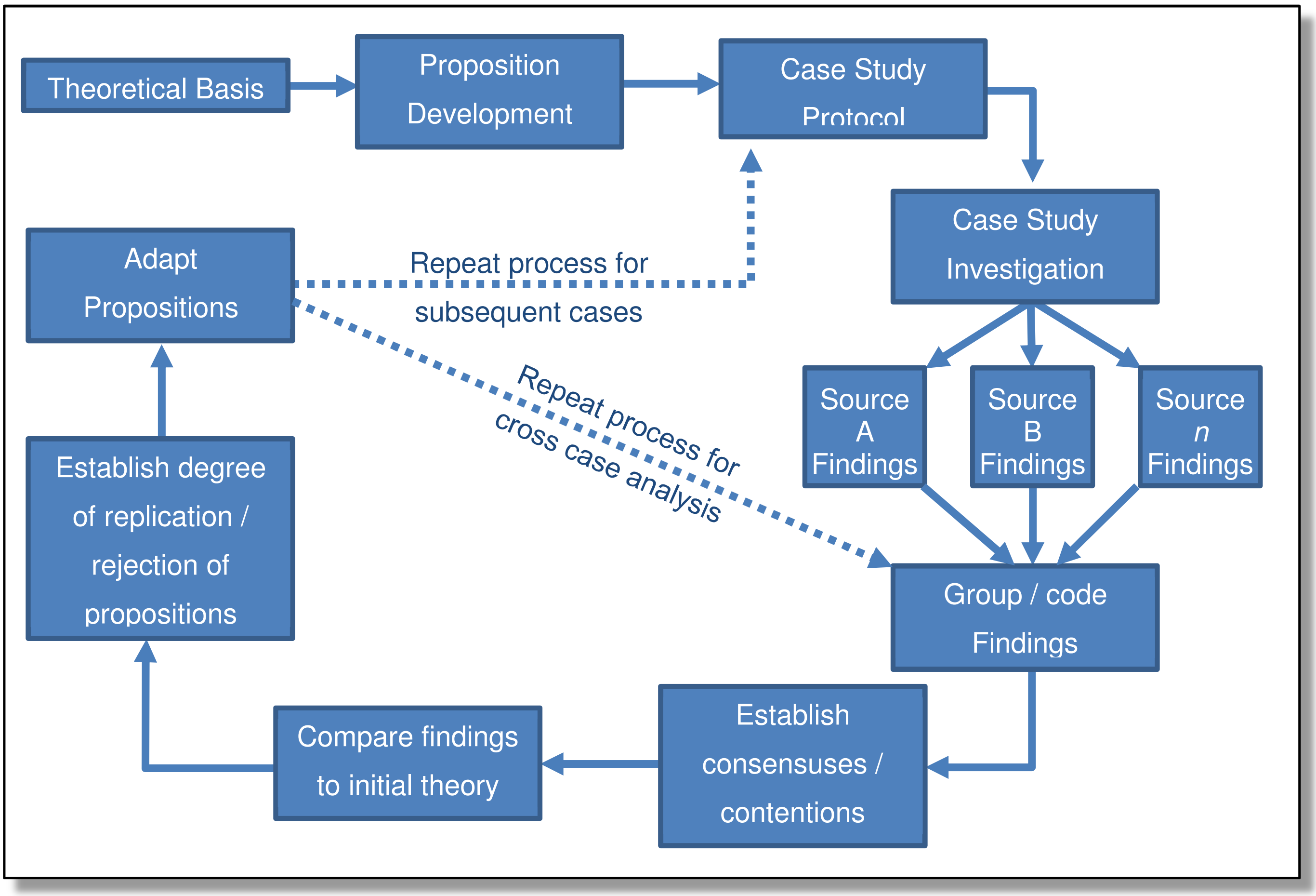
Each case study analysis was then written in full prior to the subsequent case being conducted. Once more this followed the case study analysis themes of the case study protocol, which would benefit the managing of data obtained from further cases and their analysis. Once the full case study analysis had been documented and the levels of support or rejection had been established towards the research propositions, they could be accordingly adapted so that emerging themes (e.g. the requirement for high level managerial support) could be tested in the future cases. This also consisted of some changes needing to be made to the case study protocol so questions targeting testing the adapted/newly emerged propositions could be included. The key threads/links between the research aim and objectives, preceding literature, research propositions and primary research findings were therefore maintained throughout the entire process to assist in maintaining high levels of validity.

Based on this analysis, the extent to which replication had been established or not could be identified so that the subsequent case study protocol could be adapted accordingly. This adopted data analysis process is illustrated in Figure 4.12.

This process aligns seamlessly with both of the analytical strategies proposed earlier (i.e. *relying on theoretical propositions* and *the examination of rival theories*) (see Section 4.6.4.1). It did however have implications for the data collection stage as it requires a multiple case study approach to be adopted (see Section 4.6.5). In terms of the analytic strategy the decision to conduct multiple cases is beneficial to the application of pattern matching due to the ability to rule out validity threats by comparing contrasting cases much more easily (Yin, 2009).

Furthermore, this method calls for the cases to be conducted sequentially rather than simultaneously. This is due to enabling the opportunity for the initial research propositions to be altered prior to additional cases being conducted. This shows a benefit of adopting an abductive research approach (see Section 4.2.1). This enables differing patterns to be predicted and tested in a process known as creating theoretical replication (Yin, 2009). Alternatively, if the predicted patterns are detected then identical subsequent cases can be carried out to produce literal replication (Yin, 2009).

In addition, cross-case synthesis which is also designed to be used to analyse multiple cases was adopted. The most attractive element of this approach, which is absent in that of pattern matching, was that it enabled independently conducted case studies to be analysed in relation to the findings of this study (Yin, 2009). Therefore, similar but independently conducted cases were analysed for similar patterns. As such, through utilising a combination of analytical methods, a higher degree of internal and external validity should be achieved (see Section 4.5.2).



4.6.5 Single vs. Multiple Case Studies

As stated in the preceding section of this chapter, an additional consideration to be made was the appropriateness of adopting a single or multiple-case study approach. Yin (2009) suggests that a single-case study design is appropriate when the single case represents:

1. The critical case (where the theory has specified a clear set of propositions and the circumstances within which they are believed to be true matches a single case only);
2. An extreme or unique case (where the study is interested in something that is so rare that only a single case is available);
3. A representative or typical case (when the case represents a typical project);

4. A revelatory case (when a previously inaccessible opportunity to study a phenomenon arises); or,
5. A longitudinal case (where the same case is studied at two or more different points in time)

This research does not entirely represent any of the above and therefore appears inappropriate to adopt a single-case design. The most well aligned circumstance is that of it being a representative or typical case. This is due to it previously being argued (see Section 2.6.1) that healthcare infrastructure projects are relatively repetitive projects (Abdou *et al.*, 2003) and therefore one case may be representative of other, most, or all cases. This being said, due to the variation in possible delivery methods alone including; design-bid-build (DBB), design and build (D&B), partnering and the private finance initiative (PFI), the degree of repetition appears only to be limited to the context implied by Adbou *et al.* (2003). This is in the form of the extent to which lessons learnt could be applied to future projects, rather than the actual process undertaken for each and every project.

Furthermore, Yin (2009) states that the evidence arising from multiple cases is generally considered to be more compelling and robust. Therefore he suggests that often the decision to conduct single-case designs is usually not out of choice due to it aligning with the previously outlined circumstances for adopting a single-case. The multiple-case design is not considered to be entirely idealistic or without its drawbacks. For example, conducting a multiple case-study is viewed as being resource and time intensive which may be beyond the means of a single researcher (Yin, 2009).

As a result of these considerations it was apparent that a multiple-case study design was both the most applicable and beneficial approach. This was due to it being able to facilitate the generation of a greater richness of information. A multiple-case approach also enables the inevitable variation in the delivery of healthcare research projects to be investigated. However, due to the concern of the resource intensity of such an approach and in particular the time limitations apparent in this study, a multiple-case study approach limited to three cases was adopted.

Consequently, various important implications for the data collection design to surface in the form of the need to strategically select cases, as well as to perform data collection sequentially and independently of other cases. These considerations will now be discussed in greater detail.

4.6.6 Selection of Appropriate Cases

The selection of cases has long been identified as being a critical aspect of theory building. For example, Eisenhardt (1989) stated that cases should be chosen strategically to either replicate previous cases, or to fill theoretical categories and provide examples of polar types. Seale *et al.* (2004) agree by suggesting that the ability to generalise findings is heightened through the strategic selection of cases. For example, they declare that a typical or average case may not present the same richness of information as can be determined from atypical or extreme cases.

Conducting a multiple-case study is different from multiple respondents in a survey (Yin, 2009). This is due to the aim of a multiple-case design being to replicate the findings of the previous case to provide literal replication, similar to that of a repetition of an experiment where the variables remain the same to replicate the initial experiment's findings (Yin, 2009). Alternatively, future cases may be identified with differing experimental conditions to test whether the findings matched what was predicted to happen and therefore present theoretical replication (Yin, 2009).

Due to the recognition that the time limitations of this study limits the number of cases being studied (see Section 4.6.5) the strategy for case selection needed careful consideration to enable literal or theoretical replication. Targeting purely representative cases was unlikely to extract the same depth of information than if a combination of strategies was utilised. This was due to representative cases or random samples being viewed as unable to provide the necessary amount of information on any given problem or phenomenon because they merely describe its symptoms and how frequently they occur (Seale *et al.*, 2004). In comparison, extreme, deviant or variation cases are more applicable to small samples as they can often reveal more information and therefore clarify the deeper causes behind a given problem and their consequences (Seale *et al.*, 2004).

Accordingly, the case selection strategy adopted consisted of a combination of representative and variation cases. To attempt to replicate the anticipated findings derived from the theory base, the identification and selection of a typical and representative case was targeted for the initial case. Subsequent cases were then identified on the degree to which they varied on significant aspects to test theoretical or literal replication of the preceding case study findings. The adoption of this secondary strategy was also viewed as a means to test and rule out validity threats (see Section 4.6.4: Pattern Matching) as reoccurring patterns between extreme cases and/or predicting how changes in significant variables will affect the findings can improve the overall internal validity of the findings (see Table 4.3).

To apply such replication logic (rather than the sampling logic relevant to surveys), each single-case study was carried out independently and sequentially rather than simultaneously. This enabled theory to be tested in the first case and adapted if necessary to produce theoretical replication, or alternatively, kept the same to produce literal replication (Yin, 2009). To achieve this it was crucial to explicitly predict the similar or contrasting results beforehand (Yin, 2009), which was conducted through developing new, or adapting/rejecting current research propositions.

4.6.7 Case Study Validity and Reliability

Although considerations required to form the most idealistic and appropriate case study design has been thoroughly conducted, it does not entirely rule out the opportunity for bias and validity threats. As such, Yin (2009) developed the four following tests which are designed to assess the quality and rigour of the research design:

- **Construct Validity** – the extent to which a study investigates what it sets out to investigate and therefore tests the degree to which the investigative procedures led to an accurate observation of reality (Gibbert *et al.*, 2008);
- **Internal Validity** – refers to whether the researcher has provided a plausible argument regarding the defence of the research conclusions in terms of being causally related to the observations made (Fellows and Liu, 2008; Gibbert *et al.*, 2008; Yin, 2009);
- **External Validity** – concerns whether the findings can be generalised to other circumstances other than those initially tested and therefore the applicability of the results obtained from a sample to the wider population (Fellows and Liu, 2008); and,
- **Reliability** – the extent to which random error is absent and therefore the degree to which subsequent researchers could arrive at the same conclusions if the study was repeated (Gibbert *et al.*, 2008).

Table 4.3 illustrates a range of tactics to heighten validity and reliability as well as the phase of research in which the tactic is to be applied in. The measures adopted throughout this research study's design and completion to ensure its validity and reliability have also been incorporated within this table.

Table 4.3: Case Study Tactics and Avoidance Measures for Four Design Validity and Reliability Tests. Source: Adapted from Yin (2009)

Tests	Case Study Tactic	Phase of Research to Apply Tactic	Adopted Measures to Ensure Validity and Reliability and Cross Reference
Construct Validity	• Use multiple sources of evidence • Establish chain of evidence • Have key informants review draft case study report	Data collection Data collection Composition	• Multiple (also known as comparative) case studies rather than single cases were used to improve the ability to generalise findings • Multiple sources of evidence were obtained (interviews, observations, document supplementation, discussions) • Chain of evidence established (see Appendix B.1) • Key informants reviewed draft case study report
Internal Validity	• Perform pattern matching • Do explanation building • Address rival explanations • Use logic models (n/a)	Data analysis Data analysis Data analysis Data analysis	• Pattern matching was performed between cases • Cross-case synthesis was performed between cases • The prediction of how findings would be altered depending on changes in the cases selected was performed • Exploration of rival theories was conducted • Comparison of findings to other related research was undertaken • Multiple methods and triangulation were utilised to validate the evidence as far as reasonably possible.
External Validity	• Use theory in single-case studies (n/a) • Use replication logic in multiple-case studies	Research design Research design	• Pattern matching of findings with other related research was undertaken • Prediction of literal or theoretical replication depending on changes within the cases' characteristics was performed
Reliability	• Use case study protocol • Develop case study database	Data collection Data collection	• Case study protocol developed and followed rigorously • Case study database developed

4.7 Summary of Alignment between Research Objectives and Propositions

This chapter has documented the stringent contemplation of the considerations involved in developing a robust and reliable methodology framework. This has resulted in the planning of a sequential, multiple case study investigation approach. A multiplicity of considerations has been debated in combining the most appropriate and complimentary alternatives that enable the initial research question to be answered.

One of these key considerations is the adoption of the technique of developing research propositions that are based upon current theory. This enables key areas of interest to be tested in the form of an analysis regarding whether data supports or rejects the developed propositions. A brief overview of how these propositions align with the initial research objectives is provided below.

Objective 1: To examine existing literature relating to the need for and barriers against design-construction learning loops

Although this research objective is specifically targeted at the literature review phase of this study, a fundamental research proposition to test in subsequent phases arose as a result. In assessing the need for design-construction feedback loops it was identified that better channels of communication and knowledge sharing between these participants could significantly enhance the degree of learning and therefore continuous improvement (see Section 4.6.2). As a result, this objective is being investigated further than simply through the literature review so that the extent of the need and barriers can be discovered and research in this area enhanced as a result.

Objective 2: To establish the potential and limitations of current knowledge management procedures

This objective is covered by a wider number of propositions as multiple areas of potential strength and weakness arose from theory. For example, it was identified that a purely technological approach is likely to lead to the criticisms aimed at FGKM approaches, thus highlighting the need for human socialisation to be present. Consequently, the development of proposition 3 aims to test whether a socio-technical systems approach presents the ability to improve the extent to which tacit knowledge can be shared (see Section 4.6.2).

Further weaknesses of current practice were incorporated into other proposition testing such as that of the failure to capture and share knowledge live or as soon after its generation as possible. This pointed to the need to improve opportunities to conduct knowledge management activities live and during busy working schedules (i.e. proposition 2a: see Section 4.6.2). The over utilisation of text as a transfer format was identified as reducing tacit knowledge sharing and therefore the testing of proposition 2b aims to identify which formats of knowledge capture are best suited to transfer tacit knowledge (see Section 4.6.2).

Objective 3: To establish the potential and limitations of current feedback loops designed to improve design quality

This objective has been met by testing both propositions 1 and 2 (see Section 4.6.2) by investigating current practices designed to enable knowledge feedback and sharing across discipline divides. In investigating proposition 1, questions surrounding what current practices consist of; their positive and negative attributes and how they can be further improved were generated. Similarly, proposition 2 generated related questions designed to understand how buildability related information, knowledge and learning can be improved.

Objective 4: Evaluate which technologies/techniques are most effective to assist learning activities

The literature review highlighted that various KM techniques and technologies are available and that not one isolated technique or technology is suited to satisfying all contexts and all stages of the KM lifecycle. Therefore this objective is concerned with investigate which techniques and technologies are best suited to differing phases, whilst within the limitations and restrictions posed by the industry, projects, organisations and individuals. Accordingly, proposition 3 (see Section 4.6.2) has been developed directly from the interest in investigating this area further.

In addition, propositions 4 and 4a (see Section 4.6.2) satisfy this objective by targeting specific technologies that are designed to improve KM processes. For example, a significant deficiency in current KM processes is directed towards the lack of timely knowledge capture and sharing opportunities. Accordingly, the development of mobile technologies has been recognised as potentially assisting in overcoming these deficiencies.

Objective 5: To improve cross-organisational boundary learning within infrastructure projects

Although no one proposition directly meets this objective in isolation, all of the formulated propositions and the findings relating to their support or rejection are designed to satisfy this objective. For example, the investigation of current knowledge feedback procedures and socio-technical systems, a more well-founded KM feedback loop can be developed that enables cross-organisational learning. Accordingly, the development of each proposition is viewed as addressing vital components of the overall aim of this project.

5 Results

5.1 Introduction

This chapter presents the findings of the main research activities undertaken in this study in the form of three case studies.

As sequential case studies were determined as being beneficial (see Section 4.6.5), the findings of each impacts on the design of future cases (see Figure 5.2). The intentions of each stage and how they were carried out are discussed later in this section. This includes detailing how decisions or findings from preceding studies impact on the design considerations required for subsequent cases and therefore forms a narrative for Figure 5.2.

The findings of each case study have been documented individually (see Sections 5.2, 5.3 and 5.4). The only cross-case references made at this stage are in the form of forwarding emergent or adapting research propositions from one case to the preparation stage of the next.

Each case is documented thematically according to the case study protocol (see Appendix B.2), which was designed to test the research propositions that had been identified from preceding research activities. Brief references to how these findings relate to other independent studies are made in an effort to provide additional clarity; however, a full analysis and discussion of the resultant findings in relation to external studies is documented in the cross-case analysis (see Chapter 6). The coding and analysis of the data has been conducted in line with the process documented within the methodological chapter (see Section 4.6.4.3). The themes applied are:

- Establishment of the need for a knowledge feedback loop;
- Types of Reusable Buildability Knowledge;
- Current KM Procedures;
- Current Resources; and,
- Foreseen Difficulties and Coping Strategies.

These analytical themes along with the interest areas and the questions they provoke are illustrated in (see Figure 5.3).

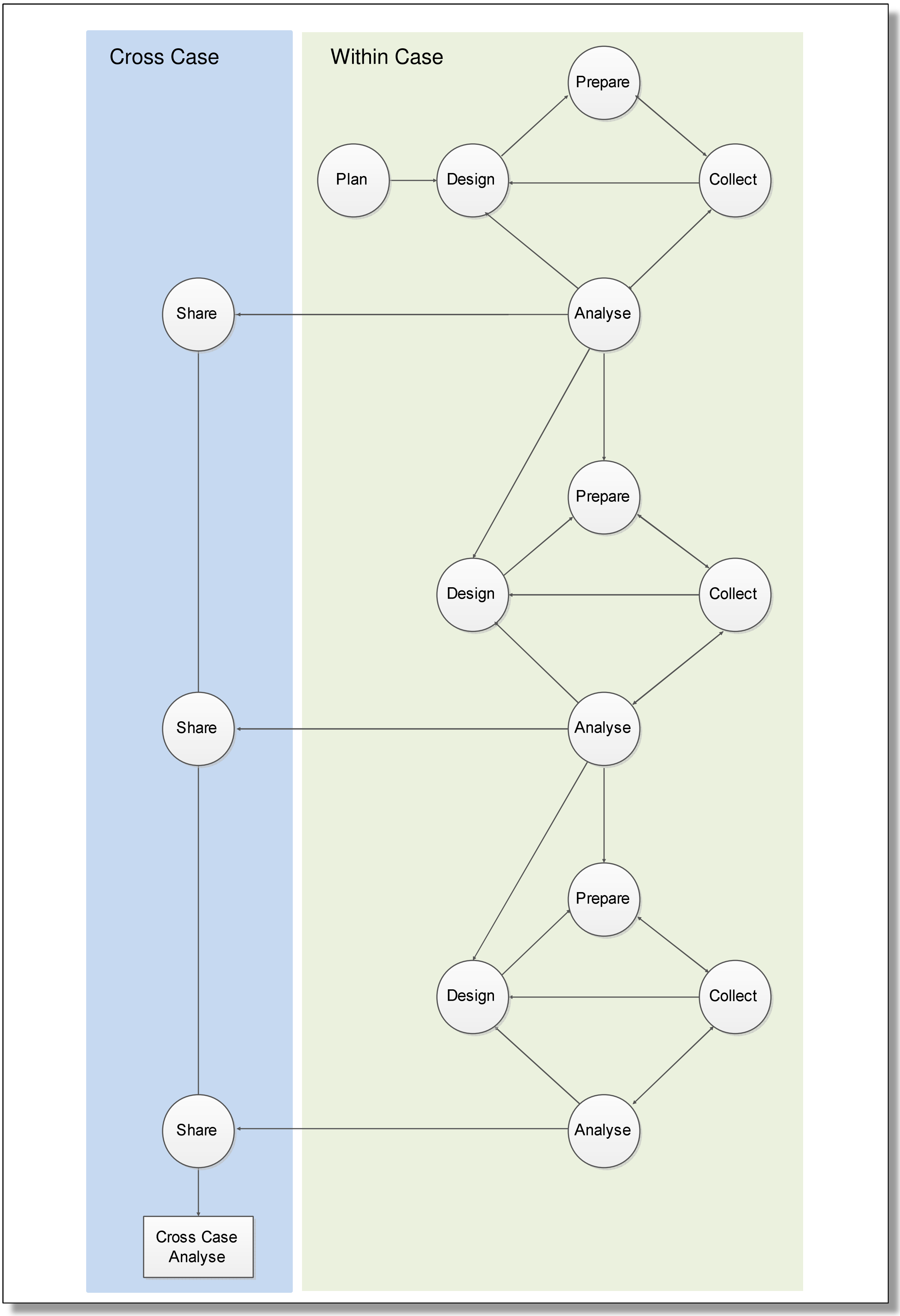


Figure 5.1: Sequential Case Study Iterative Process. Source: Adapted from Yin (2009)

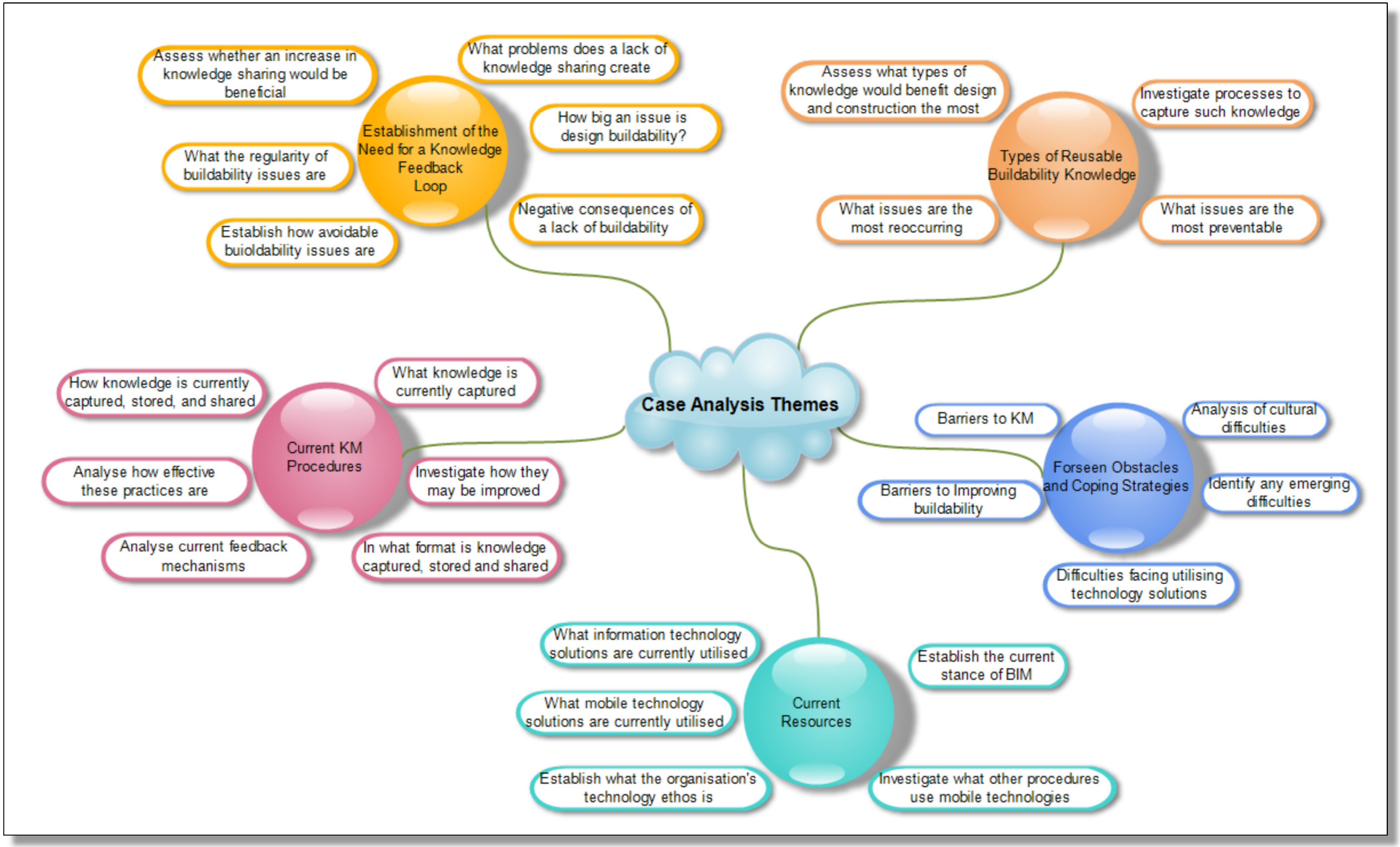


Figure 5.2: Case Study Analytical Themes and Questions Provoked

5.1.1 Case Study Analysis

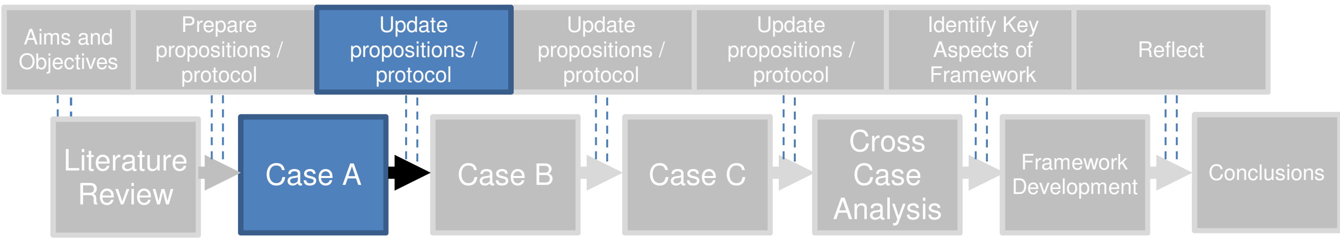
This section details how the mass quantity of qualitative data obtained was managed and consequently analysed. Each case study consisted of at least two verbal one-to-one interviews being conducted, background research to the case and supplementary evidence such as knowledge repository example being obtained.

To improve the responses obtained, a copy of the case study protocol (see Appendix B.2) was sent to each participant prior to their interview taking place. This allowed them to consider the key aspects surrounding each question in more detail than if they were delivered impromptu. The case study protocol was organised according to the previously discussed analytical themes (Figure 5.3), which aided the questions to naturally flow from one interest area to the next, which simultaneously aided managing the response data obtained.

Once the interviews had been conducted, they were fully transcribed individually. This enabled the identification of any gaps in the data, which enabled follow-on questions of interest to be put to the interviewee whilst the topics remained prevalent in their minds. The next stage of the analysis was to organise the data across sources so that it could be analysed as a whole. This was achieved by coding the data according to the question that it answered so that answers to the same questions could be compared. Further coding was necessary due to the nature of the semi-structured interview adopted (see Section 4.5.2), in which some answers crossed the boundaries of certain questions and topics and therefore had to be included in the analysis of multiple areas. This allowed a second revisit to the data sources if any further data gaps or the requirement for clarification was identified.

An analysis of any consensus or contentions between the primary data could then be established, with this then being compared to that established through the literature review (Chapters 2 and 3). The initial research aim and objectives (Chapter 1) led to the identification of key interest areas to examine within previous literature. In turn this led to identifying key research propositions (Chapter 4), which formed the basis for the case study protocol development (Appendix B.2). Through this a vast amount of qualitative data was generated and analysed (Chapters 5 and 6). This detailed and planned process therefore provided a high degree of rigour (Yin, 2009), which guarded against Eisenhardt's (1989) warning towards the difficulty of coping with a staggering amount of data that would inevitably be obtained.

Each case study analysis was then written in full prior to the subsequent case being conducted. Once more this followed the case study analysis themes of the case study protocol, which would benefit the managing of data obtained from further cases and their analysis. Once the full case study analysis had been documented and the levels of support or rejection had been established towards the research propositions, they could be accordingly adapted so that emerging themes (e.g. the requirement for high level managerial support) could be tested in the future cases. This also consisted of some changes needing to be made to the case study protocol so questions targeting testing the adapted/newly emerged propositions could be included. The key threads/links between the research aim and objectives, preceding literature, research propositions and primary research findings were therefore maintained throughout the entire process to assist in maintaining high levels of validity.



5.2 Case Study A

5.2.1 Characteristics of Case Study A

The characteristics of both the contracting organisation and the project making up this case are supplied below. An explanation of how such characteristics support its adoption as the representative initial case are given (see Table 5.1).

The characteristics determined that this organisation and project was able to offer the credentials necessary to be a representative case and therefore suitable to test the initial research propositions upon. This judgement was subsequently supported by those interviewed according to their experiences within the industry and the sector. For example, the Lead Architect (LA) described this project as *"average"* in terms of its size and its expected functionality on completion. The complexity of its delivery, concerning integrating the extension into an existing an operational hospital, was also suggested as being something that they do *"all of the time"*. This was echoed by the Construction Project Manager (CPM) who said that this project *"is not out of the norm; it has some innovative design features in terms of circulation, but in terms of delivery method it is about normal."*

Table 5.1: Case Study A Organisational and Project Characteristics

Organisational Characteristics:
One of the six Principle Supple Chain Partners (PSCPs) selected by the NHS (NHS, 2011);
A large player in healthcare infrastructure projects, with a presence predominantly in the UK but having delivered healthcare facilities worldwide also;
Delivered £500million worth of healthcare projects; mainly through the ProCure21 or the more recent ProCure21+ procurement frameworks;
A large organisation with revenue of £2billion and employ over 50,000 employees worldwide; They resemble a large multifunctional, multinational construction organisation; and,
They expressed an interest in this study; - Indicated that KM was an area in which they believed strongly in, but perhaps could improve upon; and, - The organisation therefore had mature or maturing KM practices to investigate in the form of Wiki type learning, intranet resources and learning forums.

Project Characteristics:
A £20million intensive care and children's ward department extension;
The hospital serves a population of approximately 300,000, with the average population served for local hospitals being 200-250,000 (Kagioglou and Tzortzopoulos, 2010);
Delivered through the P21+ framework and therefore representative of the most commonly adopted procurement and delivery methods for supplying healthcare facilities within the UK;
The facility itself is viewed as adopting innovative design aspects. These included adopting a different way of thinking in terms of how circulation can work and how departments can use central services or utility areas easily with very little travel. As such there may be a greater desire for lessons to be learnt from this innovative project to achieve the aim of continuous improvement; and,
The project delivery method was viewed as being fairly standard within the P21+ framework and therefore could enable generalisation to other projects adopting the same approach.

5.2.1.1 The Research Setting

This case consisted of four main data collection points; two in-depth interviews, an observation of a design team meeting (DTM) and the gathering of supplementary empirical material.

The two in-depth interviews both lasted approximately ninety minutes in length and were conducted with the CPM and the LA of this project. A further forty minute follow up interview was conducted with the CPM at a later date to clarify that the processes stipulated in the initial interview had been interpreted correctly or not. Each interview was conducted in person, recorded and transcribed prior to data analysis.

As noted by Georg and Tryggestad (2009), interviews are insufficient on their own and need to be supplemented with appropriate documentary material such as reports, memos, decision protocols, drawings, pictures, movies, press releases, and articles in local newspapers, magazines or the internet. This is to be able to fully appreciate the case being studied, which was developed through accessing published organisational reports, magazine and internet press releases and drawings. As the interviews were conducted at the project's site itself and in a site office, such communicative drawings and the physical building itself were viewable from this position. This allowed the interviewee and interviewer to relate certain questions to areas of the building to further clarify their points of view.

A particular data area of the study which required supplementary material to be analysed included the output of the KM system implemented. As such, examples of knowledge contributions were provided by the construction organisation under the stipulation that they were to be used to evaluate the format only, with the content of them not being published in anyway.

Finally, an observation of the design team meeting was undertaken. This was conducted with the researcher being present at the monthly meeting and all participants being aware of their presence and the reasons for their attendance in advance. This reassurance to the group was given from the CPM and acted to insure that the meeting was carried out in its usual form without the researcher impacting on its course. Present at the meeting was the CPM, two construction personnel, two M+E personnel, the LA, a junior architect and two client representatives.

5.2.1.2 Initial Research Propositions

Preceding research has led to vital research questions arise. As such research propositions concerning the expected outcomes of these questions have been formulated. The rationale supporting the basis of these propositions can be followed through the documented chain of evidence which is included in Appendix B.1. The research propositions to be tested within this case are as follows:

Proposition 1 - a feedback loop between the phases design and construction could improve the level of vital learning conducted within healthcare infrastructure projects

Proposition 2 – the capture and feedback of buildability instances to designers can improve design quality, reduce costs and time.

> **Proposition 2a –** the usefulness of the knowledge captured is improved the nearer to the learning event occurring the eventual capture takes place.
>
> **Proposition 2b –** vital tacit knowledge can be captured and fed back to designers if a variety of capture formats are utilised.

Proposition 3 – the overall KM approach should take the form of a socio-technical systems approach in preference of being purely technique or technology centred.

Proposition 4 – to meet the need for live capture of learning instances onsite mobile technologies can be utilised to assist

> **Proposition 4a** – BIM provides a potential platform for the proposed feedback loop

5.2.2 Establishing the Need for Buildability Feedback

A primary objective for this study (see Section 1.2) was to establish the need for improving knowledge flows between design and construction. Accordingly this section reports the data collection designed to test research propositions 1 and 2 in particular (see Section 5.3.1.2).

5.2.2.1 Negative Effects of Buildability Issues

The main negative effects of buildability issues were that of the need for design rework and therefore schedule slippage. This was attributed to the CPM's high level of experience and extensive knowledge base allowing the majority of buildability issues to be identified prior to them being built. However, in the instances of an issue not being identified early enough for that component to be redesigned, reduced levels of end quality and/or delays resulted. For example, the use of an innovative cladding material which had not previously been utilised by the design or construction team was a solution that was thought to lower the overall cost of the facility. Due to uncertainties with how the product would react, it was not discovered until too late that the steel frame was not appropriately set out for its use. Therefore, a delay was encountered whilst an alternative solution was sourced. However, to preserve the desired end quality of the facility, it was decided that the steel framing should be dismantled and re-erected resulting in a significant schedule slippage and cost implications which had to be absorbed.

This is a negative effect of buildability issues which is viewed as avoidable through improved KM. For example, if this newly discovered knowledge was captured and communicated to other personnel within the organisations involved, the opportunity for the same mistakes to be repeated would undoubtedly be lessoned. For this to be the case KM procedures need to facilitate locating knowledge sources more effectively than currently is the case.

An additional negative consequence not previously identified was that of the possibility for *heightened levels of conflict* between the design and construction parties. This was recognised as emerging as a direct result of the need to undertake design rework, thus increasing the possibility that individual teams' objectives and desires are less fully met than originally anticipated. For example, if a detail was preferential to the design of a facility from a design team's perspective, it was observed that its aesthetic appearance is unlikely to be a strong enough argument for its implementation if it was difficult to construct. For instance, within a healthcare context, for curves to be incorporated in a design it would depend upon a case being made for the functionality benefits it would offer; such as if it was easier to clean or whether it presented heightened medical advantages. This would ultimately be determined on the extent of the evidence base regarding the effects of curved walls within hospital design. Its greater aesthetic appeal is unlikely to outweigh the buildability issues surrounding constructing curved walls. Therefore this could lead to disputes if the design team's objectives become less fully satisfied.

This scenario was observed during the DTM where a disagreement concerning a suspended light fixing arose. Due to a preceding design change concerning the positioning of a staircase, a high ceiling light fitting was no longer accessible. The design team proposed that the light fitting could be set within a frame which could be lowered using a winch system. This would maintain the aesthetic appeal of the original design. However, due to the increased construction complexity and cost involved in constructing a frame and winch system, this was rejected. Instead the construction team proposed that the client was supplied with a portable elevation tower which is collapsible for storage, but could be erected on demand when the light fitting needed to be changed and/or inspected. This proposal was ultimately selected as it resulted in a reduced cost and more efficient solution.

This finding aligns with a previously pronounced intention of this research (see Section 2.7.2.4) which reads:

> *To not oversimplify or standardise healthcare facilities so that the overall effectiveness of the facility in use is reduced, but alternatively, to supplement the information generated as a result of evidence based design research and POEs.*

In achieving this objective, it is evident that although client and contractor needs may be met, those of the design team are less likely to be fully satisfied. This presents the opportunity for disharmony due to each phase having varying end goals, which is the result of the difference between a production and a service viewpoint. This was highlighted by the lead architect by stating, "*design is a service that is sold whether an end physical product is produced or not, whereas construction organisations see their product as being the building itself.*"

It is apparent that the desire and efforts to improve buildability on the part of contractors, through seeking an industry-wide change towards "*the standardisation of methods that work, rather than reinventing the wheel each time"* (CPM), are at present experiencing degrees of resistance. This is due to it being perceived as restricting a designer's creativity (Moore, 1993). However, a contradicting premise was voiced by the lead architect, who stated that as a practise they actively seek out details that have worked well, according to post project evaluations (PPEs). These details then get published within their offices in the desire to become standard details on future jobs. Accordingly inconsistencies regarding the desires of the design team have been identified. On one hand over standardisation and simplification of designs are resisted, thus leading to *heightened levels of conflict*; whereas on the other standardisation of details is welcomed.

This finding indicates that efforts to embrace the requirements and challenges of becoming evidence-based designers, as set out by Hamilton (2003) and Mcculloch (2010) (see Section 3.2.4.2) are both being made and resisted at the same time, and by the same personnel. Therefore it is not as clear cut as being an 'evidence based designer' or not, but is in fact extremely subjective. Ultimately it depends on each individual item and the degree to which it influences the achievement of the overall project's goals, and/or their discipline's goals and objectives.

5.2.2.2 Regularity of Buildability Issues

This section identifies how often the preceding negative effects of buildability issues are experienced. As a result, a fuller evaluation of the impact of buildability issues can be made, which in turn enables the need for improved buildability feedback to be more accurately established.

This case showed that buildability issues are a daily problem due to having to manage the expectations of those involved. For example, site personnel have different end goals, ways of working and means to present information to that of design teams. Therefore, the difficulty to overcome them on a daily basis revolves around generating an understanding of each other's needs and wants. This perspective was unanimously voiced by the design and construction phase representatives within this case, with the design representative stating that:

> *"Some contractors are merely there to deliver the building and they really do not care about the design. So where the construction team and the design team come from are two different things"* (Lead Architect).

Similarly, the CPM believes that having to generate an "*understanding of each other's objectives, critical factors and beliefs of what the client wants"* is the biggest contributor to buildability issues. Therefore, in the early stages of a project it was adjudged that buildability issues caused greater problems due to there being less understanding of each other's needs. As time progresses and relationships are nurtured, these become less apparent and also easier to resolve amicably. Consequently, the level of understanding and cooperation between the parties is viewed as directly impacting upon the number of buildability issues. This judgement is discussed further later in Section 5.3.6.1. A graphical representation of these findings is shown in Figure 5.4.

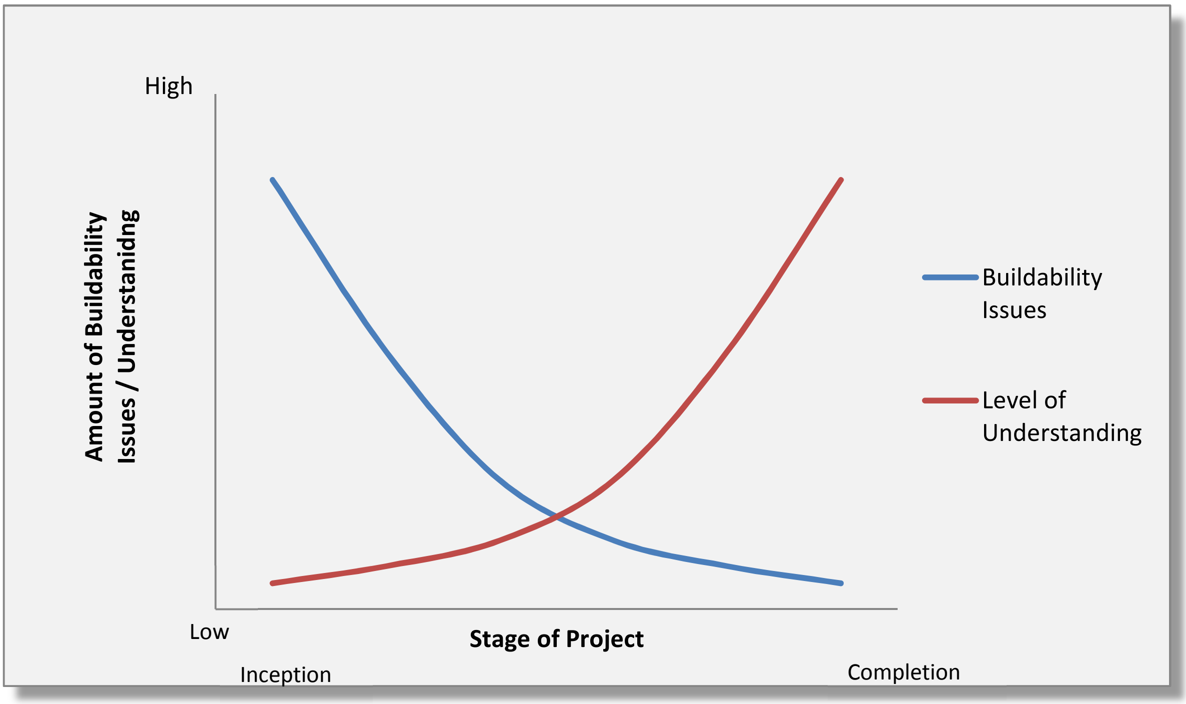


Figure 5.3: Relationship Between the Level of Understanding Between Design and Construction and its Subsequent Impact on the Amount of Buildability Issues Experienced

5.2.2.3 Reoccurrence of Avoidable Buildability Issues

By investigating the levels of experiencing reoccurrences of previous issues, it is possible to determine the extent to which the same issues are reoccurring time and again, or it is the emergence of new issues that are causing the problem. This will enable the extent to which issues are avoidable to be established.

Even though it was believed that currently adopted processes such as DTMs enable 90-95% of buildability issues to be identified and alleviated prior to them being discovered onsite, repetitive buildability issues were noted. The CPM stated that designers select details that they have utilised on other projects, but due to them not seeing the detail being built, they are unaware of the construction difficulties they cause. This indicates that the reoccurrence of such issues could be reduced as a result of feedback of appropriate knowledge. Thus the strengthening of research proposition 1 (see Section 5.3.1.2) has been noted.

The high detection and avoidance rate of issues was attributed to the significant levels of experience of the site team and in particular, the CPM. However, in the cases of less experienced site teams, failure to identify issues as early is thought to be much greater. For instance, the site manager stated:

> *"It is about having a certain level of knowledge and conveying that information to designers, but my issue comes when you have younger site managers /*

project managers trying to do that. They will probably jump into the same holes we did some years ago. So what have we learnt really?"

The changing trend in the entry routes into the industry, in terms of how individuals gain the experience and/or qualifications to gain employment, were highlighted as exasperating this current problem further. The tendency to pursue a degree at University is resulting in individuals seeking project management roles having been exposed to less time onsite and therefore less opportunity to generate their own pool of knowledge and experience. Similarly, the CPM felt that designers were also disadvantaged from reduced levels of onsite experience due to more time being spent utilising computer aided design methods.

Repetitive buildability issues are therefore evidently occurring unnecessarily, with the degree to which they affect the overall project ultimately depending on the experience of the team members involved. This indicates towards the need to adopt a more open knowledge sharing culture between the differing parties. On the design side this would improve the degree to which construction based knowledge can be gained and therefore integrated into future designs without the need for increased levels of physical involvement onsite. This is beneficial due to increased physical involvement being a near impossibility due to the significant time and cost restraints that it would entail (see Section 2.7.2).

From a construction perspective, these findings have demonstrated that a more open flow of knowledge between the parties would enable an earlier understanding of each other's needs, as well as improved levels of construction knowledge being integrated early on within designs. This demonstrates substantial support for research proposition 1 (see Section 5.3.1.2) as it is apparent that there is a common belief that feedback can lead to improved levels of learning.

5.2.3 Types of Valuable Buildability Knowledge

The differing factors to affect buildability were not only discovered to be viewed as affecting buildability to varying degrees, but also the categorisation of factors differed substantially across authors (see Section 3.2.2). Accordingly this section explores which factors are viewed as the most avoidable if the concerning knowledge can be shared.

The above unearthing of the ill-defined boundaries between areas for standardisation and those of design creativity (see Section 5.3.2.1) complicate this matter. This is due to the difficulty in defining which components of healthcare facilities should be standardised to build upon lessons learnt and prevent the unnecessary reinvention of the wheel. For example, the LA specified that *"depending on who you work with, buildability gets expressed in different* *ways, with it being rather subjective and often coming down to personal preference, even within the same firm".* The building in this case was built on steel framework with prefabricated elements bolted together, which was seen as an effective way of building as it got the shell around it much faster than traditional brickwork. However, the architect continued to state that they had "*worked on other jobs in which this method was suggested but it was not adopted due to the builder's personal preference."*

The difficulty in reaching a consensus regarding the factors of buildability (see Section 3.2.2) can be attributed to the degree of subjectivity surrounding the subject. As such, the greatest difficulty in generating an effective understanding of each party's individualistic needs is related to the change in project teams from one project to the next. In fact, it was specified as being the biggest single difficulty. For example, due to the time period that the current construction and design teams have worked together (approximately three years), it was apparent that they have developed a good relationship and understanding of each other's needs and wants. By breaking up the team at the end of a project, this understanding is immediately lost. It will then ultimately take many months to redevelop this understanding on the next project. As such, the strength of this assertion for the need and benefits of attempting to keep the core team members together was substantial; with the CPM specifying that it is *"the biggest single thing"* that would improve the situation.

These findings align with the opinions of numerous authors who bring attention to the negative effects temporary project teams can have on attaining on-going learning (see Section 2.7). As such these viewpoints have elucidated how the barriers of *fragmentation between phases* and *temporary project partnerships* may be overcome, through ensuring that an understanding of each other's needs and wants is generated. However, to overcome the inevitable subjectivity and individuality, this understanding is viewed as best being created through the utilisation of recurring project teams. Accordingly, this desire is discussed further later in this analysis (see Section 5.3.6.1).

This being said, an area in which there is a real mutual desire for greater standardisation and the feedback of knowledge is that of reducing the variation of details used. The designers within this case are actively seeking to formulate a dynamic list of details to become standard practise companywide. They also believe that if previous examples and evaluations of utilising details were captured it would enlighten future contractors of their actual buildability. Similarly, the construction side demonstrated the desire for such issues to be captured and shared. This is to:

- Reduce the reoccurrence of past failures, thus lessoning the need for design rework (if detected) or avoidable problems (if undetected); and,
- Reduce the variation of details and solutions (i.e. the reinvention of the wheel).

This signifies that not only would feedback of knowledge from construction personnel to designers be beneficial, but in the opposite direction also. Therefore, taking into account Fischer and Tatum's (1997) five categories of buildability knowledge (see Section 3.2.2: Figure 3.4), *detailing knowledge* appears to be the most desirable to be transferred.

The CPM continued by expressing a concern with the industry wide lack of information sharing concerning the variety of details used. This stretched further than the need for heightened integration between design and construction, to also include the manufacturers and suppliers of materials. It was suggested that they could do more to enable informed decisions being made regarding the utilisation of their products. This was substantiated by suggesting that the construction industry is far behind that of other industries in conducting case studies of the usage and potential of the products that they supply. This implies that the need to share knowledge extends further than the immediate project boundaries but to suppliers also.

5.2.4 Current Knowledge Management Procedures

This section aims to establish current processes adopted to capture lessons learnt. The types of knowledge and lessons that are currently captured are then discussed. The main techniques and technologies utilised to support KM processes are also identified so that an analysis of both '*how*' and '*what*' is captured can be undertaken.

5.2.4.1 Methods Utilised to Capture Lessons learnt

PPE

The majority of lessons learnt from both the construction and design sides are captured at the end of the project through a review process known as the post project evaluation (PPE). This is mainly due to the lack of time during the project itself and therefore only once the project is completed is there time to reflect. The CPM stated that *"in terms of any formal lessons learnt, there just is not enough time really".* During the project this is in terms of personnel being occupied with other tasks, or once the project has been completed, the need to move employees onto the ensuing projects.

The only on-going capture of lessons learnt surrounds their key performance indicators (KPIs), which concentrate on issues such as stakeholder relationships, design team performance and health and safety (see Section 5.3.4.2). However, technical issues and knowledge surrounding them (i.e. buildability issues) are not captured throughout the project. The PPE also predominantly focuses on the above issues; however, the LA indicated that buildability is covered to some extent within this review, but is not the most pressing concern. The lack of on-going capture was seen as leading to the self-confessed loss of knowledge due to the time lapse between the event occurring and it being captured, with the CPM declaring that:

> *"People have small memories, so with me being here for three years, there will be a lot of things that happened in the first and second year that will never be remembered. This is because you only remember the biggest or most recent things and the littler things get forgotten along the way".*

A further reason proposed for failing to conduct such practises was given by the CPM. He stated that their organisation used to conduct P21 monthly meetings where all of the P21 teams within a region would meet to discuss lessons learnt from their respective projects. These were viewed as being "*great",* especially for disseminating lessons effectively across projects. However, due to time demands, these have become much less frequent and have instead been replaced by meetings at a higher management level which mainly concentrate on strategic issues. Therefore, the *"nitty-gritty surrounding designing a building and putting it together first time around"* is being lost because it is not being shared. For this to become reality it was said to need to *"originate from a more local level, instigated by senior management"* (CPM).

This signifies towards senior construction management within this case not fully appreciating the benefits of on-going KM and continuous learning, or if they do, they are outweighed by short-term project goals. In comparison, the benefits appear to be understood on the part of the CPM who actively advocates the need to introduce knowledge sharing discussions once more. In fact, this desire indicates that the investment of their limited and strained time is outweighed by the benefits to be gained. These views are shown through the opinion that:

> *"I think people need to talk more between teams and lessons learnt would go a lot further" [but] "some influence from higher management would benefit to instigate or lead these sessions so that they could be forced through" (CPM).*

Alternatively, the organisational benefits of capturing and disseminating lessons learnt appear to be more widely understood from a design perspective. This is due to greater efforts being made towards capturing lessons learnt arising through the PPEs and buildability specific lessons obtained through DTMs. These are taken and then organisational discussions are conducted to attempt to disseminate them and standardise best practice within their firm.

Accordingly, this analysis has indicated that for time and effort to be allocated to capturing lessons learnt throughout a project, senior level management must realise its benefits. This leads to a top-down approach to ensure that there is sufficient opportunity to take part in knowledge sharing discussions. Somewhat surprisingly, this is likely to be welcomed by project level personnel rather than resisted. Consequently, a further research proposition has become apparent in the form of:

> **Proposition 6** – a heightened priority given to lessons learnt from top level management would lead to more time and effort being allocated to the on-going activity throughout the project.

Case Writing

The current KMS is concentrated on extracting historical experience related knowledge from proficient employees at project management (PM) level or higher, in an attempt to protect against the occurrence of knowledge loss (see Section 2.5.4). This is conducted through a process of brainstorming regarding a certain topic. For instance, a PM is empowered to concentrate on a certain topic such as structures. Other PMs will therefore look at other matters, each noting down their experience regarding that topic. Through a group brainstorming session, others will then contribute their knowledge and opinions to extract the key points. A document detailing the main issues for an inexperienced employee to look out for is therefore produced. This intranet KM process is illustrated in Figure 5.7 (see Section 5.3.4.4).

This is viewed as a possible way to fill the aforementioned knowledge void arising due to the changes in entry paths into the industry (see Section 5.3.4.3: Mentoring/Training). At the same time it is also a potential method to replace one-to-one mentoring, which is resource intensive and now possibly less appropriate due to the changing entry paths (see Section 5.3.4.3: Mentoring/Training). This is due to the intranet enabling online access to stored knowledge and therefore enables knowledge to be shared without having to be in the physical presence of, or somehow contact its originator.

This is viewed as an improvement compared to past attempts to store similar historical knowledge in physical documents housed in filing cabinets due to the extreme difficulty in locating the original document, the potential for damage or destruction of the document and the inability for more than one employee to access the document at any one time. This being said, both methods are viewed as being more closely aligned with the management of explicit knowledge. This is due to the failure to provide means for users to locate and interact with others so that dialogue, reflection, and perspective making can occur.

5.2.4.2 Types of Issues Currently Captured as Lessons Learnt

It is essential to identify what types of issues are currently captured as lessons learnt as well as establishing why they are viewed as important learning opportunities. This enables an assessment to be made on whether buildability related goals are viewed as important learning opportunities or not, the reasons for the discovered scenario and therefore means for improvement.

As cited in the preceding section (see Section 5.3.4.1), the types of issues currently captured as lessons learnt predominantly cover a variety of matters which resemble the project's KPI model. This is evidently limited to those that are necessary to satisfy the needs and wants of the client, as well as what is expected of contractors by law and socially. As such, the metrics which assess the level of success an organisation or a project has achieved are aimed at measuring among other things, environmental factors such as relationships with stakeholders, social responsibility and client satisfaction, with very little regard towards technical issues.

Metrics become benchmarks to which comparisons can be made between projects and likewise between varying contractors as they are widely understood within the industry. These issues therefore dominate the learning objectives of the individual organisations involved as they aim to continuously improve in the areas in which they will ultimately be adjudged. As a result, learning activities such as reflection and adaptation are evident in these areas. This is shown through matters such as how well each party has worked with others and how they can improve performance in future projects being reflected upon at the end of projects. However, buildability issues are not seeing as a high a priority on such an agenda and therefore the double-loop learning process required to continuously improve is being neglected.

The difficulty of applying a metric to buildability issues throughout a project, as well as the problem of measuring how they have transpired into organisational improvements is evidently impacting the realisation of the need to improve in this area. This is due to it being very difficult to evaluate the positive effect that efforts and expenditure are having. Therefore, if an organisation cannot be evaluated upon their effectiveness in a particular area, it has been discovered that they will prioritise their efforts to those areas in which they can be appraised. Consequently this finding deviates marginally from that of the viewpoint of

Davenport *et al* (1998) who believe that senior executives will only allocate the necessary resources to KM practices where economic benefits are evident.

This once more points towards the need for clients and/or top level management to recognise the need to continuously improve and enforce learning goals upon contractors (Tan *et al.*, 2011). This viewpoint was tested in a follow up interview with the CPM through asking what affect the introduction of a form of measurement would have on the priority given to capturing buildability related lessons learnt. This form of measurement would surround how well knowledge/lessons learnt were captured and managed within a project. This measure was found as likely to lead to more time being attributed to the activity and therefore demonstrates further support for the developed additional research proposition 5 (see Section 5.3.4.1). It also signifies that Keegan and Turner's (2001) suggestion of empowering project managers to articulate learning objectives at the project's outset is unlikely to lead to the necessary improvements in this area. This is due to evidence indicating that project managers will prioritise the learning objectives that they are ultimately going to be appraised upon.

Furthermore, it was discovered that although knowledge/learning objectives were set at the outset of each project, it was only to the extent of dictating which benchmarks were important to reach. This means that the rationale behind why such benchmarks are of importance are not well communicated. For example, it was stated by the CPM that although his/her level of experience meant that the need to conduct lessons learnt in these areas was understood, they were *"not sure if this statement would be true for younger professionals".* For learning objectives to be supported it appears crucial that firstly they are fully understood. Therefore, a fundamental improvement in this area is that of implementing buildability related knowledge objectives from the top-down. However, this movement on its own will reap limited benefits due to the importance of supporting it with effective communication regarding the rationale surrounding why they are important and the benefits that they entail.

5.2.4.3 Supportive KM Techniques Utilised

This section highlights the main KM techniques utilised within this case to support the phases of the KM lifecycle (see Section 2.5).

<u>Framework Collaboration</u>

The main technique used is a collaborative technique known as frameworking (see Section 2.8.2), which is a form of partnering that is naturally installed due to this project being constructed under the healthcare initiative of a P21 framework.

It was distinctly obvious through the act of observing the DTM, discussions of problems collaboratively, improvements and innovative solutions could be developed. This was the case when devising a solution to overcome the problem of the inaccessible light fitting (see Section 5.3.2.1).

In addition, the P21 framework, where contractors are involved right from the start of the project (before a design team has been allocated in most cases), further improved the performance of the overall project. This was demonstrated by the lead architect who stated that:

> *"The advantage of the P21 framework is that it becomes like a design and build contract where the contractor leads the process, so for the client there is only one port of contact required instead of managing the design and construction teams separately. Then the contractor will divulge any problems down to designers, so they are effectively the employer."*

Being involved in the project right from the beginning enables the contractor to integrate construction input much earlier on, preventing the need for design rework to improve buildability. This is in line with Latham's (1994) assertion that such early integration is required if the industry's efficiency and performance is going to improve. A further advantageous facet of this was also noted in enabling a significant barrier to the effectiveness of partnering to be lessened. This was in the form of the requirement to nurture an effective relationship between parties so that learning can be transferred between organisations. In traditional delivery methods where the contractor becomes involved much later on in the process, the time available to nurture relationships is drastically reduced. The time it takes to develop effective relationships is demonstrated through the following responses:

> *"We have been working together for a couple of years together now, so as you can see there is a dynamic that works within the team but that takes a while to achieve" (CPM; and,*
>
> *"It is hard to see from today, but if you were sat here at the start of the project, compared to now the learning curve is massive. We now know each other's skill sets, what we expect from each other, what we can do and that is why it is much slicker now, but in the early days it was not" (CPM).*

Areas in which this collaborative technique did not lead to automatic benefits were also identified. These included that of disseminating learning to the wider population of the organisation (see Sections: 5.3.4.3: Communities of Practice and 5.3.4.4: Intranet) and the problem of repeatedly having to nurture relationships at the start of each new project (see Section 5.3.6).

Post Project Evaluations and Lessons Learnt

PPEs were identified as the single most used method to reflect upon project outcomes, and therefore identify the main lessons to be learnt. Consequently this case is viewed as suffering the two main drawbacks of this method. These are; buildability related lessons learnt being restricted to the construction phase only; and, the opportunity for knowledge loss/deterioration due to the point of reflection and capture being deferred to a later point in time (Tan *et al.*, 2011). The implications of the latter have been discussed previously (see Section 5.3.4.1) and therefore this section continues to analyse the effects of not transferring knowledge effectively across organisational boundaries.

The PPE is conducted at the end of the project, and consists of design and construction representatives being present. Some disparity was observed between the two parties to the extent to which buildability featured in such reviews. From a construction perspective, this review reflects upon the relationship effectiveness between the parties, with a more in-depth internal construction-based review (including buildability issues) being conducted separately. This demonstrates the above premonition, that buildability related lessons are predominantly isolated to construction personnel only. Therefore, as identified in section 2.8.5.1 the danger of lessons learnt not being transferred effectively between phases is apparent.

The LA however, suggests that buildability is covered within such meetings; but, it is not given the same attention or importance as relationship issues. This was suggested by the CPM as being due to the KPIs of the industry as a whole and *"the reality of where the industry is heading"* in terms of *"concentrating too much on political stuff before we get into what or how we can do it."* This implies that a disproportionate amount of emphasis is being given towards attaining ethical goals such as sustainability and stakeholder satisfaction, compared to that of quality and efficiency. This is thus harnessing the degree to which the quality of the output provided by the industry is continuous improved. This is further indication that if continuous improvement of the efficiency, effectiveness and quality of the industry is to be achieved, a greater level of importance must be allocated to the capture, sharing and reuse of lessons from previous projects. This further supports propositions 1 and 2 (see section 5.2.1.2), as well as the newly developed proposition 7 (see Section 5.3.4.1).

Until this heightened priority is instigated, the chances of attaining the efficiency improvements outlined by Latham (1994), Egan (1998) and more recently by Wolstenholme (2009) appear slim. This is because at present; the knowledge being fed back to designers is extremely limited and primarily consists of three methods, depending on the phase the project is in. These are illustrated in Table 5.2.

Table 5.2: Limited Nature of Design-Construction Feedback

Project Stage	Method of Feedback
Design	That achieved through natural integration between design and construction.
Construction	Discussions regarding design changes, issues and problems deliberated at DTMs.
Occupancy	Lessons learnt identified during PPE's (generally consisting of relationship improvement measure etc.).

As a result, critical knowledge surrounding specific successes or problems that have been overcome without the need for design rework is not being fed back. For instance, in many cases aspects of the design will be constructed effectively, either in terms of it being right first time (i.e. a design success), or the construction team being able to overcome a problem without the need for design rework. In such cases no discussions will be had between the parties as in neither circumstance has it been to the detriment of the project. Therefore knowledge surrounding how this aspect may have been improved further is unlikely to be transferred. This may form a closeout lesson learnt for the construction personnel, arising from their internal review. However, such vital improvements are not being transferred across organisational divides and hence the opportunity for continuous improvement is being lost (see Figure 5.6).

This can be due to a similar barrier to the one noted as causing clients to be reluctant to lead learning initiatives (see Sections 2.7.2.2 and 5.3.4.1). In this instance, because the transfer of knowledge to designers is at the end of a project, it is unlikely to benefit the construction organisation in question unless they repetitively work with the same design team. Therefore the added investment in time and resources, although potentially benefitting the industry, does not occur due to the lack of direct benefits to the organisation making the investment. However, by altering by conducting reviews and lesson learnt capture procedures throughout the duration of a project, the perception of assisting a potential competitor is reduced. This is due to the current project being the focus of participants' minds and therefore efforts made towards lessons learnt are more likely to be viewed as contributing to the project in hand.

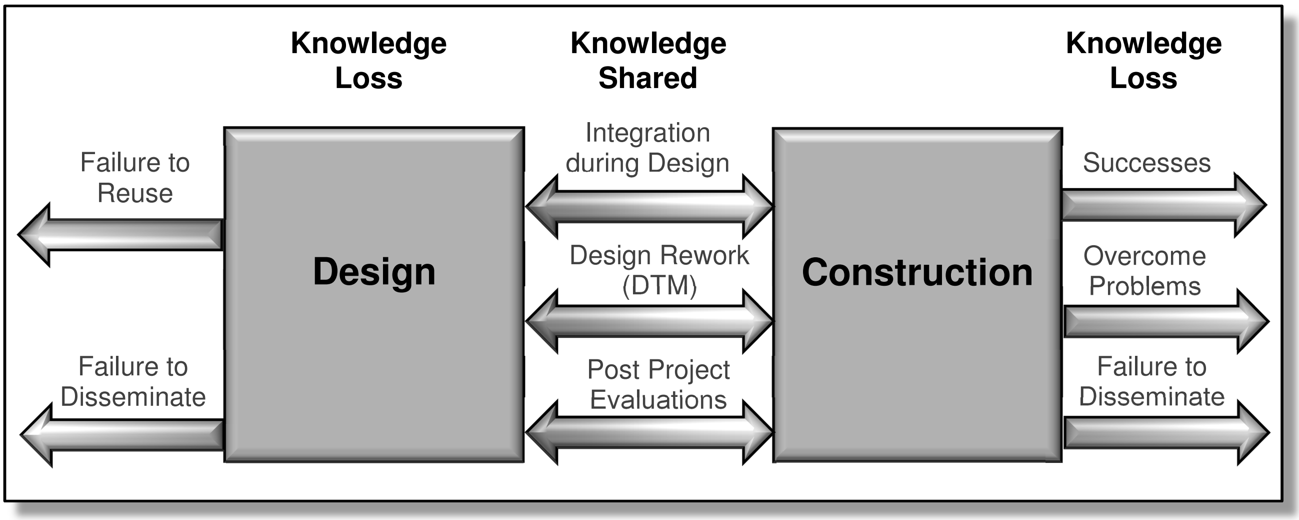


Figure 5.5: Cross Phase Sharing Within Case Study A

Debriefing

Debriefing is viewed as a means to transfer lessons learnt to others within the wider organisation than those present within the project itself or its project review (see Section 2.8.5.3). As previously discussed (see Section 5.3.4.1), this technique is being utilised to a far greater extent within the design organisation than was apparent within the contracting organisation. This was shown through taking the DTM minutes and discussing them with the wider organisation, with the aim to produce a continuously evolving companywide list of standards and best practice.

Alternatively, the construction organisation disseminates knowledge through their online intranet KM system and CoPs. This is due to these methods being more complementary to the much larger size of the construction organisation compared with the architectural company. However, as discussed later (see Sections 5.3.4.3 and 5.3.4.4) none of these are being utilised effectively or regularly enough. Consequently, each project has become an island of knowledge with very little transferring of lessons between them. This was demonstrated through the CPM's view that:

> *"What you find is that we tend to live in little silos in construction and we are kind of little teams and that means we do not share as well as we should do. If there was some sort of cross pollination then it would help."*

A direct consequence of this is the on-going unnecessary reinvention of the wheel. For example, within this case there were issues regarding constructing continued pile walls and putting a radial membrane on them whilst still in-keeping with what they were trying to achieve. The CPM is certain that this problem had been encountered and overcome multiple times; however, due to there being no effective ways of identifying internal or external sources of knowledge they were forced to come up with yet another solution to the problem.

Communities of Practice

CoPs used to be utilised by the construction organisation on a monthly basis, where every P21 team in a region would meet up and discuss lessons learnt (see Section 5.3.4.1). These were described as *"fantastic"* and the *"best form"* for knowledge sharing; however, due to time and cost restraints these have become much less frequent. In their place, a more senior level CoP has been initiated. These are not only seen as being less effective for project level lessons learnt due to them predominantly concentrating on more strategic issues rather than technical improvements, but also because any lessons that are learnt as a result are disseminated through a form of published minutes.

An alternative form of a CoP being utilised is a Wiki type learning space where employees can post issues that they have, with others assisting in answering them. As discussed further later on in this analysis (see Section 5.3.4.4: Intranet), the low levels of participation are resulting in this form of CoP being viewed as ineffective. This is because, in the time between posting an issue on the Wiki space and receiving constructive answers, the issue has either already been resolved or more than likely a reinvention of the wheel has occurred.

As such, it is clear that although it is much more resource intensive, the ensuing knowledge transfer that results from communities of practice incorporating live two-way communication is greater than that from inert forms. To further improve the value of such a technique it is also evident that effective debriefing needs to be conducted in accordance with such a session. Alternatively the knowledge shared remains within the heads of the privileged few who attended the original session.

Mentoring / Training

As highlighted in Section 2.8.6.2, mentoring and training was viewed as an extremely effective method of transferring experience and knowledge from one individual to another and thus preventing knowledge loss. This was viewed particularly in the scenario of succession planning where older members of an organisation mentor younger members who will naturally succeed them in the future.

For example, the CPM stated that *"If you were going to build your façade out of block work or brickwork then you would probably go for a bit of work experience on site and see it being* *done and then you take that knowledge to your next project."* However, the CPM also continued by suggesting that this form of knowledge transfer, although sincerely powerful in the past, is not as commonplace as it once was. This was attributed to the growing trend of those pursuing a career in the construction industry attending university and therefore entering the industry at a later stage of life. This was demonstrated through the view that:

> *"What we have found over the years within the industry, is that the practical knowledge from the younger guys is not there anymore as they are not from trades backgrounds, but they are from university and they have not seen as much construction." [Therefore, whereas they used to seek work experience opportunities, nowadays] "They do not have the access to that exposure that we were able to do when we were younger and that is causing a big void with what our younger staff are capable of doing" (CPM).*

As a result, this discovery signifies that there is a greater need for alternative KM mechanisms now and going forward than there has been in the past. Alternatively, the ability to limit buildability issues through experience, which is currently being attempted, will become a much less realistic achievement. Consequently, buildability issues could in fact become an even greater problem in the future.

<u>Reassignment of Employees</u>

Although previously identified as not satisfying this study's research objectives, due to it involving the redeployment of individuals to similar roles and therefore not facilitating design-construction knowledge transfer (see Section 2.8.6.3), this method was still viewed as one of the most common forms of knowledge sharing within the industry. This is due to its project nature resulting in the natural redeployment of individuals once projects have been completed.

However, the extent to which this is beneficial to the organisation must be questioned as it is not as straight forward as any knowledge sharing is beneficial. For instance, the breaking up of project teams was viewed by the CPM as being detrimental to the continual learning capabilities of them. As such, the knowledge transfer benefits of redeploying employees was seen as being drastically outweighed by the potential ability to learn through maintaining the same core team repeatedly. Consequently, this ambiguity is discussed further later in this chapter (see Section 5.3.6.1).

5.2.4.4 Supportive KM Technologies Utilised

Intranet

The construction organisation within this case utilises an intranet to support their KMS. This was said as being in an embryonic state with:

- The content stored not being expansive;
- The means to categorise the content still being developed; and,
- The awareness of its availability needing to grow.

The content of this KMS has been identified as consisting of predominantly historic knowledge (see Section 5.3.4.1). The overall process to achieve this is illustrated in Figure 5.7.

This has been seen as being more closely aligned with the management of explicit knowledge rather than that of tacit knowledge (see Section 5.3.4.1: Case Writing). This was further confirmed through undertaking an analysis of actual contributions of knowledge to the system. Access to these examples was granted by the case study organisation under the stipulation that they were confidential and must not be published in any way. Through this analysis it was evident that the organisation's intranet KMS closely resembles what Koch (2003) describes as a store of information on various knowledge areas (see Section 2.9.2). These are said to include the capture of best practice and more mature 'explicit' information such as standards, guidelines, templates for formulas and other documents, which are viewed as being of less use (see Section 2.5.4). This could be a contributing reason for the overall KM system's slow uptake. For example, the CPM stated that they themselves *"do not use it at all as* [they] *do not think it is developed enough and that needs to change,"* with the format and the information captured being highlighted as areas for improvement. Accordingly, for an intranet based system to be effective, not only does it need to be efficient to use but the content and its presentation must be also suitable, which at present is not the case.

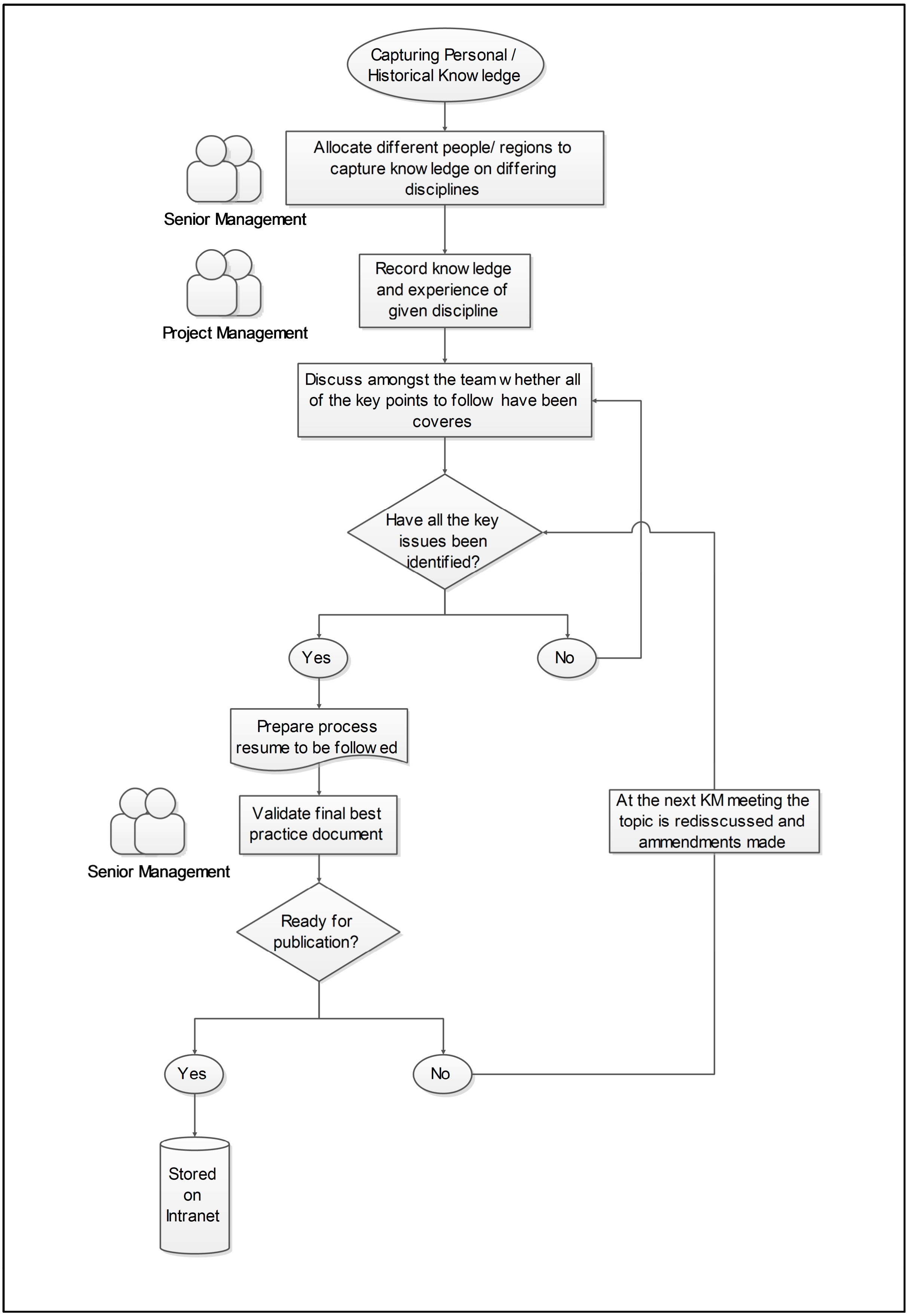


Figure 5.6: Case Study A's Intranet Based KM Process

Data-Mining

The information and knowledge stored within the KMS are referenced according to the Standard Method of Measurement Seventh Edition (SMM7) codes. These codes aim to provide a consistent method for measuring building works and good practice through providing detailed information, classification tables and supplementary rules separated into twenty two different sections (RICS, 1988).

Once stored within this structure, the KMS either performs searches or the user can drill down on certain sections to locate the knowledge they require. However, due to the SMM7 not being all inclusive, this was not viewed as always leading to the desired results. For example, the CPM stated that *"you will find that not every section is covered, so there will always be something that is not on there."* This in turn leads to one of three following courses of action being taken:

1. The need for a non-standard categorisation being developed to accommodate the new contribution;
2. The contribution to be filed under an existing but non ideal category, which could result in it being difficult to locate in future; or,
3. The contribution being deemed as not of a high enough importance to be saved on the system.

It was indicated that in most instances it is the third course of action that is taken due to *"trying to pick up the bigger subjects that affect the most projects, like frames and envelopes and hopefully somewhere along the line the smaller subjects will be dealt with"* (CPM). This is likely to result in a knowledge void occurring, which in turn leads to the perception of the KMS being incomplete *and "not developed enough"* (CPM).

The subsequent data mining of the stored knowledge is used to locate appropriate results (see Section 2.9.4). This is well suited to the current system as it has been highlighted that the knowledge captured is predominantly in text form. Therefore data mining tools are able to identify and match patterns of data (Egbu and Botterill, 2002) and return results which contain similar data. As computers are unable to understand text as humans do, this is viewed as potentially heightening the dissatisfaction levels of the knowledge identification process. For example, if knowledge regarding a topic as vague as doors was desired this is likely to return a high number of unrelated contributions which have the word door in them. This would lead to the user having to sift through the mass of results in an attempt to find the most appropriate.

Furthermore, with the contributions predominantly being in text format, the identification of the most appropriate results is also a lengthy undertaking due to having to read or scan part of each document to assess its suitability. As such, it is apparent that this process, although aiding the user to narrow down the amount of data available, is not without its limitations.

5.2.4.5 Format of Knowledge Capture / Storage

The influence that the format has on the overall quality of knowledge contributions within a KMS has been noted throughout this study (see Sections 2.2.4 and 2.8.6.1). Within this case it has previously been discussed how the format of contributions can adversely affect subsequent stages of the KM lifecycle and thus the satisfaction levels of the users (see Section 5.3.4.1, 5.3.4.3 and 5.3.4.4).

Text is also viewed as influencing preceding stages of the KM lifecycle to some extent also. For example, due to this case organisation's desire to use a fairly standardised template for the contributions of knowledge, it requires planning and organisation to insert the required information into the document in the first instance. As such, the desire to perform the capture of knowledge live and remotely out on site (see Section 2.5.4) is viewed as being highly unlikely utilising this process. It is more suited to returning to the site office before it is undertaken. As a result, the capture format is inadvertently affecting the capture process itself and potentially the knowledge transfer satisfaction levels eventually experienced (see Section 2.5.4).

Table 5.3 summarises the main advantages and disadvantages identified of using text as the predominant, and in most cases, the sole format for knowledge capture. Furthermore, the table also indicates the potential negative effects to be experienced. These resultant effects are seen as leading to heightening the levels of dissatisfaction towards the system, which may ultimately lead to it not being utilised.

These inadvertent knock on effects were evident within this case with the CPM displaying signs of disapproval with the format chosen. For example, it was desired that pictures, photographs and diagrams were used more often to *"make it concise and a shorter read"* as well as *"being more user friendly."* This, along with the previously identified desire to increase the number of physical discussion opportunities (see Sections 5.3.4.1 and 5.3.4.3: Communities of Practice), shows support for research proposition 2b (see Section 5.3.1.2). This extends to all knowledge transfer practices and not only across organisational divides.

Table 5.3: Advantages, Disadvantages and Inadvertent Consequences of Text as the Sole KM Format

Advantages of Text	Inadvertent Knock-on Effects
• Assists in conducting data mining to identify relevant knowledge sources	- Potential for numerous irrelevant results being returned - Time consuming process sifting through the results - Dissatisfaction levels heightened
• Enables a standardised document structure to be created more easily	- The most suited format for the type of knowledge, the intended recipient or the scenario may not be used. - Knowledge reuse / transfer is less effective - Dissatisfaction levels heightened
• Enables hidden/ obscured problems to be described	+ Enables a greater understanding of the problem / context + Improves the extent to which knowledge is transferred + Satisfaction levels heightened
• Low cost • Uses existing resources • Reduction in the storage capacity required	+ Reduced need for training as skills generally already in place + Greater confidence in conducting the process + Satisfaction levels heightened
Disadvantages of Text	**Inadvertent Knock-on Effects**
• Difficult to quickly preview the data mining results	- Takes time to locate appropriate contributions - Dissatisfaction levels heightened
• Less effective for the transfer of tacit knowledge	- Knowledge is not shared to its full extent - Users may feel that the knowledge gained does not warrant time exhausted - Dissatisfaction levels heightened
• Encourages the capture process to be deferred to a later point in time	- The opportunity for knowledge deterioration / knowledge loss is increased - Quality of knowledge stored may be perceived as not being sufficient - Dissatisfaction levels heightened
• Difficult to convey the context of the scenario	- User does not understand the context in which the knowledge emerged - The user is unable or has difficulty in related the stored knowledge to the new scenario - Dissatisfaction levels heightened

The LA also supported this view, but simultaneously questioned whether any format is more effective than others as they all have their strengths and limitations and therefore could be suitable at differing occasions. For instance, in situations where it is complicated to describe the scenario concisely, then a *"video or photograph would benefit."* This is due to it enabling the recipient to understand the context in which knowledge originally emerged to a much greater extent. However, utilising any format in isolation appears to be problematic. For example, the LA stated that *"it depends what the problem is, as sometimes things are hidden"* and therefore the use of photographs and/or videos would be inappropriate. As such, it is clear that it is not the case that one size fits all with regards to the process, the content, or the format. Instead flexibility is required within each aspect.

5.2.5 Current Resources

To establish the potential resource base utilisable for the proposed feedback framework, the identification of the current technological resources utilised within this case was desired. This is due to it previously being highlighted that various technologies are able to support the KM process (see Section 2.9).

5.2.5.1 Information Technology

The overall ethos of the construction organisation regarding the adoption of innovative technologies was viewed as being *"second best"* compared with the most innovative and outward looking companies within the industry. This was due to the CPM believing that the organisation liked to see what direction the industry was heading before committing to such investments and that they *"do not lead anything*" in terms of technology implementation. As such, a conservative technology strategy was identified.

As a result, non-current and out-dated software packages such as non-latest editions of Microsoft Office are currently being utilised. However, the organisation was viewed as holding the majority of the array of potential KM supportive technologies identified in Section 2.9. These include:

- Personal Computers;
- Laptops;
- Mobile Phones;
- Intranet; and
- Data Mining Tools.

5.2.5.2 Mobile Technologies

Due to the fairly infant nature of the majority of recent advancements in the area of mobile technologies (Chen, 2008), this was an area in which this organisation's reactive technology ethos is demonstrating significant gaps in their KM resource base. For instance, mobile phones (not smart phones) and email devices such as BlackBerrys were the only mobile specific handsets utilised on site and these tended to only be within senior management roles. No PDA's, smart phones or tablet devices were currently being used for other processes and therefore, the utilisation of such for the purpose of KM would require the purchase of new resources.

This being said, the CPM voiced their desire to plug this hole as at present *"inefficient processes are being adopted to do the basic things on site."* It was thought that although there is an initial outlay for such resources, the money being lost through inefficient practices outweighs this. The CPM wholeheartedly believes that the widespread adoption of mobile technology is the direction the industry is heading; however at this point in time some organisations are being slow to realise this.

Internet connectivity on site was viewed as being below adequate if it was required within the proposed framework. It is hardwired and perceived as being relatively slow compared to market leading offerings. In regards to wireless internet, the site did not offer this facility; however, the CPM once more stated that he was of the opinion that this would slowly change.

The organisation is trialling a mobile technology snagging system at the time of this investigation. Such a solution would therefore involve the incorporation of mobile devices such as PDAs or smartphones as well as improved wireless networks and internet connectivity to sites. As such the inclusion of mobile technologies within any devised feedback framework appears to align with the direction of the industry even if it is not in line with its current position.

5.2.5.3 Building Information Modelling

The future direction regarding the industry's uptake of 3D BIM was both clear and indistinct at the same time. There was a strong belief that BIM would be widely adopted in the future; however, at present its adoption is much laboured and being attempted in a piecemeal fashion. This is due to the high degree of uncertainty towards how the use of the technology will be structured in terms of *"who owns the model, who is responsible for it and what the capabilities are of the individual partners involved"* (LA). This obstacle was suggested as perhaps being less apparent within the P21 framework, due to it being clearer cut that the contractor would assume overall responsibility for the model.

Further reasons for its slow adoption emerged in the form of:

- Little evidence of what the potential pitfalls are, resulting in each package trailing it individually;
- The investment required; and,
- SME's not having the resource base to commit to its adoption.

This being said, the benefits of BIM were demonstrated as being widely understood from a design and construction perspective with efficiency, quality, integration and buildability improvements all being cited. In addition, the new government initiative which is demanding that all government projects utilise BIM by 2016 was viewed as a significant driving force. Therefore even conservative construction organisations are at the early stages of initiating the adoption of BIM, even though it is earlier than they would normally feel comfortable with.

Although the future direction for the industry indicates the widespread adoption of BIM, at present there appears to be too many unknowns surrounding the form it will eventually retain. As such, the desire to align any development of a feedback framework with that of BIM is currently too premature. As such, these findings have in some instances supported, but in others opposed, the initial research proposition 4a (see Section 5.4.1.2). Accordingly, this research proposition has been adapted to read:

> **Proposition 4a.1** - The potential of BIM provides a probable platform to share knowledge between project participants; however at present it is too premature to predict in what form this will emerge

5.2.6 Foreseen Difficulties and Potential Coping Strategies

Following the identification of the barriers to KM and OL identified through a review of literature (see Section 2.7), this section discusses the most prominent obstacles to overcome in the view of the participants of this case. A further exploration of the problems noted and how they may be reduced as far as reasonably possible has been established through utilising the knowledge and experience held by the project's participants. Consequently, a fuller understanding to how the barriers may be mitigated has been established and therefore more informed coping strategies developed.

As some of these obstacles and coping strategies have indirectly been discussed within previous sections of this analysis this section continues to provide a more in-depth discussion of the main difficulties facing the transfer of knowledge that have not previously been fully debated.

5.2.6.1 Difficulty Nurturing Relationships

The single biggest aspect of the nature of the construction industry that the CPM stated that they would change was that they would attempt to maintain the same core of the project team repeatedly. This was to enable and extract the benefits of continual learning from one project to the next. For instance, the CPM declared that:

> *"The biggest thing is that teams change and what a change in personal means is that you are starting from square one again. It means you are taking six steps back in understanding each other's objectives, critical factors, what we believe the client wants and what we have done before. I think a change in project teams is probably the worst thing that can happen."*

Therefore by keeping the core of the project team together the CPM felt that the understanding developed between the participating teams would already be in place at the start of the next and this would save a great deal of time and effort in its early stages. This was observed during the DTM where the dynamic of the project team was one that everyone was pulling in the same direction towards the successful completion of the project. It was evident that compromises were being made on an on-going basis for the greater good of this overarching objective and thus in preference for the attainment of individual objectives.

Their skill sets, expectations and capabilities were all well-known, which was a contributing factor attributed to why the CPM believed the project team was *"a lot slicker now, but in the early days it was not"* (CPM). However, the time spent in developing effective relationships is ultimately lost once the project ends and the team is disbanded (see Section 5.3.2.2: Figure 5.4). Consequently, at the start of the next project nurturing this understanding and integration once more is an arduous task, with it being described as having to get *"an old wheel moving again"* (CPM).

The strength of this belief expanded further, with the CPM stating that:

> *"If you were to take this whole team and go and build another hospital I think you would find the success would be enormous. If you were to plant this team as it stands in another hospital project wherever it was you would find the results you get would be a far more efficient building in terms of its design, very little error during design and I think that it would work."*

This theory was tested through incorporating related questions in the subsequent interview protocol with the LA. This resulted in a similarly strong opinion advocating the need for more continuity between project teams. It was said that:

> *"I think it would be very positive but it does not happen enough" (Lead Architect).*

The reason for this was due to design teams and contracting teams having to move around depending on the contracts that they obtain. Therefore it was proposed that such an arrangement requires client leadership to enforce the same team that worked on past projects are mobilised to work on subsequent projects. For this to occur, clients must first become more informed about the benefits of continuity and in particular how learning from past projects can positively affect future ones. This is once more a scenario that would be much easier to achieve in the cases of repetitive clients such as within healthcare.

Utilising the same team as past projects ultimately resembles integration occurring before the project has even begun due to a certain level of knowledge amalgamation and understanding having been developed from past projects. Therefore, according to the *Pareto Principle* (see Section 3.2.4.3) partnering arrangements appear to significantly improve the likelihood of a successful project.

It was also said that the need for continuity must be understood on an organisational level as well as an industrial one, because at present, there is not enough repetition of teams within either contracting or design organisations. This was shown through the opinion that *"I think even if the whole design team moved from job to job it would be beneficial. It is how you learn to work together a lot better but it does not happen"* (LA).

Appropriately, the strength of this argument has led to the development of a further research proposition in the form of:

> ***Proposition 8:*** *Utilising repetitive core teams leads to learning to naturally take place and thus enables continual improvement more readily than contrived methods of knowledge management.*

5.2.6.2 Knowledge Protection / Hoarding

Another significant barrier to KM within this case was the culture of knowledge protection within the industry. It was observed that the fear of other individuals benefitting from shared knowledge was the most significant out of the three potential beneficiaries (i.e. individuals, projects, or organisations). This was shown through the view that sharing knowledge is seen as a weakness that others may exploit. For example, it was stated that:

> *"There is an ethos in the industry within the old school chaps, where sharing knowledge is seen as a weakness and there is a culture generally in the industry, and not just here, where asking a fellow peer what would they do is seen as a weakness. I suppose we are all competing for roles and promotions etc. and that stifles things in terms of going ahead" (CPM).*

The CPM continued to suggest that such a fear of weakness is in fact apparent within the younger generation also as:

> *"When you are younger you feel under pressure to say that you know things and that you are good enough, [for instance] "take me back twenty years, would I admit to somebody that I did not know something, probably not. Would I admit it now because I am a bit older and longer in the tooth, I wouldn't really care."*

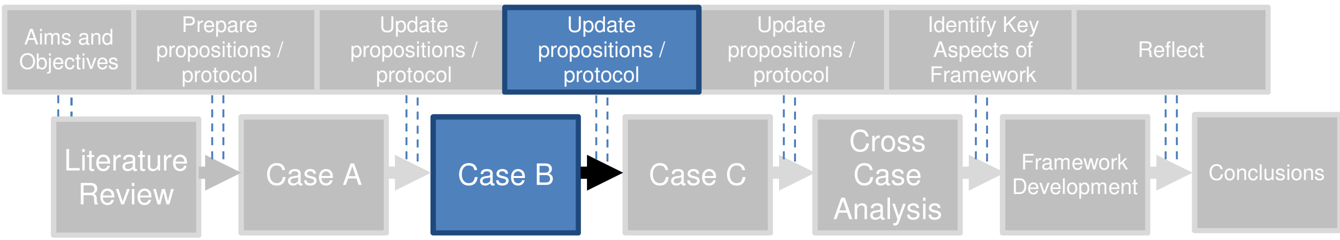
When asked whether they believed knowledge hoarding and protection is an issue within the industry, the LA opposed this viewpoint by stating *"No not really it is generally fairly open."* Consequently, the extent to which this barrier is apparent is indistinguishable through the findings of this case alone. It appears that it may in fact be a culturally engrained ethos and not one that is shared across the industry. Either way, it can be concluded that such an ethos is detrimental to the extent to which the organisation itself and its participants can learn from its most important knowledge resource; its employees.

5.2.7 Summary of Findings

This analysis has highlighted multiple areas of interest which include supportive and converging findings to both past research and the developed research propositions for this study. To investigate these findings further such points will thus be incorporated into the following case studies' designs. A summary of the key research findings arising from this case study include:

- Significant knowledge loss is occurring when teams break up after the project has been completed due to ineffective knowledge capture processes;
- There is a reliance on the knowledge of experienced personnel but without this being shared effectively this will create a void of knowledge once they leave the organisation;
- Changes in the entry routes into the industry are causing mentoring and training to be more difficult to conduct and therefore exasperating the potential knowledge void further;
- Buildability issues are currently being accepted as a tolerable aspect of construction projects which are not as important to learn from as other 'environmental' issues;
- Attempts are being made to manage knowledge and therefore there is an indication that KM is valued; however, the processes in place are deemed as unlikely to extract the desired results;
- There is evidence that the feedback of knowledge would lead to on-going learning and the reduction of repetitive mistakes;
- A two-way knowledge flow would benefit innovation, efficiency and effectiveness of teams;

- Detailing of buildings are an area in which greater standardisation is desired from both sides;
- Top management need to raise the priority of lessons learnt alongside sustainability, health and safety and relationships if they are to be taken seriously;
- Benchmarking of both buildability and lessons learnt are difficult to measure;
- The capture of examples and case studies would improve the understanding within the industry;
- The reasons why learning goals are important need to be effectively communicated to project participants;
- Networks to share knowledge within the industry are poor and viewed as being far more undeveloped than other industries thus causing knowledge silos;
- Time and cost are critical success factors regarding the capture and management of knowledge;
- Early integration of teams is needed and framework arrangements are beneficial enablers of this;
- Utilisation of a variety of formats is needed rather than purely text; and,
- The knowledge capture format must compliment the learning situation.



5.3 Case Study B

The findings of Case Study A, has enabled the confirming of a proposition in the instances in which findings supported them; or, adapting a proposition in line with the new empirical evidence. None of the research propositions were viewed as being miss targeted enough to be rejected at this stage. It is therefore critical that the dynamics of Case Study B portray the characteristics necessary to be able to test the full array of research propositions which include both the original and those that have since emerged. The design of Case Study B follows the same method as in Case A and was conducted once Case Study A had been fully completed and analysed. This allows the selection of Case Study B to be as well aligned with the new set of research propositions as possible.

5.3.1 Characteristics of Case Study B

The main difference between the organisation and project selection of this case, to that of Case Study A, was the need to test what effect utilising repetitive core teams had on the ability to continuously learn (i.e. Proposition 8; see Section 5.3.6.1). A project where the key interfacing organisations (design and construction) had worked with each other on a healthcare project before was therefore selected. The characteristics of this project enabled this proposition to be examined due to it being a D&B contract which permitted the contractor to select the design team. In this instance the contractor selected a design organisation that they had had previous experience of working with and therefore the benefits of this on-going relationship could be examined.

In comparison, other propositions such as that of heightening the priority of lessons learnt from a senior management's perspective (i.e. Proposition 7; see Appendix B.1), was viewed as a proposition that was less dependent on the organisation and project selection. Therefore it was viewed as possible to test through the slight adaptation of interview questions.

The main organisation was once more a large contractor with a significant history in the delivery of healthcare infrastructure projects. This was a feature that was viewed as key to enabling a comparison of KM and feedback practices to be undertaken, without interfering with the testing of other research propositions. All of the other research propositions were viewed as being suited to being tested within the boundaries of this contracting organisation, established through the initial discussions conducted prior to the case study commencing. In particular, the propositions relating to the use of mobile technologies and BIM (i.e. Propositions 4, 4a and 4b) were regarded as being examinable to a greater extent within this organisation than was the case within Case Study A. This was due to their heightened level of adoption and experience within both of these technological areas. An overview of the key organisation and project characteristics are tabulated in Table 5.4.

Table 5.4: Case Study B Organisational and Project Characteristics

Organisational Characteristics:
The organisation is a large multinational organisation with over a century of construction experience;
They are one of the largest contractors for UK healthcare infrastructure projects, with experience in over £1.5 billion worth of domestic projects ranging from large complex and multidisciplinary hospital facilities (£550-600m) down to small specialist facilities (£5-10m);
It is a fundamental aim of the organisation to strive towards continuous improvement, through the harnessing of good relationships;
The organisation incorporates a philosophy of openly sharing information and knowledge with other project participants in order to encourage innovation, learning and high performance;
They are experienced in the full range of healthcare facility contract delivery methods including PFI, public private partnership (PPP), P21+, LIFT and traditional contracting.
Project Characteristics:
A large general hospital and maternity services extension to an existing hospital facility;
It is over £150 million in value delivered through a public private partnership (PPP);
The repetition of established relationships was incorporated by ensuring that the same design organisation from a previously successful project was once more implemented in this project;
The design of the expansion incorporated features that had been implemented on other hospitals recently constructed within the UK. This was viewed as specifically enabling lessons learnt and continuous improvement;
The project was viewed as a typical large hospital expansion and therefore could enable findings to be generalised further than the confines of the project in question; and,
The project delivery method was a PPP contract which enabled differences and similarities to the more commonly adopted P21+ framework to be established.
A special purpose vehicle (SPV) has been formed to develop, build, maintain and operate the facility during the contracted period.

5.3.1.1 The Research Setting

This case consists of five main data collection points. Four of these are in the form of in-depth interviews and the fifth through gathering supplementary empirical material. The four in-depth interviews were conducted separately with the interviewees including the:

- Project director responsible for the construction team (CPD);
- Project director responsible for safeguarding the interests of the SPV (SPVD);
- Senior project manager (SPM); and,
- Architect associate (AA)

For conciseness each interviewee will be referred to by their respective acronyms. Each interview lasted approximately 60-80 minutes and was conducted in person, recorded and transcribed prior to data analysis. Follow up questions were asked to further clarify responses where necessary. These were conducted via telephone or email.

Organisational reports, magazine and internet press releases, drawings and outputs from their KM system were all assessed as supplementary material. Once more the interviews were conducted at the project's site itself within the main site office. This enabled drawings and the physical building itself to be referenced to by both the interviewer and interviewee to further clarify their points of view.

Due to this project having progressed to the handover planning stage, with completion being imminent, the opportunity to observe a DTM was not available. To overcome this absent data collection point, interviews with a greater number of participants were conducted to establish how the dynamics of the project team play out in practice. Furthermore, greater attention was given to extracting the issues surrounding how the team works together and shares knowledge.

5.3.1.2 Case Study B Research Propositions

The altered and emergent propositions to test in addition to the original set (see Section 5.3.1.2) are summarised below:

Altered/Emergent Research Propositions:

> **Proposition 4a.1** - The potential of BIM provides a probable platform to share knowledge between project participants; however at present it is too premature to predict in what form this will emerge

Proposition 7 – a heightened priority given to lessons learnt from top level management would lead to more time and effort being allocated to the on-going activity throughout the project

> **Proposition 7a –** greater assurances and communication from top level management of the KM process would lead to a reduction in the fear of reflecting upon mistakes

Proposition 8: Utilising repetitive core teams leads to learning to naturally take place and thus enables continual improvement more readily than contrived methods of knowledge

5.3.2 Establishing the Need for a Knowledge Feedback Loop

5.3.2.1 Negative Effects of Buildability Issues

The most fundamental negative effects resulting from buildability issues were:

- The need to conduct rework;
- Reinvention of the wheel; and,
- Reduction of quality of the end product.

Each of these were identified during the literature review (see Section 3.2.3) and therefore no additional negative effects have been identified. Each of the above are discussed further in the next section due to an investigation into the causes and regularity of such issues occurring (see Section 5.4.2.2).

5.3.2.2 Regularity of Buildability Issues

In general the aforementioned negative effects of buildability issues (see Section 5.4.2.1) were viewed as arising throughout the project as a result of:

- The difficulty in managing project participant requirements and objectives;
- The adopted method of construction; and,
- Design errors/omissions or improvements not being identified until it was too late.

In the case of buildability issues arising due to it being difficult to manage project participant requirements and objectives, it was found that this is being caused by the differing perspectives and critical success factors targeted by individual organisations and end users.

These issues arise throughout the project due to desires and needs changing as the project evolves. For example, once a baby unit had been mostly built, an owner realised that the unit would not function optimally the way it was being laid out even though it was something that they had previously signed up for. This was due to the intervening doors obstructing the view of the clinical staff, preventing them from seeing from one end of the unit to the other. Ultimately this change was able to be adopted at this late stage as it only required full length glass doors being fitted. However, this draws attention to the willingness to detect and correct issues (i.e. single-loop learning).

Fortunately in this instance the late design change was straightforward enough to implement; however it was highlighted that this is not always the case due to the possibility for it to lead to substantial increased costs or schedule delays. It was stressed by the CPD that often it is too late on in the project to make a change, which if understood in the planning phase, would have been straightforward to integrate. In either case, such late changes can result in the altering of the attainment levels of other stakeholders' objectives and this can cause tensions.

The degree to which such tensions developed ultimately depended on how well integrated the respective teams were early on in the project. For instance, the SPM stated that *"what you have to ensure is that we understand the end users' needs as early on in the plan as possible. If you do not get that right, then when the structure is built there will be implications with regard to the need for additional secondary steel for example."* This need for early integration was advocated by all of the participants interviewed so that relationships and understanding of each other's needs and wants could be established. This can be seen through the following assertions:

> *"The more work you can do upfront the fewer problems you have further down the line" (SPVD).*
>
> *"I am involved myself with the a quality of product and that is to do with raising awareness about getting things built correctly, engaging with the design team early enough in the job, involving the supply chain early enough in the design" (SPM).*
>
> *"Because they [the construction team] are there right from the inception and through the feasibility studies they are constantly giving you the feedback about the cost and buildability issues" (AA).*

The integration within this case preceded the initiation of the project itself in some cases. This is due to the contracting team appointing a design team that they had had previous experience working with. The benefits of doing so were fundamentally related to the effective relationship that had been developed. For instance:

> *"We have a good understanding with them; they know what we are expecting and we have got a pretty good understanding of what they will give us" (CPD).*

This is not only enabled the understanding between key organisations to be in place prior to the project commencing, but also reduced the opportunity for conflicts of interest to arise as a result, thus supporting research proposition 8 (see Section 5.4.1.2). This being said, a greater investigation into the testing of this proposition is documented later in this analysis (see Section 5.4.6.3).

The second cause for buildability issues to arise was that of the adopted construction method, in the form of prefabrication and modularisation. This involves components of the building to be manufactured off-site in parallel to preceding phases of construction taking place. Once built, the components were brought to site at the desired point in time to be installed into the building. In particular, plant rooms, en suite pods and service risers were all constructed using this method.

This method was therefore viewed as enabling much greater control, efficiently and quality during the manufacture of such elements. However, its adoption also presented the possibility for buildability issues if the modules were not delivered in a timely manner. This is due to work not being able to continue past a certain point until the modules had been installed. For example, *"if you build the partitions ahead of the modules then you will not be able to shoe horn them into the building"* (CPD). To ensure that this is not the case, early integration was once more advocated. For example, it is not always the case that rework can be conducted under this construction method. *"You need to get on-board very early on with your detailed design of your internal layout and space planning because modules are all about the 3D imaging of how your ductwork, pipework, medical gases and all of these things go together"* (CPD).

Finally, the third cause of buildability issues was that of design mistakes, omissions, or improvements to designs not being identified until too late. An example of design omissions being identified was that previously reported in the form of access points to external valves and for cleaning purposes not being present in the initial design. Solutions to these buildability issues therefore had to be sought late on in the construction phase.

These findings therefore have highlighted that buildability issues occur naturally throughout the projects development; however they are ultimately limited by the degree to which heightened levels of communication, feedback and in general, knowledge sharing occur. As such, research propositions 1 and 2 (see Section 5.4.1.2) have been strengthened through this analysis.

5.3.2.3 Reoccurrence of Avoidable Buildability Issues

Evidence of reoccurring yet avoidable buildability issues was detected. For instance, it was suggested that:

> *"All of the instances that we have discussed are all things that have affected me and this project in the last few weeks. They are not new issues, they are reoccurring issues that hurt the business and are still happening here" (SPM).*

This not only demonstrates the negative effect buildability issues can cause on the contracting organisation and the project as a whole, but also that this harm is being experienced on an on-going basis unnecessarily. It was also discovered that the degree to which reoccurring buildability issues harm the contracting organisation ultimately depends on the amount of accumulated knowledge and experience the designated team has gained. This in turn enables them to identify potential problems prior to them occurring. For example, regarding how buildability issues can be identified and avoided, the SPM said:

> *"Some of it is experience and being aware of what you can come up against. I have been here for 3 years here, but some of those that came to work with me have been involved in other healthcare projects in similar scenarios so they come with that experience."*

This shows that if the senior project team does not have an extensive knowledge/experience base to draw upon, buildability issues are even more likely to reoccur unnecessarily. Therefore there is a significant over dependency on the collated knowledge of senior individuals within teams. In continuing with this present setup, the above statement indicates towards the promotion of utilising repetitive teams to exploit the accumulated knowledge that they bring. Although reinforcing research proposition 8 (see Section 5.4.1.2), this strategy is viewed as potentially leading to knowledge silos where teams are highly knowledgeable and work effectively together but independently of other similar teams. Further benefits and drawbacks of such a solution are discussed later in this analysis (see Section 5.4.6.3).

Positively, the organisation conducts site visits to other projects with similar remits, to attempt to transfer knowledge across projects (see Section 5.4.4.1). However, these findings confirm that there is currently an over tendency to conduct single-loop learning in. The process of identifying buildability issues and taking evasive action resembles that of the detection and correction approach most commonly associated with single-loop learning (see Section 2.4.2.2). Although this case conducts procedures which incorporate the act of reflection (i.e. identifying problems to warn other employees about them); it does not consist of questioning the current procedures and values. As such, it is evident that improved KM and in particular, knowledge sharing, is required if industry inefficiencies such as buildability issues are to be reduced. Once more this strengthens research propositions 1 and 2 (see Section 5.4.1.2).

5.3.3 Types of Valuable Buildability Knowledge

It was noted that there is a need to increase the awareness of the importance of conducting lessons learnt if improvements regarding efficiency and quality, are to materialise (SPM). This highlights the necessity for a more formulised feedback strategy to be adopted, as well as the requirement to raise the priority associated with KM (i.e. supporting research propositions 1 and 6 respectively) (see Section 5.4.1.2). However, this premise does not direct towards what types of issues that would have the greatest positive effect. Accordingly, this section aims to identify what types of knowledge would be the most beneficial if shared.

The SPVD suggested a comprehensive range of issues that would improve the future buildability of projects if they were shared more effectively. These included:

- Construction methods;
- Construction materials;
- Access; and,
- Maintainability.

This was confirmed as useful information by the AA, who highlighted that knowledge regarding new materials and construction techniques were the most pressing issues to be transferred. In relation to Fischer and Tatum's (1997) classification of buildability knowledge (see Section 3.2.2) this directs towards application heuristics, detailing knowledge and exogenous knowledge being the most useful.

Offering further definition, the CPD stated that they believe *"the most important issues that design teams need to be aware and appreciative of are the detailing of buildings."* This was also viewed as significantly increasing in importance due to the energy efficiency targets imposed on new buildings. For instance, the CPD continued by stating *"it is going to be more* *important going forward as we now have air tightness tests on buildings and the leakage rate is being reduced."* This finding therefore has two main implications:

- Demonstrates that enforced benchmarks are strived for by organisations as it reflects on the quality of service they provide; and,
- The selection criterion of details appears to be shifting away from simply their aesthetical and functional offerings, towards also incorporating how they impact the energy efficiency of the building.

This outcome therefore modernises the findings of Fischer and Tatum (1997) and Arditi and Gunaydin (1997) by indicating towards knowledge surrounding the detailing of buildings potentially being the most beneficial if shared between project phases. This is a key finding, as it identifies a strong indication to an area that would be suitable to form the key learning objective of both the design and construction organisation's KM regimes.

Further evidence of the mutual desire to improve key areas of project performance was also noted. It was viewed that most of the learning surrounds that from failures, difficulties or complications, usually resulting in rework. Although viewed as omitting a vast degree of learning instances (i.e. successes and manageable issues) (see Section 5.4.4.2), it demonstrates a focus to improve upon instances that have been harmful to the project so that they do not happen again. Therefore the presence of a blame culture does not seem to be apparent in preference for both party's improving the services that they offer. For example the AA stated that *"I think the spirit has been very open throughout the project and if there has been an issue we have tackled it together."*

There was strong indication to suggest that the on-going working relationship between the main contractor and design team was a positive contributor to the lack of fear of being blamed due to the familiarity and trust that had been developed. For example, *"they are people that you know, you have worked with and you can trust"* (SPVD). Therefore, this level of trust and understanding of each other's motives (i.e. to continuously improve together) results in each party being confident that any negative feedback is for the greater good of the performance of the combined team. Accordingly, this is further avocation for the utilisation of repeat teams and forming strategic alliances or partnering agreements. Although this strengthens research proposition 8 (see Section 5.4.1.2), a more in-depth scrutiny of this matter will be discussed later in this analysis (see Section 5.4.6.3).

5.3.4 Current Knowledge Management Procedures

5.3.4.1 Methods Utilised to Capture Lessons Learnt

Post Project Evaluations

The most formal method to capture lessons learnt is the forthcoming close out discussions at the end of the project in the form of PPEs. Present at such evaluations are to be the main project parties (design, construction and the SPV); however each participating party indicated that they would do their own internal review also. As a result of these evaluations, individual close out lesson learnt documents are formulated and distilled within each organisation.

These evaluations focus on a variety of issues, each of which is discussed in the following section of this analysis (see Section 5.4.4.2). Regardless of the issues covered, this form of knowledge capture and transfer is viewed as being fundamentally flawed due to the time lapse between the learning event and its capture causing knowledge deterioration (Matlay, 2000; Von Krogh *et al.*, 2001).

Encouragingly the SPM mentioned that in some cases notes are made throughout the project to remind themselves of issues that have occurred. For instance, if an error in the design was detected then this would be recorded in their schedule. This is viewed as being an improvement upon simply relying on individuals to recall issues at the end of a project. However, the absence of the learning opportunity being captured live in preference for conducting a process of 'jogging the memory' remains flawed. For example, this memory aid may result in the instance not being forgotten altogether, however, details surrounding the problem are likely to be less vivid as time passes (Kamara *et al.*, 2003).

The SPVD countered this perspective by stating that they believed that *"if an issue is worth remembering, they are the ones you remember."* This demonstrates the aforementioned problem of only issues which had the most impact (usually negative) being the issues that are remembered and discussed (see Section 5.4.2). Furthermore, the opportunity to capture the context and understanding through other formats such as photographs and videos of even these significant issues is still lost due to the project progressing past this stage. Therefore knowledge deterioration remains evident.

Site Observations

To supplement the above form of knowledge capture and transfer, site visits to other similar projects were conducted. These consist of senior members of the project team taking members of the construction and design teams, as well as SPV representatives to other similar projects that their organisation is undertaking at that time. These generally take place during the planning phase of a new project in the hope that lessons learnt can be incorporated in their next project. This is an example, of how knowledge integrated at the earliest possible stage is considered as being more beneficial due to the heightened ability to adapt the upcoming project to incorporate such learning (see Section 3.2.4.3: Figure 3.6).

This method was viewed as an invaluable means of gaining an understanding of problems that have occurred on other projects and therefore should be learnt from and mitigated against on future projects. The degree of learning achieved was also suggested as being far greater than that which could be learnt utilising other non-observatory methods (see Section 5.4.4.5). This greater degree of learning is indicative of the benefits of conducting mentoring and training (see Section 2.8.6.2).

Similarly to mentoring and training, site visits are limited due to their resource intensiveness resulting in only a few members of the organisation being privileged enough to benefit from them at any one time. For example, when questioned about the degree of resource intensiveness of this activity, the CPD suggested that *"it obviously does put more of a strain on resources, but it is only for half a day and it is no worse than when somebody is on holiday."*

Accordingly, it was viewed as beneficial and manageable in terms of resources, but the ability to conduct such resource intensive KM techniques was attributed to the overall size of the project and the amount of resources that they had at their disposal. For instance, the project was described as being *"fortunate because the scale of the building means we have a reasonable number of staff that can be allocated"* [to such activities]. This is therefore a technique in which SME organisations are less likely to be able to conduct.

Therefore the passing on of problems from one project to the next in this way has been identified as not leading to the desired continual avoidance of previous issues. It may be the case that issues arising from a preceding project are discussed and mitigated against for the subsequent project; however it is significantly likely that because those issues did not affect the subsequent project, they will ultimately be neglected when passing on knowledge to future projects. This thus enables them to reoccur once more at a later date. A simplified example of this scenario is illustrated in Figure 5.8.

As can be seen, due to the prospective site personnel from project 2 visiting project 1 before their project is about to commence, they are able to access knowledge regarding which issues they need to look out for (i.e. A, B and C). However, when it comes to site personnel from project 3 visiting project 2 in the future, because buildability issues A, B and C were avoided during project 2, they are unlikely to be discussed. Accordingly, the opportunity has once more arisen for project 3 to experience the problems that affected project 1. It is therefore clear that this KM technique must be accompanied by other KM techniques and technologies if the full extent of experience from one project is going to be transferred to future projects.

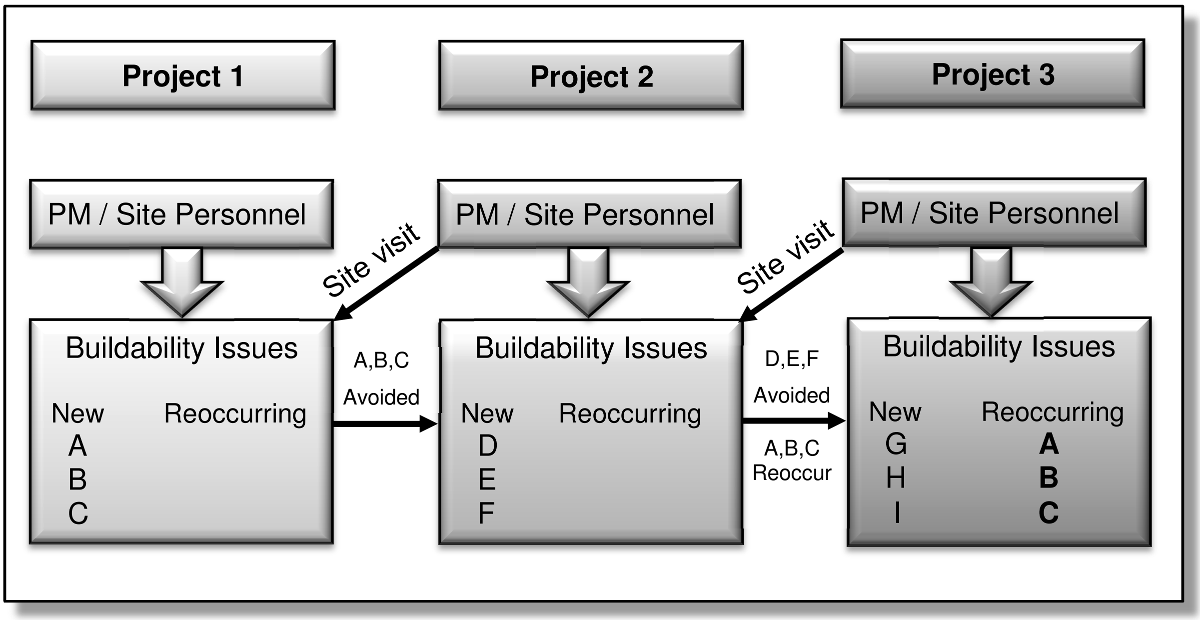


Figure 5.7: Site Visit Knowledge Transfer Leading to Reoccurring Buildability Issues

Design Team Meetings (DTMs)

A third method in which lessons learnt are discussed amongst the differing project participants is through DTMs. Unfortunately it was not possible to observe a DTM within this case; however, they were said to be held a couple of times a month and were very general in their focus (SPM). The main purpose of DTMs is to divulge information regarding the status of works, discussing different work packages and to resolve issues in person with those who are most affected by them. Through discussing the differing issues arising throughout the project, knowledge is therefore transferred informally across organisational divides. As such, this method is one of the main methods currently adopted for sharing knowledge across organisational divides even though this is not its primary intention.

A key benefit of this method is that it enables relationships to be built and an understanding of each other's needs and desires to be gained. For example, the AA described the DTM as being the main method to gain feedback on the buildability of designs. During this activity they debate different solutions and then the construction personnel communicate how each alternative can benefit the construction phase from their point of view. Although this process of knowledge sharing was described as *"never being in a formal manner,"* it was viewed as an indispensable method for enabling an understanding of each party's needs and expectations to be gained (AA).

The extent to which these lessons were captured and disseminated to the wider population than those present at the DTMs, is questionable. From a construction point of view there was little evidence of any formal capture process of the issues discussed within the meeting other than through the form of minutes and in the heads of those who attended. This is a dangerous strategy to adopt as it opens up the organisation to the potential of knowledge loss.

More positively, it was found from the design perspective that lessons learnt report was generated towards the end of the project and distributed via their intranet system within their organisation. Although demonstrating a greater appreciation for the need to distribute learning outcomes with the wider population, this method is not without its downfalls. Similarly to that of PPEs, the time lapse between the DTM taking place and the eventual publication of this report inevitably leads to a large number of the more subtle lessons not being captured (see Section 5.4.4.1: Post Project Evaluations).

This section has therefore highlighted that although each singular method for capturing lessons learnt are not ideally suited in isolation, the combination of the three methods does overcome some of their individual shortcomings. For example, the impracticality of numerous employees of an organisation being present on site visits or at DTMs is overcome through attempting to disseminate the accumulated knowledge through lesson learnt reports. Similarly, the need for two way communication to effectively gain a full understanding of the issues discussed are apparent within site visits, DTMs and PPEs, but not within the eventual written reports disseminated to the wider organisation. This supports the notion that not one singular KM technique or technology is ideally suited to support the full KM lifecycle (see Section 2.10.1), thus enhancing research proposition 3 (see Section 5.4.1.2).

This being said, this analysis has highlighted drawbacks of each of the currently utilised methods. Accordingly these drawbacks are illustrated below, with the method(s) that they are applicable to also indicated (see Figure 5.9).

5.3.4.2 Types of Issues Currently Captured as Lessons Learnt

<u>Failures and Mistakes</u>

As has been shown (see Section 5.4.4.1) the lessons gained throughout the project relate to issues which have impacted, or would impact the project in a negative way if not resolved. Focusing on issues that have the potential to negatively impact either the current or future projects is seen as highly beneficial due to the ability to reflect upon their negative outcome and prevent it from occurring in the future. This act of reflection enables the criticism of the relevant ideas, theories or actions to be undertaken in the view to invalidate or improve them, thus learning from previous mistakes (Hart, 2005).

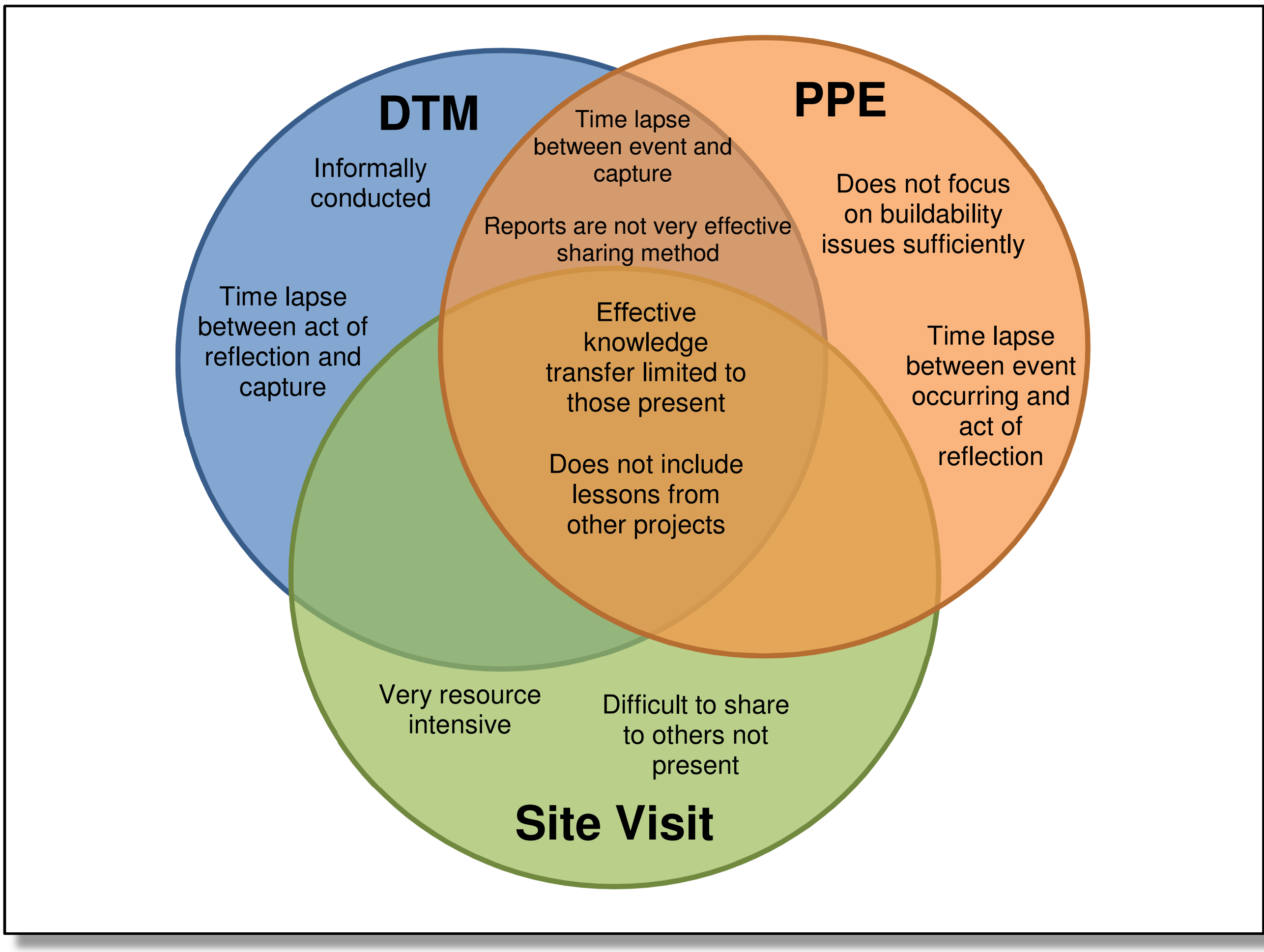


Figure 5.8: Drawbacks of Case Study B's Adopted Lessons Learnt Capture Procedures

Although these methods (see Section 5.3.4.1) are designed to enable the identification and reflection of mistakes there was significant evidence to suggest that in reality this was not the case. For example, the SPM highlighted the need for a cultural shift towards being willing to learn from mistakes if they are to continuously improve, by stating:

> *"Culturally we need to change our mind-set as we are not learning from mistakes so that we do not make them again. If you make a mistake you do not want to make it again; that is what we do in our private lives, but at work even though we individually learn from our mistakes I am not always sure that we make sure that we implement this into the next job"*

In concurrence the CPD suggested that there is a distinct reluctance to revisit past mistakes because *"people do not like looking at them as they can be embarrassing."* However, this culture seems to differ depending on the level of the organisational hierarchy in question. The above reluctance to reflect on mistakes is evident at an operative level; however, there appears to be a much greater desire to learn from mistakes at a director level. For example, when asked whether they believed the main contractor's culture is supportive or unsupportive towards learning, the SPVD specified that it is *"very supportive. I think that the directors see it as fundamental."* This difference in perspective is primarily due to the feeling of ownership of mistakes felt by site operatives, which thus causes a sense of fear during the examination of why they occurred and how they can be avoided in future. Therefore mistakes are personal and difficult to deal with as it is a reflection of the operative's performance. In comparison this is not the case at a director level, which causes there to be a lesser degree of anxiety attached to examining them.

It is therefore suggested that if a change in culture is going to be achieved there is a need for greater support from more senior levels of the organisation. This should be achieved through improving the degree of communication in the form of heightened insurances regarding the process, the benefits of it and how it will lead to mutually beneficial improvements going forward. This is foreseen to lead to all levels of the organisation gaining a greater appreciation of the necessity to learn from past mistakes, a reduction in the fear of doing so and therefore more effective learning materialising.

In particular this has interesting implications for research proposition 7 (see Section 5.4.1.2). As such, a subsidiary research proposition has been developed, which reads:

> **Proposition 7a –** greater assurances and communication from top level management of the KM process would lead to a reduction in the fear of reflecting upon mistakes

Successes

Each participant acknowledged the need to increase the degree to which successes were integrated into the act of reflection. For example, when asked questions regarding whether the feedback of both buildability successes and failures would benefit future projects or not, the following responses were given:

> *"It would. It is all about raising awareness and highlighting the importance of the lessons learnt and bad practice etc." (SPM);*

"Oh yes. I think we are fortunate here because of the scale of this building we have a reasonable number of staff and therefore you can allocate duties for people to go and check things… So we could probably present examples of good and bad practice" (CPD);

"Certainly within our [internal] lessons learnt document we include a positive side of items which include good aspects of the project that worked well. It is essential, because if you only point out the negative then you will have missed half of the project" (AA); and,

"It is not just about your successes but it's also about the failures" (SPVD).

However, the current practices adopted within this case appear to neglect critical learning opportunities arising from successes of the project. This can lead to a lack of effective learning in two main scenarios; successes and manageable errors. Firstly, if designers are not being made aware of the solutions that were effective (i.e. successes), the opportunity to repeat them, or even standardise them may be lost.

The opportunity to learn and improve was also identified as being lost in the case of slight buildability issues, which did not cause significant enough problems to require the act of rework. This was seen in the form of designers repeating failing strategies due to not being made aware of the need for improvement. For instance, when the construction team can overcome issues without the designers needing to be made aware of it, then the designers *"might look at the same solution again and it might cause the buildability issue once more,* [even though] *it could have been improved upon"* (AA).

This feedback of knowledge at present is not being naturally transferred as the construction team are the ones that experience the problems, develop the solutions and evaluate their effectiveness. This learning is therefore isolated to the construction phase only. For example, the AA continued by suggesting that because *"they* [the construction team] *are out on-site and we might not be, they just deal with it."* This supports the view (see Section 3.2.5), that vital lessons arising during the construction phase are not being fed back to those who could best utilise the resultant knowledge (i.e. designers). As such this finding presents the strongest support thus far for research propositions 1 and 2. Without it, it has been discovered that the level of continuous improvement to be gained utilising current processes is likely to remain restricted due to the focus solely being on areas of weakness.

Other Issues

Other than buildability the main issues captured as lessons learnt include:

- Health and safety;
- Quality of product; and,
- Sustainability.

These were said to be focused on in terms of capturing lessons learnt much more than technical buildability issues. This is due to the desire to satisfy the client, as many of these issues are contract requirements (CPD). This indicates towards strengthening research proposition 7 (see Section 5.4.1.2), which suggested that heightening the priority given to lessons learnt from top management would lead to greater resources being allocated to the activity. However, where these findings deviate from this proposition, is that for the importance to be assigned, it must firstly be client led.

This signifies that the organisational benefits of learning from buildability issues is either not fully understood by top level management, or they are viewed as not being a significant enough incentive for this activity to be prioritised alongside other learning objectives. The need to improve in this area is summarised by the SPM who states that *"they are not new issues; they are recurring issues that hurt the business and are still happening here."* Interestingly, when queried about whether heightened priority from top level management would lead to more time and effort being expended on this activity, the response was *"no, not at the moment. There is enough going on at the moment what with quality of product, health and safety and sustainability."*

As a result, present contradictory evidence regarding how the capture of buildability related lessons learnt could be elevated in priority is detected. On one hand it is viewed as requiring client and top management intervention for this to materialise; whereas, on the other, the incorporation of additional learning objectives appears to be too great of a demand on restricted resources at present. It was suggested that to minimise the degree to which this change would exasperate the demand on resources, new learning initiatives must align with existing resources and fit current procedures the best they can (SPM and AA). Accordingly, research proposition 7 has been adapted to incorporate the discovery that the heightened priority needs to be client led, to now read:

Proposition 7.1 - a heightened priority given to lessons learnt from clients and/or top level management would lead to more time and effort being allocated to the on-going activity throughout the project.

5.3.4.3 Supportive KM Techniques Utilised

In addition to PPEs, and mentoring and training in the form of site visits (see Section 5.4.4.1), this case also demonstrated additional KM techniques which will now be discussed.

Framework Collaboration

This case utilises the collaborative technique of frameworking (see Section 2.8.2), to deliver this healthcare project. The most popularly used framework agreement in recent years for healthcare infrastructure delivery is the freshly developed P21+ framework; however, this project has utilised a private-public-partnership (PPP). PPP projects, like private finance initiative (PFI) projects involve private sector organisations engaging in providing public infrastructure and services through concession contracts for a duration of up to forty years (Smyth and Edkins, 2007). As such, PPPs fill a space between traditionally procured government projects and full privatisation (Grimsey and Lewis, 2005).

Unlike the P21+ framework which is financed by the public sector, the PPP arrangement involves government and external funding. Contracts are made between the public sector and a 'special purpose vehicle' (SPV), which brings together a group of private sector companies, often including a construction company, a facilities manager and financiers (Spackman, 2002). The typical arrangement of this type of procurement partnership is shown in Figure 5.9.

The area of interest relating to this collaborative technique is the extent to which it enables learning to take place. Firstly, the most significant enabler of learning that it presents is the early integration of project participants. As the SPV is similar to that of a new business start-up (Harris, 2004), all of the participants of the project began collaborating right at the outset of the project. Compared with traditional DBB projects, the ability for construction professionals to influence the project through integrating their knowledge and experience is much greater. This is achieved through enabling the generation of mutual trust, respect and credibility between project participants, thus leading to becoming more team focused (Jergeas and Van der Put, 2001).

This benefit was voiced by the SPVD who specified that usually a large part of problems are to do with people's expectations not being fulfilled. However, through integrating them all early on in the project it was possible to get them to all sign up to an agreed set of expectations. Similarly from the viewpoint of the construction team, early integration enables their expectations to be understood at a much earlier stage than is the case with the DBB method. For example, the incorporation of their experience in effective construction methods was able to be integrated. This resulted in a steel frame structure method being adopted, which thus permitted prefabrication and modularisation to be implemented (SPM). The design of the modules was also benefitted by *“getting on board very early with the detailed design* [as how] *the ductwork, pipework, medical gases and all of these things are going to go together”* could be mutually planned much earlier on in the process (CPD).

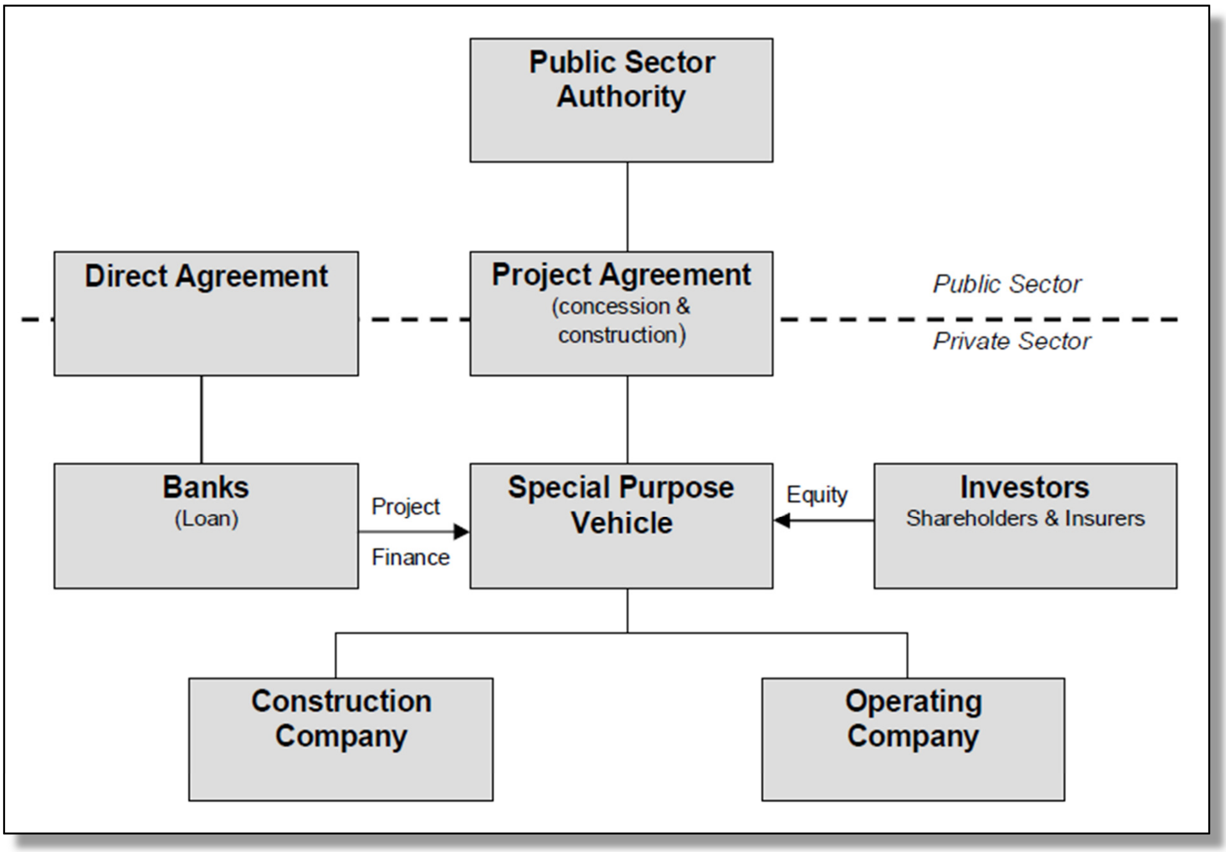


Figure 5.9: Typical PPP Project Structure. Source: PricewaterhouseCoopers c.f. Harris (2004)

The need for early integration and the generation of mutual understanding was viewed as stretching further than simply between the design and construction phases, but that of the client also. This is critically important as the understanding of the end users’ needs has to be well understood at the very start of the project as all three of these main participants’ needs and expectations impact the achievement of others. For example, the client may specify the ceiling height required for the wards; however the construction team will need to determine the ceiling void required to accommodate all of the services that have been designed to be accessed from each room (CPD). Therefore, within a DBB format, the client and the design team may have developed a design not accounting for the changes that the construction personnel would suggest. Accordingly, this would either result in building an inefficient facility, or the need for significant design rework to incorporate them. Within both scenarios, early integration would heighten the likelihood of a more cost effective and smooth project delivery.

The beneficial impact of a move towards this form of procurement was also advocated by the AA. In support with the above scenario, the lack of integrating the construction team early on in the project was viewed as making it far more difficult to accommodate their expectations *“because you have missed the opportunity”* (AA). Alternatively, early integration leads to a *“more buildable solution”* (AA).

This positive impact of early integration was experienced throughout the duration of the project and was not simply limited to the start-up phase. The AA stated that *“because the contractor was there from day one it was beneficial and we were able to get feedback”* (AA). This open sharing of knowledge is both facilitated by and assists in the strengthening of relationships between the phases. Consequently, beneficial impacts were experienced right up until the final stages of the project. This was shown through the testimony that the *“relationships on this project have been quite good, so when we have found things quite late on as we have done during construction, they can be corrected”* (SPVD).

Partnering

Another form of collaboration employed during this case was that of strategic partnering. This was a significant characteristic of this case’s selection (see Section 5.4.1) due to it enabling the testing of proposition 8 (see Section 5.4.1.2).

This method was seen as beneficial as it facilitated the nurturing of an on-going professional relationship, which led to heightened levels of trust and in turn assists in knowledge sharing, openness and communication (SPVD). The favourable impact of this technique was advocated unequivocally across those interviewed with the SPVD going as far to suggest that *“it is probably one of the biggest* [positive] *factors.”* So much so that the utilisation of companies that the main contractor has had prior experience working with and thus developed effective working relationships was also utilised to appoint consultants for building and civil and M+E.

This being said, a discovery of significant interest was the limited extent to which a strategic partnership alone was able to lead to the above benefits. It was found that a strategic partnership or strong working relationship between two organisations may lead to a preference to work together in future projects; however, it is not as straightforward as simply agreeing to work together for these benefits to materialise. For example, it was highlighted that the interaction between these two organisations within the region in which this project resided was working extremely effectively and therefore the benefits stated above were apparent. However, due to both of these organisations being large multinational companies, a similar healthcare project in a differing region, attempting to benefit from the working relationship of these two organisations, was far less effective.

These differing outcomes were identified as being attributed to the need to nurture relationships on a personal rather than organisational level. Regardless of how secure the organisational relationships between two parties are evidence suggests that for a successful project delivery to materialise, effective personal relationships have to be developed. The success of this case was found to be due to the two teams incorporating some of the same personnel that had worked together on a previous healthcare project. Therefore, personal relationships that had built up were directly transferred to this project during its inception.

Accordingly, these findings have indicated support for the assertion made within the Latham Report (1994) that improving the levels of integration between partners and stakeholders improves the performance of the construction project. Furthermore, such partnering leads to heightened levels of trust and understanding which endorses Barlow and Jashapara's (1998) recognition of it engendering a lower risk environment. However, partnering alone is insufficient and more critically the eventual level of learning appears to be directly related to the degree to which repeat relationships can be utilised, thus demonstrating significant support for research proposition 8 (see Section 5.4.1.2).

<u>Reassignment of employees</u>

Due to the project based nature of the construction industry, a natural technique available is the reassignment of successful and knowledgeable employees (Lord and Ranft, 2000) (see Section 2.8.6.3). Although applied by all construction organisations, unintentionally in most cases, this technique is discussed specifically within this case due to it becoming apparent that it potentially impacts on the ability for other techniques to present the full extent of their beneficial potential. For example, repetitive teams enable developed relationships to be transferred from one project to the next (see Section 5.4.4.3: Partnering). However, if these teams are broken up, the difficulty in nurturing these relationships is once more apparent.

It was suggested that experience and knowledge regarding the demands of delivering a large hospital project are transferred to the next healthcare project through reassigning experienced and knowledgeable employees (SPM). However it was also highlighted that it was human nature to seek out new challenges and therefore want to move onto different types of projects also (CPD). This was shown through the view that some employees working on this three year project had previously been working on a two year hospital project. As such it was felt that *"if they know what they are getting with no surprises then it may become a bit of a grind"* and they will ultimately want to move on (CPD).

This reassignment of employees to different project types will therefore enable knowledge gained from one sector to be transferred to others, but at the same time it will limit the positive effects of the learning derived from partnering.

Communities of Practice (CoPs)

Within this case two main forms of CoPs were identified. One was a technological solution utilising an intranet system and will therefore be discussed in the following section of this analysis (see Section 5.4.4.4: Intranet). The other was in the form of DTMs which have previously been discussed (see Section 5.4.4.1: Design Team Meetings).

5.3.4.4 Supportive KM Technologies Utilised

Intranet

Both the construction and design organisations within this case utilise an intranet system to support their main KMS. Within the design firm, lesson learnt reports are prepared usually by the associate or director in charge of the project, with them then being published and stored on the intranet system. The system is divided into differing divisions, with healthcare being one of them. The report's presentation is not confined by a template; however, the process that is gone through is a systematic one consisting of reviewing all of the different levels of designs and elevations, as well as the individual work packages.

A similar process is undertaken by the contracting organisation; however, reports on best practice and lessons learnt are slightly more confined. They are developed in a one page format before being posted onto the intranet KM system. These can be prepared by anyone in the organisation who feels inclined to share something, which is then discussed by a few colleagues before posting it (CPD). This informal process was said to be the only method to which posted knowledge is validated as it is generally based on trust and that what is posted will be of use to others.

The main benefit of these systems was viewed as being the ability to remotely store and access documents and reports. Due to both the design and contracting organisations being geographically distributed, this system allows any internal employee to access the other region's entire repository of knowledge. This remote access is beneficial due to the efficiency of accessing stored information without having to travel to a different site office where they are physically stored, or request a colleague to send the desired reports via email.

Further findings support common conclusions surrounding intranets; however, they seamlessly align with the cited drawbacks of this solution (see Section 2.9.2). Firstly, and the most significant drawback is the inability for this technology, in its current state, to contend with face-to-face interactions and discussions. Therefore the act of reflection and ability to generate a full understanding is seen to be absent (Stenmark, 2002). This dissatisfaction in the process was highlighted by the CPD who stated *"the major issue is how we get people to communicate better; rather than having to go and read things, people need to be shown."*

The reports published on these two intranet systems are predominantly text based with some graphics and photographs incorporated also. As such the above desire for more interactive, and if possible, two-way communicative solutions indicate towards the inability for this format to transfer more valuable tacit knowledge.

Furthermore, Stenmark (2002) continued to recognise that when physical meetings are not possible, virtual meetings through the intranet may provide a viable substitution; however at present this option has not been implemented. As such, the systems in place appear to share knowledge passively, with very little active distribution taking place (Markus, 2001). Within the design organisation some evidence of active distribution was noted with the ability to flag information for certain people's attention; however this was rarely taken advantage of. This is resulting in knowledge being posted onto the system but unless people are aware that it is there it will never be looked at. In turn, this is leading to the reduction in inclination for employees to expend efforts on contributing to the system. For example, it was said that *"you could think you have a great idea, share it with others, post it on the intranet but nobody else would look at it"* (CPD). Then when asked whether this could become a barrier for people to post knowledge on the system in the future the response was *"it is quite possible. I think that may be the case. Somebody needs to be quite passionate about something to post it up there."* As such, long-term consequences of this lack of motivation are seen to be the reduction in usage of the system as users of the knowledge base view them as incomplete and/or obsolete (see Section 2.9.2). This leads to an on-going cycle of disillusionment towards KM practices as is discussed later in the cross case analysis (see Section 6.3.3).

The SPM confirmed this perspective by suggesting that the reasons why they *"could not remember the last time* [they] *went on it" wa*s a combination of a lack of time and that the knowledge stored was not sufficiently complete. A further barrier yet to be identified emerged as also causing project managers and team members to not be forthcoming in contributing to the system. The above scenario where someone has to be quite passionate about something to post it onto the system is viewed as only occurring when somebody is aware that they are doing something "*different and unique"* (CPM). In reality, due to team members being absorbed in their responsibilities on a daily basis, it is in fact very difficult for those involved to identify whether what they are doing is different and unique as it appears to be relatively mundane to themselves. For example:

> *"It is often difficult to get people to relate to the fact that they are doing something different as they just see it as part of their day job. Why would they tell somebody what they are doing as they feel they are just doing what they are paid to do? In reality they are doing something a little bit unique so they should be sharing it, but people do become a little bit blinkered and they become convinced that there is nothing to share" (CPD).*

Consequently, intranet's inability to assist the identification phase of the KM lifecycle is further restricting their worth. It is viewed that to improve their value to these organisations, they should be complimented with a KM technique or technology that is effective in the identification of new knowledge. For example, site visits are beneficial in identifying what aspects of projects are 'out of the norm' and therefore are knowledge capture opportunities.

For instance, by asking a group of employees what is unique and special about the processes they implement on a daily basis, they may not be able to identify many examples as they do not have anything to compare it too. However, if a group of individuals from another project were taken and shown other ways of working, it is much easier for both groups to identify the respective differences. They can then reflect on these differences, attempt to develop new ideas (i.e. learning) and thus identify knowledge capture opportunities. These could thus result in reports of the site visits being documented and posted onto the intranet system to convey those areas of learning to others.

These findings exhibit how a purely technique or technological based KM system is unlikely to lead to the most effective KM framework, thus strengthening the foundation of research proposition 3 (see Section 5.3.1.2).

5.3.4.5 Format of Knowledge Capture/Storage

The format of knowledge capture has been recognised as a significantly influential aspect on the degree to which knowledge can be captured, stored and transferred (see Section 2.8.6.1). In particular, it has been noted that in the case of tacit knowledge, written language is far less beneficial than oral communication (Lee and Egbu, 2007). These findings were paralleled within this case, demonstrated through the following quotes:

> *"We include images, extracts of drawings etc. to illustrate it. Because if you put things in words especially from an architectural side it is difficult to understand, so we try to keep it short and graphic if we can, using photographs and the like" (AA).*

> *"The major issue is how we get people to communicate better; graphically rather than having to go and read things is what is needed. People need to be shown" (CPD).*

The need to be shown or explained tasks within construction was further advocated by the CPD who stated that *"to understand how to hang a door or to fit a lock it is a lot easier to stand and watch it being done than it is trying to read the instructions."* This was predominantly due to the construction industry being viewed as a "*physical"* service industry and therefore the knowledge exchange needs to be more *"visual"* than at present. For instance, the CPD continued to acknowledge that the capture format adopted *"tends to be in text,* [sometimes supplemented] *with photographs as well."*

This was discovered as being a contributing factor to the slow adoption rate of the intranet system. For instance, the SPM stated that they had not been on the knowledge exchange portal for a significant period of time, and in fact could not remember the last time they used it. This was attributed to the perception that it was not effective in transferring knowledge, as well as time demands restricting their ability to seek out knowledge in this way.

The implications of these findings are numerous. Firstly, these perspectives demonstrate significant support for research proposition 2b which states that vital tacit knowledge can be captured and fed back to designers if a variety of capture formats are utilised (see Section 5.3.1.2). For instance, the opposing satisfaction levels of the two comparative CoPs are largely attributed to the differing transfer formats that they facilitate. DTMs were viewed positively due to the ability to communicate face-to-face, explain perspectives in real time and overall generate a full understanding of any problems, solutions and people's perspectives (see Section 5.4.4.3: CoPs). The intranet based CoP has not been widely used and the satisfaction levels of its effectiveness when utilised are low due to the knowledge captured being text based resulting in the sharing of knowledge also being text dependent. This was viewed as being much more difficult to understand, demonstrated through the opinion that:

> *"If you write down your thoughts and I read them back have I picked up your thoughts? It all depends on how succinct you are and how closely aligned my understanding of certain words is with how you understand certain words. However, visually and graphically it is almost unambiguous isn't it?"*

A finding of significance therefore is that visual and/or oral communication is required for the transfer of tacit knowledge to occur. This expands the findings of Lee and Egbu (2007) who advocated the need for oral communication to transfer tacit knowledge. Although face-to-face communication is viewed as the most effective means to generate understanding and thus transfer tacit knowledge, visual forms of knowledge capture in the form of photographs, graphs and videos are also capable of tacit knowledge transfer in some instances.

More definitively, dynamic visual aids such as videos were viewed as more beneficial than alternative static forms such as photographs, graphs or tables. For example, in the case of transferring knowledge related to specific tasks, the CPM suggested that standing and watching someone perform the task would be an effective means for knowledge transfer (i.e. allowing for two way communication in addition to generating an understanding from watching the task being completed). However, they continued to suggest that an alternative option would be to watch a video of somebody completing the task, which would also enable this understanding to be generated. As such, the direction towards the need for visual, and if possible, dynamic capture formats to be utilised has indicated towards the need to adapt research proposition 2b to read:

Research Proposition 2b.1: Vital tacit knowledge can be captured and fed back to designers through the utilisation of oral and/or visually based formats.

A significant drawback of the KM technique of mentoring and training has been identified as being its resource intensity (see Section 2.8.6.2). However, the discovery of the potential effectiveness of videos in providing a high level of understanding, compared with that possible through static visual aids (i.e. photographs, graphs and tables) or text, could overcome the degree to which mentoring and training is limited to a privileged few. For instance, the same training and mentoring session if captured on video can be dispersed companywide with very little additional effort or cost. The full extent of the beneficial aspects of this assessment of the video format is illustrated below (see Figure 5.10).

Accordingly, these findings align with those of Ruikar (2010) who suggests through incorporating multimedia outputs, such as those facilitated by podcasts; it is possible to accommodate a wide variety of learning abilities and styles, whilst facilitating self-paced learning. This draws attention to the application of technology within a KM structure which previously had been viewed as being more appropriately aligned with the transfer of explicit knowledge (Al-Ghassani *et al.*, 2005). For example, KM technologies have historically been viewed as being suited to the collection, collation, storage, analysis and dissemination of information (Roberts, 2000; De Jager, 2007). They thus assist the creation and diffusion process of knowledge that can be codified and reduced to data (Roberts, 2000).

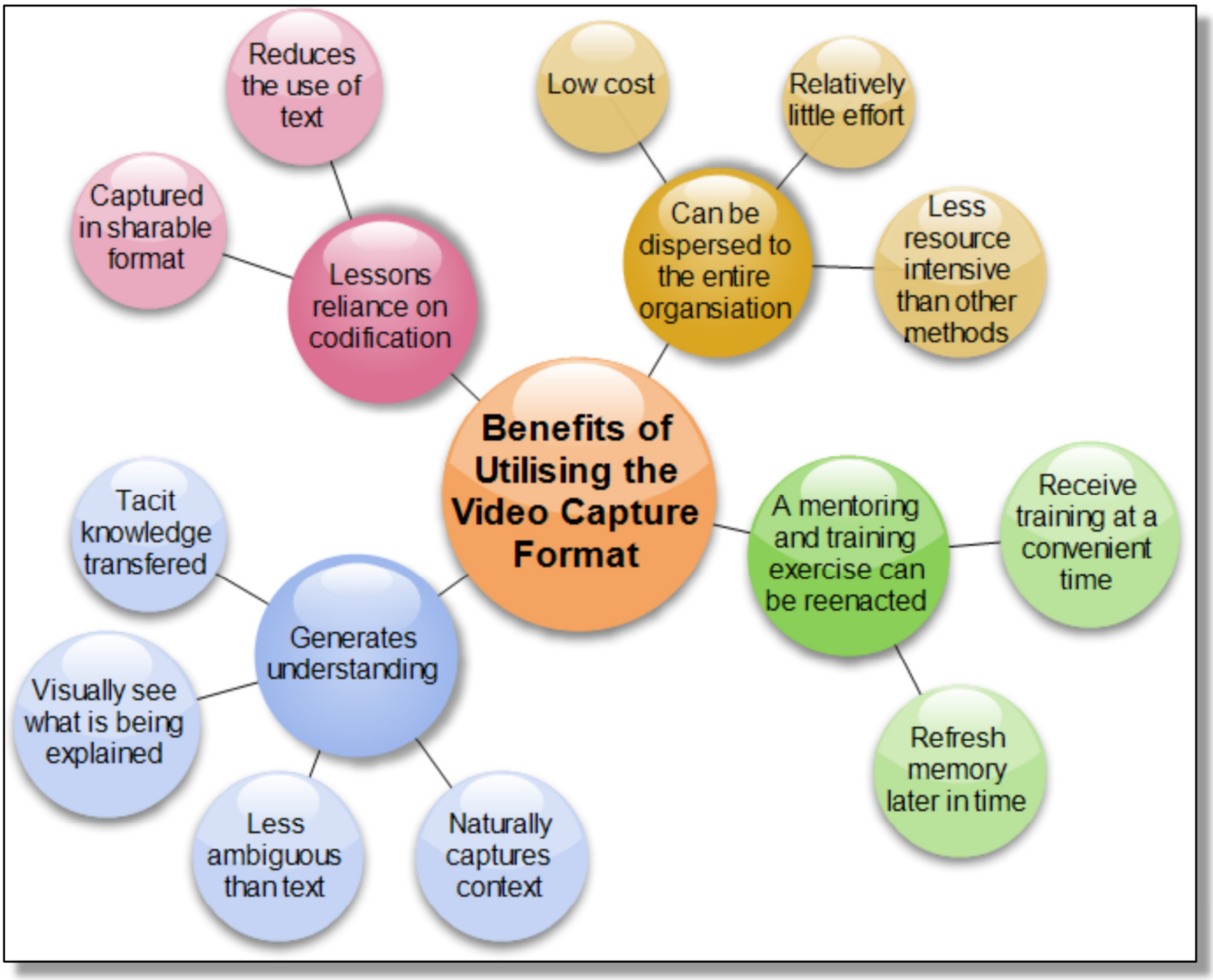


Figure 5.10: Benefits of Utilising Video as a Knowledge Capture Format

In defence of these perspectives, they were voiced prior to many of the technological advancements in smartphones and tablet computers and therefore the benefits of video as a capture format was ultimately neglected. As a result, there is a far less distinct separation between KM techniques and technologies, where previously KM techniques were said to be suited to the transfer of tacit knowledge and KM technologies to explicit knowledge (Al-Ghassani *et al.*, 2005). Consequently this demonstrates evidence to support research proposition 4, which stated that mobile technologies can be utilised to assist the live capture of learning instances (see Section 5.4.1.2). Furthermore, this section has discovered that to transfer knowledge effectively, and especially in the case of tacit knowledge, a greater extent of visualisation is required.

5.3.5 Current Resources

5.3.5.1 Information Technology

The main contracting organisation's technology adoption ethos was viewed as being *"one of the industry's leaders, not the leader but up there in the top five"* (CPD). Recent investment has predominantly been in mobile computing, including improvements in their wireless networking and the use of PDA devices. The relevant KM supportive technologies identified within this case include:

- Personal Computers;
- Laptops;
- PDAs
- Mobile Phones;
- Intranet; and,
- Data Mining Tools

5.3.5.2 Mobile Technologies

As a result of their proactive technology adoption strategy, PDA devices have been implemented widely across the organisation. These were predominantly used to support snagging and inspection processes, but other uses for them were said as being investigated (SPM). The PDA devices implemented were not viewed as being *'cutting edge'* in the technological world, but were seen as advanced in terms of the construction industry.

Although not currently adopted, it was stated that alternatives to PDAs were also being investigated such as touch screen tablet devices and smart phones. This was to progress towards the most idealistic technological solutions and move away from traditional paper based alternatives where appropriate. The perceived benefits include:

- Reduction in the reliance on paper and printing due to storing all drawings on the devices (cost and environmental benefits);
- Not having to return to site offices so often (time benefits); and,
- Increased communication out on site.

These findings support the use of mobile technologies in the KM lifecycle as they are already utilised for other activities. This reduces the barriers of a 'lack of resources' and 'resistance to change' towards any developed framework that incorporates mobile technology usage.

5.3.5.3 Building Information Modelling

It was found that the use of BIM is very much in its infancy. BIM was not used on this project; however it was stated as being trialled on other projects that have recently commenced. This was said to be due to acknowledging the need to be in a position to fully utilise BIM on all government projects by 2016. It appears that such a government initiative is likely to accelerate the adoption rate of BIM in the near future. As such, solutions to many of the obstacles that would otherwise hinder BIM adoption (see Section 2.9.5.2) are viewed as being sought much more readily than if government intervention had not been forthcoming.

A mutual characteristic of the two organisations that enables them to embark on the implementation of BIM more readily than other organisations is their size. With both the main contractor and the design organisation being large multinational organisations, a greater degree of investment in training and new processes was observed. Similarly, the projects that they both target as a result of their respective sizes compliment the use of BIM. This is due to them tending to only target large projects such as hospitals which are ideally suited to the use of BIM (AA). As such influential factors on the adoption of BIM have been identified as:

- Size of the organisation;
- Size of the project; and,
- Government intervention.

A significant challenge to the adoption of BIM was identified as needing to overcome the difficulties caused by inter-organisational use of BIMs. For example, it was stated:

> *"I think [the main obstacle facing the adoption of BIM] will be the sharing of the BIM model between the professions. There are some practical things that need to be done, such as ensuring that there are consistent drawing standards and things like that to ensure that the BIM model is consistent and accurate" (AA).*

This supports the newly adapted research proposition 4a.1 (see Section 5.3.5.3). This acknowledges that although BIM provides the potential to assist in the sharing of knowledge between project participants, it is currently at too embryonic a state for this study to align with. This is due to the significant degree of uncertainty that surrounds its final makeup in terms of ownership, inter-organisational processes and legal requirements.

5.3.6 Difficulties Foreseen and Potential Coping Strategies

5.3.6.1 Lack of Resources

A lack of resources such as time and funding are highly significant barriers to overcome (Tan *et al.*, 2011). These are viewed as being fairly interchangeable due to the ability to afford more time if an increase in funding is allocated to swelling the pool of employees. Therefore they will be discussed as synonymous.

Once more this barrier was seen as a highly significant barrier to KM practices. For example, the CPD stated that they thought *"time was always the driver;"* with the SPM believing that *"it is all down to time, we do not always have time to sit down and go through things."* Therefore the act of reflection and discussing matters that could have been improved, or would have been beneficial to include in future projects get deferred indefinitely in preference for attaining short term project objectives.

This barrier appeared as being less prevalent in large infrastructure projects, such as healthcare developments, compared with smaller ones. That is due to there being *"more opportunity to deliver these nice to haves on a large project than there is on smaller projects as* [on smaller projects] *they have less staff and they run out of time to do all of these tasks"* (CPD). Alternatively, the most beneficial coping strategy when implementing new initiatives of any kind was said to be to *"try and make it fit with what is already available, using current procedures and resources"* (SPM). This is supportive of the perspective that for a new feedback framework to be adopted it is critical that the exasperation of existing time and cost pressures are minimised (see Section 2.7.3.3).

5.3.6.2 Unsupportive Cultures

A further significant barrier hindering the extent to which KM initiatives are supported was that of unsupportive cultures. It was said that the organisational cultures of the main participants of this project was very supportive of KM and learning in general. However, this was not viewed to be the case throughout the industry, or necessarily from project to project. There was also differing perspectives noted from within the same contracting organisation to the extent to which they believe their organisation is open to learning from past mistakes, successes and the act of KM in general.

The CPD and the SPVD stated that they believed the contracting organisation was very supportive and open about discussing issues that had deviated from their planned course. However, this was largely attributed to the personnel involved and in particular, the effective working relationship the contracting organisation had with the appointed architects. This supportive and open culture was viewed as being beneficial in enabling ideas to be shared readily between project participants. In addition it was attributed to leading to a heightened level of confidence surrounding feeling comfortable with admitting mistakes rather than remaining silent. For example, it was stated that:

> *"There certainly is not the culture here that you should stay quiet and say nothing in case you might be wrong; it is far better to be wrong and be told why you are wrong instead of bottling it up. The younger guys we have working here, they are not shy, so there is not a problem in that" (CPD).*

As such, it was found that a supportive organisational culture is fundamental to enable learning to take place, with it needing to be created across organisational divides if effective on-going learning is to materialise. In the instance of this case, a fairly effective learning culture appears to have been developed both within the boundaries of the separate organisations and across their organisational divides. In general however, the SPM believed that the industry still requires a cultural change towards becoming more open and honest if buildability issues were to be highlighted and learnt from. They stated that they deemed the industry as not doing enough to reflect on past issues in order to continuously improve; although this is gradually improving. The repetition of organisational relationships between the main contractor and the design team has however, been shown as a beneficial strategy in nurturing such a supportive culture.

5.3.6.3 Nurturing Project Relationships

The partnership arrangement adopted was described as a 'preferred working relationship' rather than a more rigid strategic partnership. This means that when a healthcare project tender is won, the main contractor prefers to appoint this architectural organisational where possible due to their positive previous experiences. However, this is not an exclusive arrangement as they do also use other architecture firms for both healthcare and other sector projects when they feel it necessary.

The main advantage advocated for such partnerships was the on-going understanding and trust between the two organisations. This leads to greater efficiency in the start-up phase of projects due to an understanding between the parties already being in place. For example, in considering Carlile's (2002) three barriers to sharing knowledge across organisational divides, the nurturing of an on-going relationship between two organisations is viewed as reducing all three. These barriers are in the form of syntactic (language); semantic (meaning); and, pragmatic (practice) (see Section 2.7.2).

However, it was apparent that it is not as simplistic as forming a strategic or preferential alliance with another organisation for these relationship benefits to naturally materialise on all new projects (see Section 5.4.4.3). The key to the success of this project was the appointment of some of the same personnel from both organisations that had previously worked together recently (SPM). In comparison, the amalgamation of the same two organisations on a completely separate healthcare project did not perform to the same high standard, due to the same understanding not having been nurtured (SPM).

This finding demonstrates that although partnerships have the ability to deliver more straight forward nurturing of relationships, if a new project constitutes the forming of a completely new project team, the syntactic, semantic and pragmatic barriers to knowledge sharing across divides will once more need to be broken down. As such, in agreement with other authors, partnering appears to present an effective knowledge sharing technique (Latham, 1994; Barlow and Jashapara, 1998; Kamara *et al.*, 2003). However, this study deviates from these perspectives in that partnering on its own appears limited. The aspect of such arrangements which are most critical to achieve on-going learning is the repetition of key personnel working together. This prolongs the trust and understanding that they experience and is essential for learning (Barlow and Jashapara, 1998), but can only be fostered on a personal and not organisational level. This shows substantial support for research proposition 8 (see Section 5.4.1.2); however, it has drawn attention to the need to test what effect the repetition of personal relationships has on subsequent projects. This additional research proposition reads:

> **Proposition 8a** – Effective relationships that enable knowledge transfer and learning are personal and not organisational, so for on-going natural learning to emerge from partnering, repetitive personnel is essential.

5.3.6.4 Knowledge Protection / Hoarding

Even though the effective on-going relationship between the main contractor and design team has previously been said to lead to a more open and supportive culture (see Section 5.4.6.2), the tendency to withhold knowledge from others was detected. This was observed through the SPM cautioning that even within a partnering agreement *"you need to be careful what you disclose to other people and what you disclose to competitors because there may be things that you do not want other people to know we are doing well here because it is good for us."* This is despite the CPM suggesting that any attempt to protect knowledge is not worthwhile due to the designers that they employ also working for their competitors. Therefore, good ideas are shared quickly with competitors inadvertently.

Accordingly, a move towards the mind-set adopted by the CPM, that there is less worth in attempting to protect knowledge than actually openly sharing it, would have a beneficial impact throughout the industry. However, it is evident that the desire to attempt to protect competitive advantage remains and is thus resulting in a reduction in knowledge sharing between construction and design professionals.

5.3.6.5 Improving support for KM

This section examines the findings related to research proposition 7, which stated that a heightened priority given to lessons learnt from top level management would lead to more time and effort being allocated to the on-going activity throughout the project (see Section

5.4.1.2). Findings of this study have since adapted this proposition by including the need for client involvement in ensuring that such buildability related learning objectives are prioritised (see Section 5.4.4.3).

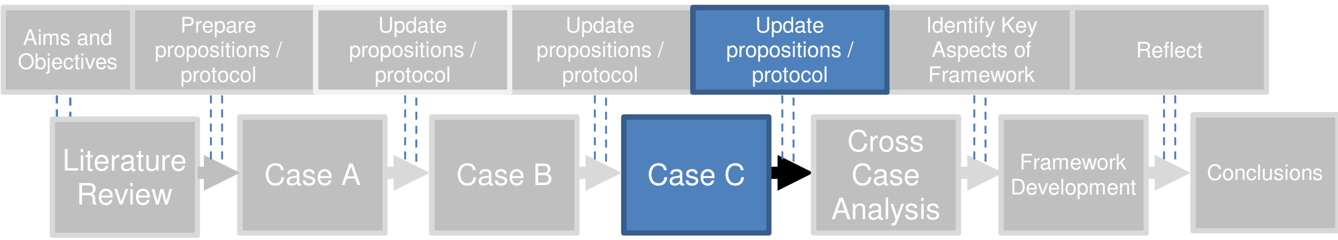
Through testing this proposition it was evident that this strategy would indeed encourage greater attention and commitment to be assigned to learning activities. The SPM believes that what is needed is to keep encouraging, involving people and raising the awareness, similar to that of quality of product, sustainability and health and safety. At present these issues are elevated in priority compared to that of both improving buildability and KM in general. For this to change on a project level, the needs and benefits of improving in these areas need to be understood at a higher level, before they are taken seriously at the project level. For instance, the SPVD recommended that *"it is all about communication at a high level and then driving that down."* Similarly the SPM suggested that this would have a positive effect on the effort attributed to the activity.

Consequently, what is required appears to be twofold. Firstly, a greater appreciation for the benefits of on-going learning needs to be understood by top level management. This being said, it has been noted that this is difficult to achieve due the difficulty in accurately determining the benefits (see Section 2.9.5.1). Secondly, a form of benchmarking to measure performance on a project level, similarly to that of other targets such as zero defects (quality of product) or zero harm (health and safety) would appear to elevate the priority given to knowledge sharing. No known benchmark to measure such an aspect of a project has been developed; however, it was noted by the AA and the SPM that such discussions are marginally covered within the PPE, although not in enough detail. This therefore directs towards a clear opportunity to improve current practices relatively simply by incorporating a form of measurement of performance regarding the effectiveness of knowledge sharing during the project. This could be integrated to feature during reviews such as PPEs. Caution must be noted however to diverge away from fostering a blame culture which causes employees to fear being exposed for making mistakes, through appropriate communication from top level management (see Section 5.4.4.2: Failures and Mistakes).

5.3.7 Summary of Findings

This analysis has highlighted multiple areas of interest which include supportive and converging findings to both past research and the developed research propositions. To investigate these findings further such points will thus be incorporated into the subsequent case study design. A summary of the key research findings arising from this case study analysis include:

- The degree to which buildability issues can be reduced is highly dependent on the degree to which early integration between all project participants is achieved;
- Causes of buildability issues include; a lack of early integration; differing desires/objectives; on-going client adaptations; and, the construction methods selected;
- A move towards a P21 or PPP design and build framework in preference of a traditional DBB arrangement enables early integration ;
- Repetitive teams enable the earliest possible integration to be achieved;
- Partnerships can assist learning, however relationships are personal and not organisational and therefore key teams should be maintained where possible;
- Negative effects of buildability include; increased rework, time slippage, increased costs, lower quality; and, the unnecessarily reinventing the wheel;
- Detailing related knowledge appears to be the most beneficial to be fed back from construction to the design phase;
- Top level management currently do not appreciate the full extent of benefits to materialise from effective KM and on-going learning;
- Short term objectives are prioritised over long term learning objectives;
- Need to incorporate some form of measurement mechanism to heighten the priority assigned to learning initiatives;
- Improved communication and reassurances are needed to foster a more open culture willing to identify mistakes and failures;
- Current KM processes consist of multiple drawbacks including a lack of live capture of knowledge due to over emphasis on learning through PPEs;
- Focusing on mistakes and failures omits the potential learning that can be gained from successes or manageable errors;
- Larger organisations/projects are able to conduct more resource intensive KM techniques, which usually are those designed to transfer tacit knowledge;
- The efficiency of the developed framework is a critical success factor as time constraints are a major barrier to learning during healthcare projects; and,
- Communication and visualisation help transfer tacit knowledge.



5.4 Case Study C

This project was chosen to test literal replication with regards to the findings of the initial and secondary case studies. In particular, it was desired to test proposition 8, which revolves around the benefits of utilising cores of successful teams repeatedly (see Section 5.4.1.2). The case selected in this instance therefore enabled the full array of propositions emerging to date to be tested.

5.4.1 Characteristics of the Organisation and Project Forming Case Study C

The final case study organisation and project was selected due to them posing the characteristics typical of enabling continuous learning to materialise. This was due to the contracting organisation being awarded multiple sequential projects within the P21 framework. Furthermore, the projects consisted of the same client and for the majority of the projects (five out of the six), the same design team.

This case was attractive to investigate the contrast between the benefits of utilising the same core teams repeatedly compared to altering the participants involved. Literal replication of the findings of the secondary case study was therefore expected regarding research proposition 8 (see Section 5.3.6.1). This is in the form of the significant benefits that utilising the same core team repeatedly can have towards continual learning objectives. This was enabled due to the similarity of the organisation's and project's characteristics, with the only notable difference being utilising the same core team repeatedly. The overall organisational characteristics and those of the sequential projects are summarised in Table 5.5.

Table 5.5: Case Study C Organisational and Project Characteristics

Organisational Characteristics
The case study organisation has a significant presence and experience in the delivery of UK healthcare infrastructure project
They have a dedicated healthcare branch of the organisation which is a member of the P21 procurement framework
They have delivered over £500million worth of healthcare projects through the ProCure21 procurement framework
They are a large multinational organisation with revenues of approximately £2billion and employ in excess of 11,000 employees worldwide

Project Characteristics
Overview of subprojects: - Project A - £5million integrated breast unit; - Project B - £4million day surgery; - Project C – £8million intensive care unit; - Project D – £2.5million septic pharmacy; - Project E - £3million operating theatres; and, - Project F - £6m multi-storey car park.
Each of the subprojects were delivered through the P21 framework;
The main contractor, design and client personnel were present throughout the competition of all of the subprojects;
The subprojects incorporated a range of construction methods including traditional and prefabricated elements and therefore were viewed as possessing a wide variety of potential lessons learnt.
None of the projects were viewed as being particularly unique in any way. They consisted of new build or refurbishments/extensions to existing facilities on a healthcare site that continued to operate throughout.

5.4.1.1 The Research Setting

This case consisted of three main data points. Two of these were in the form of in-depth interviews with a key member of both the contracting and design teams. These key perspectives were the project manager (construction) and the lead architect who was also a director of the design organisation involved. Due to all of the sequential projects having been completed approximately six months prior to this case study being conducted, project participants had dispersed and therefore access to other data points were unattainable. However, the ability to assess the full learning potential of the repetitive team arrangement was deemed as being more achievable from this reflective point of view, rather than if the projects were still in progress.

The interviews were supplemented by an analysis of a final data point which consisted of the gathering of empirical material related to each sub-project. This was in the form of organisational reports, magazine and internet press releases, drawings and outputs from their KM system.

For conciseness each interviewee will be referred to as the following acronyms hereon in:

- Construction Project Manager (CPM)
- Lead Architect (LA)

5.4.1.2 Research Propositions to be tested in Case Study C

The accumulation of the literature review, followed by that of case studies 1 and 2 (see Sections 0 and 0 respectfully), has resulted in the research propositions continuously evolving since they were initially set (see Section 4.6.2). This includes research propositions being strengthened, adapted and discredited, with additional propositions emerging in some cases (see Appendix B.1). The additional propositions that emerged or were altered due to the findings of Case B are as follows, with the rest of the propositions remaining the same (see Section 5.4.1.2):

> **Proposition 2b.1** - Vital tacit knowledge can be captured and fed back to designers through the utilisation of oral and/ or visually based formats.
>
> **Proposition 7.1** - a heightened priority given to lessons learnt from clients and / or top level management would lead to more time and effort being allocated to the on-going activity throughout the project.
>
> **Proposition 8a** – Effective relationships that enable knowledge transfer and learning are personal and not organisational, so for on-going natural learning to emerge from partnering, repetitive personnel is essential.

5.4.2 Establishing the Need for Buildability Feedback

5.4.2.1 Negative Effects of Buildability Issues

The most significant negative effects of buildability issues were that of increased time and costs. For instance, with some of the sub-projects of this case being in the form of refurbishments of existing facilities, there were noted cases where the design of the refurbishment could have been adapted to enhance their buildability. This was viewed as being without altering the facility's performance or end quality. For example, the CPM stated that in the en suite shower unit areas, if the design was altered to raise the floor by 150mm then a great deal of work to remove 150mm of the concrete floor slab, putting in gullies and re-bonding the slab, all whilst being careful not to jeopardise the slab's structural integrity could have resulted. This would thus have reduced the time and cost taken on this task and improved the value for money experienced by the client.

Similarly from a design perspective, it was felt that unless all parties were conscious of the need to adopt a buildability focus, the end product will inevitably *"take longer, be harder to maintain, be more expensive and the client will not feel that they have got value for money"* (LA). Ultimately however, the specification of the overall facility is governed by the needs and wants of the client. In the above example of a solution being offered that would have improved the buildability of the flooring of the en suite shower units; the final decision of what course of action to take was that which best aligned with the client's needs and desires. In this case the decision was taken by the client to align with *"how they have always done it"* (CPM) and therefore resulted in a more difficult to build design for this aspect.

To achieve such an understanding the greatest influential factor suggested by both design and construction perspectives was that of early integration. In this case that was facilitated firstly by the adoption of the P21 procurement method, where the contractor is appointed at the start of the process, with the design team thus being appointed by them. As a result, the contractor and client form a partnership, with the overall makeup of the project most closely aligning with that of a design-build configuration.

Unconventionally, this early integration could be instilled from the first project into following sub-projects due to the appointment of the same contractor and architects in each sub-project. A greater investigation into the benefits and drawbacks of the adoption of this repetitive arrangement is conducted later in this analysis (see Section 5.5.6.1). Such integration was said to lead to becoming team focused and instilling trust between parties at a much earlier stage than is the case with traditional DBB contracts. For example the following viewpoints demonstrate that in terms of early integration, the P21 framework was deemed as being beneficial over alternative procurement methods:

> *"I think that P21 makes it a lot easier because you are all involved earlier on" (CPM); and,*
>
> *"The advantage of the P21 procurement procedure over the traditional method is that the contractor is involved in the design process and they then bring their buildability expertise to the table during those design stages. So the buildability regarding the methods of construction and the materials used and things like that, which have big cost implications, are introduced right at the beginning of the design process" (LA).*

Once more, in the case of improving the en suite shower unit floors, this early integration enabled the contractor's suggestions to be tabled and considered at the stage that was most critical (i.e. planning and design). If such suggestions had been made once the contractor was involved under a traditional DBB arrangement, the ability to consider design alterations would have been reduced. This is due to the implications it would have on other aspects of the facility that had already been built. If they were to then be incorporated, the necessary changes would result in significant raised costs and time delays due to the need to conduct rework. This supports the findings of previous authors concerning the *Pareto Principle* (see Section 3.2.4.3), where the earlier decisions can be made, the greater the potential to positively impact the final outcome of the project (Griffith and Sidwell, 1993; Pulaski and Horman, 2005; Lam *et al.*, 2006). This is illustrated in Figure 5.11, which has been adapted from Figure 3.6 (see Section 3.2.4.3) to demonstrate the viewpoints observed within this case. As can be seen, a move towards adopting a P21 procurement framework (i.e. D&B) has a greater ability to incorporate a wider breadth of expertise at the most critical stage of the process in terms of pivotal decisions being made.

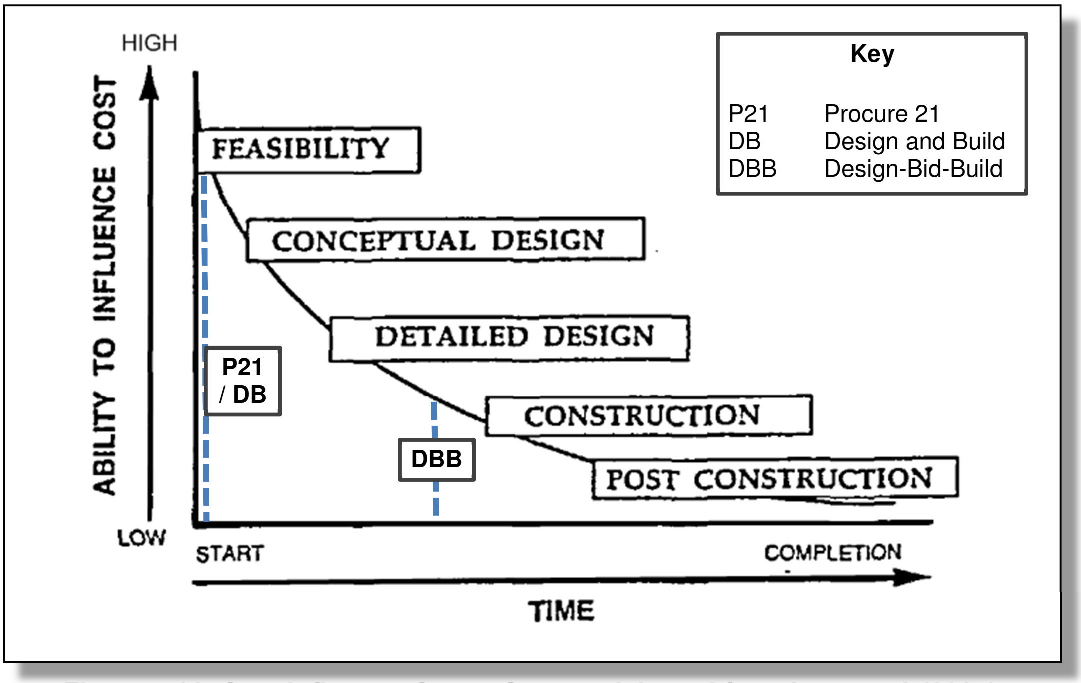


Figure 5.11: Cost Influence Curve. Source: Adapted from Lam *et al.* (2005)

These findings have three noteworthy implications within the context of this study. Firstly, a buildability focus is paramount if good value solutions are to materialise. For example, if the efficiency improvements of the industry required by Egan (1998), Latham (1994) and Wolstenholme (2009) are going to come into fruition, an industry wide focus towards improving buildability is required. This is facilitated by the second point of interest, in the form of; the need to understand, as early on in the project as possible, the needs and wants of the client. This heightens the likelihood that buildability related decisions are well aligned with them and as a consequence, the need to conduct rework will be reduced.

Finally, these were both observed as being facilitated by integrating the core of the overall project team as early on in the project as possible. This was achieved fairly naturally within this case due to the decision to adopt the P21 procurement method. As such, this indicates towards the beneficial nature of adopting a D&B configuration, in preference for the traditional DBB due to the benefits that nurturing a cohesive team from the outset of a project can offer.

This once more leads to indicating towards the beneficial impact of attempting to maintain the core of the overall project team where possible (i.e. supporting proposition 8; see Section 5.5.1.2), due to already having likely developed an effective understanding through working together previously. The strength of this argument will be deliberated further later in this analysis (see Section 5.5.6.1).

5.4.2.2 Regularity of Buildability Issues

Buildability issues arose throughout the project and were seen as inevitable. However, it was believed that efforts put in at the start of the project were fundamentally important in lessening the degree to which unexpected issues arose later. For example, the LA specified buildability workshops that were conducted at the outset were *"certainly cost effective"* as they enabled many of the pitfalls and risks of the project to be identified and mitigated against at a much earlier stage. This consisted of constructing sample rooms, combined with conducting workshops and presentations prior to the project commencing. This allowed areas of the design to be explored in advance of them being built. Accordingly, the client could then alter details; clashes could be detected and in general prospective concerns or potential buildability could be communicated amongst each other (CPM).

The overarching aim of these workshops and other demonstrative mediums were to reduce the uncertainty of the forthcoming project. Although the architects and contractor involved in these projects had completed numerous preceding projects; the unique characteristics of each new project results in levels of uncertainty. Once more in support of the *Pareto Principle* (see Section 5.5.2.1), efforts made to bring forward making key decisions has a significant effect on being able to reduce or avoid buildability issues. This is due to the increased flexibility and variety of options that remain open in the earliest stages of projects, which subsequently become increasingly more difficult to take advantage of the further the project progresses. Consequently, this supports research proposition 8 (see Section 5.4.1.2) as the early integration or repetition of teams enables early cohesion to be established.

These findings, in conjunction with those articulated in Section 5.5.2.1; indicate strong evidence towards the beneficial impacts of moving towards adopting a D&B project arrangement. This premonition is cautioned however by the CPM of this case, as in some instances projects deemed as D&B do not integrate the contractor at the earliest possible stage. What often occurs is that the client approaches an architect who together establishes the basic design prior to involving the contractor. The design team are then appointed to the contractor, who, only then get the opportunity to look at the conceptual designs. This is already too late to incorporate key buildability knowledge, unless a potentially substantial amount of rework is to be conducted and/or the client's desires are adapted. As such, the need for a buildability related feedback framework within both this configuration and that of a traditional DBB format, appears to be unquestionable, due to the need to transfer key buildability knowledge to proceeding stages of the construction lifecycle.

This being said, a move towards D&B contracts in their purest sense, where the contractor is initiated right at the outset of the contract appears to enable the most straightforward, natural and effective means of early integration. This discovery presents noteworthy implications for research proposition 1, which states *"a feedback loop between the phases of design and construction could improve the level of vital learning conducted within healthcare infrastructure projects."* This is so because this proposition appears to only hold true within the context of traditional contract arrangements such as DBB, where the introduction of the contractor is not integrated into the project team until after the pivotal stage of design. In this scenario, the need for feedback loops between design and construction from past projects appears unquestionable, as without transferring such knowledge, it cannot be incorporated in future projects.

In the instance of D&B contracts, it has been demonstrated that the need for a knowledge feedback loop between design and construction is in fact lessened. This is due to the contractor being involved from the outset of the project, which thus enables them to incorporate their knowledge and experiences more easily. However, where the need for a feedback loop remains even within pure D&B contracts is enabling the pools of knowledge held by each participating party to swell further. For example, for the design side to learn from projects it is crucial that the effects of developed solutions are fed back so that they can be reflected upon. Accordingly, this can then be installed in the early stages of the next project, whether early integration is achieved or not. As a result these findings have supported and disputed proposition 1 (see Section 5.5.1.2); with the key factor determining its accuracy, being the type of contract that is apparent.

5.4.3 Types of Valuable Buildability Knowledge

5.4.3.1 Avoidable Buildability Issues

A key area of transferrable knowledge, which was viewed as both achievable and desirable, was that of avoidable buildability issues. For example, the CPM stated that *"we have done a hospital refurbishment here, but we are not the first people ever to do so."* Therefore through the transfer of knowledge, both within their organisation (across projects) and to future project participants (across organisations) the opportunity to mitigate such avoidable issues is heightened.

This is an area that demonstrates support for the need to develop and implement more effective cross organisational feedback loops if areas of unnecessary inefficiencies are to be reduced (i.e. supporting propositions 1 and 2). A review of how the contracting organisation attempt to achieve this is deliberated later in this analysis (see Section 5.5.4).

5.4.3.2 Construction Techniques and Materials

From a design perspective, knowledge they appeared to value the greatest was that of construction techniques and materials. This is due to having to make design decisions concerning these factors, which take into consideration the upfront costs, the buildability implications, the client's desires/preferences, and the life cycle / maintenance costs. The height of this desire is in line with Fischer and Tatum's (1997) classification of buildability knowledge (see Section 3.2.2).

This is unsurprising as if the correct decisions are to be made, they must be well informed. Therefore, due to the design team not having the opportunity to observe the consequences of the decisions made, access to such knowledge is desirable to heighten the likelihood that future decisions are well informed. The strength of this finding is significant, as it not only demonstrates a need for the proposed feedback loop (i.e. supporting proposition 1), but it also indicates what areas of knowledge would be of greatest benefit if shared.

5.4.4 Current Knowledge Management Procedures

5.4.4.1 Methods Utilised to Capture lessons Learnt

Evidence Gathering

The main contractor captures lessons learnt in a form of gathering *'evidence'* from previous projects. This is in the aim to be able to more fully communicate their perspectives with those that are from differing backgrounds. For instance, the CPM stated that:

> *"We evidence gather to persuade people to do things differently, for example the architect to change details according to what we have found works best from other projects etc."*

Such evidence is currently gathered either informally (in the form of photographs) or in a formal report (with photographs attached), which is then posted onto their KM intranet system. This is therefore an example of how recorded evidence of previous problems is viewed as being a valuable aid in communicating to other participants what the issues were, how they were overcome, and what effect they had. Furthermore, the perspective that increased learning leads to over standardisation (see Section 2.7.2.4) appears to be out-dated. The current mind-set of designers seemingly having shifted away from a fear of restriction, towards actively seeking more knowledge and information to continuously learn.

Design Team Meetings

The main method of on-going knowledge transfer and capture is that of weekly or fortnightly DTMs. These involve the key members of the design team, the contractor and the client. Unfortunately, due to this case being conducted retrospectively, the opportunity to observe first-hand the dynamics of such a meeting was not possible. However, the main benefits and drawbacks, as well as how they were assembled and conducted were able to be established from the discussions held with the interviewee participants.

The main beneficial aspect of these meetings was the ability to communicate and demonstrate each party's points of view, face-to-face and more succinctly than was believed would be possible through other methods. As such, they were able to gain from other people's knowledge and experiences as well as conveying their own. For instance the LA stated that:

> *"At these meetings you can actually communicate and demonstrate effectively what you are saying and you may benefit from support from others" (LA).*

Accordingly, the face-to-face communication was viewed as enabling a greater degree of understanding to be generated for those that took part, thus supporting recognitions made earlier (see Section 2.2.4).

The main undesirable aspect of this method is the opportunity for some members to be obstructive and not open to the suggestions of others in preference for sticking to their own beliefs (LA). This creates a hospitable environment, and one that is not suited to effective knowledge transfer. Gieskes and ten Broeke (2000) and Hari *et al.* (2005) stated that through having an overly centralised organisational hierarchy, where learning is perceived to only be the responsibility, and for the benefit of, a few enlightened people (Keegan and Turner, 2001), a strong '*us-them'* culture can be created. This being said, the above perspective supplied by the LA indicates towards a '*me-them*' culture being apparent in some individuals due to competition. The opportunity for an '*us-them'* culture was detected when the obstruction is due to organisational and professional divides. For example, designers obstructing the viewpoints of members of the construction team, or vice versa.

The strong motive for this obstruction was suggested to be due to wanting to reinforce their individual beliefs and instincts (LA). To establish assurances that their initial beliefs and understanding of the situation are accurate, there is a strong desire to maintain their proposed solutions in preference for being open to alterations. As such, the need to further nurture a supportive knowledge sharing culture is apparent within some divisions of this case.

In disagreement with some of the methods of encouraging knowledge sharing and improving the supportive culture within the project arrangement (see Section 2.7.3.2); the LA stated that on most occasions the most effective means of overcoming this resistance is people power. For example, if it is only one individual that is being obstructive, the LA proclaimed that it would be *"obvious"* and therefore it is likely that the majority would overwhelm this minority obstruction. Alternatively, if this did not have the desired effect then *"appropriate managerial procedures need to be taken* [such as] *removing that person form the team"* (LA).

This is viewed as an abrupt measure and one that would not lead to a voluntarily open culture but one that is contrived and based on fear. Alternatively, through more supportive means aimed at heightening the employees understanding of the greater beneficial impact that individual and OL can have on themselves, others, the project and the organisation, overcoming this restrictive behaviour is viewed as being more likely to be achieved. For example, top management leadership, support, commitment and role models (Robinson *et al.*, 2001; Kivrak *et al.*, 2008; Ruikar *et al.*, 2009), incentives and rewards to encourage knowledge sharing activities (Kivrak *et al.*, 2008) and/or providing understanding into what insights and information are of importance along with the reasoning behind them (McDermott, 1999) are all viewed as enablers to adapt such behaviour. This is further indication of the worth and need of improved top level support and communication if a supportive knowledge sharing community is to be nurtured, thus supporting proposition 7a (see Section 5.4.1.2).

The degree to which this barrier is apparent is dependent upon the individuals involved; however, it emerged that the greater the levels of trust between the project parties, the more likely the participants are to welcome each other's ideas and input. For example, the CPM suggested that in terms of the relationship between the client and the contracting team, the openness of communication improved as the length of time progressed. Furthermore, a fortunate circumstance that enhanced this further was that of the capital planning team and client's site manager moving into the same site offices as themselves. This encouraged coherence, with the increased levels of interaction drastically improving the sense of trust between them.

This finding‘s significance is twofold. Firstly the establishment of trust and understanding between project participants is fundamentally important if a philosophy of openness is to be fostered. This has been seen as most effectively being nurtured through involvement, communication and interaction amongst the participants. Secondly, on-going trust and openness can be safeguarded if the same project teams are maintained from project to project. Within this case, the inevitability of certain members moving onto other projects was still apparent; however, the preserving of the majority of the key members enabled the levels of trust and understanding to be extended. Thus the strength of proposition 8 (see Section 5.4.1.2) and 7a (see Section 5.5.1.2) is further supported.

Post Project Evaluation (PPE)

At the end of each project, a PPE was conducted to assess the project’s degree of success. This includes, reviewing how well the project went, what went wrong and what areas could have been improved upon (LA). Accordingly, the aim of the PPE is to identify key successes so that they can be replicated in future projects, as well as areas in which improvements can be seen.

To achieve an honest and open review, representatives from the construction, design and client’s capital planning team were all present at this review. The review was then encouraged to be as open and as critical as it needed to be, as its sole aim was to continuously improve (CPM). This is especially important within this case, as identified improvements will directly benefit those who have expended resources in this process, due to them being involved in the following subprojects.

The review was said to be *“all-encompassing”* in terms of the types of issues discussed (CPM). This included; safety, buildability, relationships, communication and quality. Knowledge was also shared between parties from other projects. For instance, the LA stated that:

> *“Both the design team and the contractor's team can bring to the table feedback from other projects that they have done elsewhere and with other organisations. So as commercial architects we can take lessons learnt in the commercial market and bring them to the table of the healthcare market” (LA).*

This shows the transferability of some lessons across organisations and more importantly, across sectorial divides. As such, lessons learnt within the healthcare sector are not necessarily limited to being reapplied solely within the same sector. This being said, the LA continued by suggesting that the transferability of lessons learnt is subjective and there are no defining rules that govern which can be applied in different scenarios and which are specific to the project in which they arose. For example, *"there are elements of an office block that are not applicable to the healthcare facility. But yes we do try and introduce things and bring that experience across."* It is therefore apparent that conducting lessons learnt practices are critical in expanding participants' experience. It also appears valuable in raising the awareness of individuals in terms of what they know, as knowledge that may seem mundane and not out of the ordinary may not have occurred to other members. This can especially be the case between members of differing qualifications and responsibilities.

An issue with this process is the difficulty in achieving a purely honest and open feedback session in the presence of those that the praise or criticism is about. For example, the CPM stated that *"when you are in a room with 30 or 40 people, some people do not feel comfortable saying what they actually think."* Accordingly, vital areas for improvement are being tolerated rather than highlighted and improved upon; thus leading to the continuation of non-idealistic strategies in the future. In relation, it was cautioned that encouraging a truly open assessment of issues could also lead to a blame culture occurring. For example, the CPM continued to suggest that initially:

> *"You may be faced with silence [when asked if anything could have been done better], so we [the contractors] tend to lead by raising something that we thought could have been done better such as the time it took to get the drawings signed off. However, others then think that they are having a go at me, so what I did not like was A, B and C, and it can go on a bit like that."*

Positively, this formal in person review session is complimented with a cooling off period. The initial session is recorded and then documented in reports which are circulated to the members that took part. They then have the opportunity to review them. Through reflecting upon the details that are included, any corrections or insertions that need to be made can be included. Once complete the finalised reports are once again circulated so they can then be distributed throughout their respective organisations.

One of the most popular drawbacks targeted at this process is that of it not being conducted live (see Section 2.8.5.1). The participant's inevitable inability to recall all of the details concerning events thus causes knowledge deterioration / loss. However, interestingly, both the CPM and the LA stated that it was a very effective means of achieving its desired goal. This was attributed to it being complimented with design team meetings throughout the project, which identified issues for improvement along the way. This was viewed as important to act as reminders of what the key issues were and therefore defend against overly concentrating on the major issues or simply those that happened most recently.

As such, this PPE process has incorporated suggested improvements highlighted during the literature review (see Section 2.8.3). These include;

- Not being limited to the construction phase in isolation; and,
- Reducing the dependence on the participants' ability to recall learning opportunities.

This being said, there is still room for improvement. The main area for this is attempting to capture and codify learning instances throughout the duration of the project, rather than simply logging them to prompt their recall at a latter point in time. For example, Carrillo (2005) states that through capturing knowledge live in a structured and codified format, it enables the PPE to act as a consolidation session of these learning instances. As such, the quality of the knowledge captured is likely to be heightened.

Cross-Project Communication

A further method that attempts to disseminate lessons learnt to as many avenues of their organisation as possible is through cross-project communication. There are two strands to how this is achieved; online through an intranet system, and, face-to-face through organised cross-project meetings. The format in which this is conducted in both cases most closely aligns with that of communities of practice (see Section 2.8.4.1).

The online system consists of a store of their captured best practice documents that have been compiled as a result of similar lessons learnt activities, as well as posts from individuals that have felt the inclination to post something that they believe is of use to others. The system is supported by their intranet platform and it is split into segments (such as healthcare) to assist users in locating useful information. The benefits and drawbacks of this online KM intranet system will be discussed further in Section 5.5.4.3.

This is supported by conducting monthly healthcare meetings, where teams undertaking healthcare projects get together to discuss issues that have arose in the past, future projects that are coming up, and in general sharing their experience (CPM). This was described by the CPM as a much more effective means of transferring knowledge as people *"take things in more"* and thus demonstrates the usefulness of two-way communication in transferring tacit knowledge (see Section 2.2.4).

The main drawback of this process is limiting knowledge transfer to the healthcare department of the organisation. It emerged earlier that some lessons learnt are transferable across sectors such as between healthcare and commercial buildings (see Section 5.5.4.1:

Post Project Evaluation). Therefore to restrict the dissemination lessons is viewed as reducing the beneficial impact of their KM procedures. This is further compounded due to it being stated that the workforce from the construction team appreciate that the time and effort spent being part of these activities not only help themselves, but particularly benefits future projects that they are to be involved in. This was shown through the CPM declaring that:

> *"It is frightening because you always think the team is too busy to do these things, but it is always worthwhile. For example just going in and asking if we could pop our heads around to see what goes on really saved us lots of work and time" (CPM).*

Therefore, short-term time pressures have not resulted in neglecting the act of reflection necessary for learning. In comparison, an appreciation for the benefits of undertaking long-term learning has been detected. This is despite two substantial deterrents:

- The time lag between experiencing the benefits of long-term learning goals being substantially greater than that of reaping the rewards of achieving short-term project goals (Campanella, 1999; Carrillo *et al.*, 2000); and,
- The fact that very few clients have a requirement for lessons learnt (Carrillo, 2005).

Interestingly, in terms of the second deterrent, the opposite was the case. It was an incentive to conduct lessons learnt and continuously improve due to the client's aspiration to instil the knowledge gained from proceeding projects into subsequent projects that they ultimately undertook. The LA believed that their ability to demonstrate a high regard for learning from previous buildability issues was definitely a contributing factor in gaining the contracts for the subsequent work. This aligns with research proposition 7.1 (see Section 5.5.1.2). Accordingly, it has been demonstrated that through a widespread appreciation for the long-term benefits of learning, both from top level management and the client, the barriers faced can be overcome, including the industry specific barriers identified in Section 2.7.2.

5.4.4.2 Types of Issues Currently Captured as Lessons Learnt

<u>Success and Failures</u>

As mentioned earlier (see Section 5.5.4.1), the feedback generated through reviews focus both on successes and failures. This was attributed to the need to learn from failures to put them right, as well as the desire to repeat successes in the future. Encouragingly the processes assessed within this case appear to aim towards extracting the learning potential from these two key areas. As such it is felt that a fuller knowledge base is to materialise.

Safety

An area in which it was stated that construction organisations have a strong interest in collecting lessons learnt upon is that of safety issues. Although not directly related to the focus of this study, a finding of interest is the impact that senior management have in achieving this learning goal. Due to their desire to improve the number of safety issues experienced on each project, they were viewed as prioritising this learning objective. For example, the CPM stated that the cross-organisational learning discussions *"tended to be a lot about safety",* with at least two directors in attendance to discuss how this can be improved. This was said to ensure that it is conducted thoroughly and so that it is understood by all who attends. Consequently this leads to an increased assurance that it will be *"passed onto subcontractors and site staff"* (CPM).

This is once more a demonstration of how the priority level assigned to learning objectives is a key determining factor to the extent to which it is achieved. This is due to such objectives being incorporated into the overall assessment of how successful a project has been and therefore results in increased efforts by the project team to achieve them. As a result, this demonstrates further support for research proposition 7.1 (see Section 5.5.1.2) and the need for a form of measurement.

5.4.4.3 Supportive KM Techniques Utilised

Framework Collaboration

The main KM technique used is that of a framework in the form of the P21 framework (see Section 5.3.4.3). Throughout this write-up the noted benefits of such a framework collaboration have been established, with the greatest single benefit undoubtedly being in the form of integration of the construction team from the project's outset. Further knock on benefits have been seen to include:

- Understanding all party's needs and wants much earlier on in the process;
- Greater opportunity to utilise the full extent of the knowledge base available, during the most critical early stages of the project;
- More opportunity to develop trust and communication channels with differing fragments of the process to overcome the difficulties that presents (2.7.2.3); and
- Reduced buildability issues; and,
- A more cohesive team dynamic that leads to cost and time savings.

As will be discussed further in the analysis of the opposing KM technique, in the form of reassignment of employees (see Section 5.5.4.3: Reassignment of Employees), this technique does not support transferring knowledge beyond the boundaries of the project. As such, in line with the acknowledgement of Kululanga *et al.* (2001) frameworking as a sole technique is insufficient in supporting the entire KM lifecycle. Accordingly, the drawbacks of this method need to be bridged by the utilisation of supportive KM techniques or technologies that excel in the dissemination of knowledge. Incidentally this indicates towards research proposition 3 (see Section 5.3.1.2) holding true.

Communities of Practice

The main method utilised to capture knowledge and lessons learnt from both individuals and each project is through communities of practice. As previously discussed (see Section 5.5.4.1) post project evaluations and other lessons learnt procedures have been identified within this case. These expand to include design team meetings, client reviews and cross-project communication. These all resemble communities of practice due to them involving people who share work experiences, problem agendas, or similar learning opportunities (Hari *et al.*, 2005). An additional CoP to be identified, which so far has only been alluded to (see Section 5.5.4.1: Cross-Project Communication) is the intranet KM system, which aims to share accounts of best practice. This will be discussed further later in this analysis (see Section 5.5.4.4).

Mentoring / Training

This form of knowledge sharing was identified as being evident. It is delivered through formal training and mentoring sessions which aim to enhance the participants' skills. For example, the CPM highlighted that when employees need to progress their skills such as improving their technology literacy, there are formal training sessions that the organisation provide to strengthen these areas. These were viewed as vitally important in ensuring that the employee felt confident with their responsibilities. Without this, a lack of confidence was said to greatly heighten the employee's anxiety levels, which thus can lead to further complications such as resistance to change.

Support is therefore viewed as fundamental in any change initiative to ensure those involved feel comfortable with what is expected of them. However, for the purpose of knowledge transfer, training and mentoring is resource intensive and therefore not practical to transfer vast amounts of knowledge to a wide audience (see Section 2.8.6.2). It should therefore be utilised as a supportive measure to KM initiatives to assist members of the organisation or the project to feel comfortable in contributing, accessing and utilising knowledge through the designed KM procedures.

Reassignment of Employees

A method less used in this scenario due to the desire to maintain the same core teams, was that of reassigning employees to differing projects. In the same way that maintaining the same participants within this case ensured that the knowledge gathered during the preceding projects was reapplied in subsequent projects, reassignment of employees is normally utilised to spread lessons learnt and experience.

As a result, the method of transferring the experience and knowledge of an individual through sharing it with those that they subsequently work with appears to present an interesting dilemma. The repetition of key members of the project team not only leads to effective working relationships to be established at the most critical stage of a project (the outset) but also leads to the opportunity to continuously learn in a fairly natural way (see Section 5.5.4.1: Design Team Meetings). Conversely, reassigning a project team to various alternative projects widens the perspective audience and potentially increases the beneficial impact that is experienced. This is due to the knowledge and experience gained during the initial project benefitting multiple subsequent projects. However, it is unclear to which provides the greatest beneficial impact.

5.4.4.4 Supportive KM Technologies Utilised

Intranet

The main KM technology utilised to support the KM procedures within this case was that of an intranet system. Only the construction organisation utilised such a platform to base their electronic KM system however, with the design organisation distributing physical report documents throughout their relatively smaller organisation. The method to input knowledge contributions into the system has previously been documented (see Section 5.5.4.1: Cross Project Communication). The primary aim of using the intranet method was to enable easy remote access of knowledge from wherever the knowledge seeker may be, at a relatively low cost to the organisation. In comparison to the alternative physical report procedure, this is beneficial in that:

- Knowledge can be accessed remotely;
- Knowledge can be accessed at any time;
- Multiple persons at once can utilise stored knowledge;
- It is a relatively cheap form of knowledge distribution;
- Captures knowledge of employees that have left the organisation;
- Access to stored documents can easily be restricted for knowledge protection;
- Stored knowledge can be backed up to protect the longevity of it; and,

- Appropriate knowledge can be more easily located due to search functionality.

This being said, negative attributes of the intranet process were identified. These are issues that may be individual to the intranet system within this case, but point to areas in which users experience dissatisfaction. These include:

- The user friendliness of the system makes it difficult to locate knowledge because it is not structured in a logical manner.
    - Users are faced with what is perceived as a potentially lengthy and frustrating experience if they wish to locate knowledge through this system.
    - Users inevitably abandon their search and proceed with reinventing the wheel
- Slow internet connectivity exasperates the frustration of using the system
- The knowledge stored is self-policed and therefore may lack credibility, reusability and relevance
    - No form of knowledge validation or retirement process can cause the need to trawl through obsolete knowledge contributions

It is therefore evident that the extent to which the potential users perceive the process positively ultimately dictates its acceptance and usefulness. For example, the CPM declared that:

> *"Everybody knows that there is a lot of good stuff on the intranet that we have got. For example if you have a problem there will be somebody on their that has done it and solved it, or there will be a contact for somebody that can help you. The problem we have is that it is not the easiest of sites to go around, so people will say that they cannot be bothered to spend half an hour trying to find something on it, so instead they go about sorting out themselves and hoping for the best"*

Consequently it was viewed that the intranet system was not the most beneficial in achieving the objectives of a KM system. However, it was viewed as a valuable knowledge source during the timespans in which other preferred, but resource intensive forms of KM technique such as site visits, face-to-face meetings or training and mentoring, were not available.

5.4.4.5 Format of Knowledge Capture / Storage

This section is interested in determining the degree to which the format of stored knowledge affects the overall satisfaction level of the user. This is felt to be defined by how effective the system is at delivering its desired objective (i.e. transferring knowledge). This analysis will therefore indicate the influential impact that the format of knowledge has on the overall success of KM. Therefore the extent to which the satisfaction levels are positive or negative ultimately indicates the ability of the format used to transfer knowledge effectively.

Within this case, the primary format used for storing knowledge was text. This was generally accompanied by photographs and structured in a report a template for consistency. Although popular as a storage method, text and photographs were not viewed so positively in terms of locating or reusing the stored knowledge. As previously discussed (see Sections 5.5.4.3: Evidence Gathering and 5.5.4.4: Intranet), the usage of text and photographs in a report format is viewed as potentially exasperating the effort expended in identifying the most idealistic knowledge contribution to reuse. This is due to the need to read snippets of information of each search result before being able to determine if it is what is desired or not.

Furthermore, the combination of text and photographs was not viewed as being effective for its eventual transfer. This is particularly the case in regards to text, which thus leads to alternative KM techniques being utilised in preference for the intranet system. For example, some people will *"pick up the phone to shortcut the system* [because the process to locate appropriate knowledge, followed by the effectiveness of its eventual transfer] *is frustrating"* (CPM).

This is a seamless example of how the human mind is a more powerful knowledge recall engine compared to a computerised search tool. When asked a question, as long as it has been interpreted correctly by the listener, their mind will automatically locate the correct knowledge if it is possessed. This can then be communicated first time round. However, a computerised search tool is only able to locate near matches based on key words. This is due to not being able to understand context and meaning of words as the human brain does. Therefore, multiple near matches are returned, for the knowledge seeker to thus determine which is most ideally suited. As a result it is evident that the improved efficiency of locating knowledge is a primary reason for two-way communication to be the preferred method of knowledge transfer.

This shows that due to time demands people are only willing to allocate a very short amount of time to the task of seeking out fresh knowledge. This is shown through the view that the act of a telephone call can be deemed an inconvenience because there is a chance that there will be no response, thus requiring an email to be sent in any case (CPM). Therefore through utilising email in the first instance, other tasks can be undertaken in the meantime, safe in the knowledge that the recipient has received the request. This was discovered to be the case even though email is text based and therefore not viewed as being as effective at transferring knowledge as two-way communication. This uncovers a more thought-provoking issue that the speed of locating knowledge is of equal, if not greater importance than the effectiveness of its transfer. This highlights the significance of the barrier of time demands even more greatly.

In general, evidence gathered from this case demonstrates a preference for techniques which utilise verbal two-way communication over text based formats. This was due to:

- The ability to more effectively communicate to the desired audience rather than a generic one;
- Generation of a much greater understanding can be developed; and,
- The opportunity to request for further information to clarify details is available.

This is especially evident in relation to cross divisional learning which is proposed within this study. Carlile (2002) identified syntactic (language), semantic (meaning) and pragmatic (practice) boundaries that arise when attempting to share knowledge with those of differing backgrounds and experiences (see Section 2.7.2.3). Therefore the need to facilitate the act of clarifying ones understanding is a greater necessity than perhaps it is when transferring knowledge within the boundaries of the same lifecycle phase.

These findings indicate towards the need to incorporate verbal two-way communication within the devised feedback loop. Therefore a greater degree of precision can be applied regarding research proposition 3, which currently states that *"a socio-technical systems approach can overcome the downfalls of a purely technique or technology centred KM approach."* Accordingly, the development of an additional sub proposition has been made in the form of:

> **Proposition 3c** – verbal two-way communication is needed in order to provide efficient location of appropriate knowledge and effective knowledge transfer

The prospect to assess how the aforementioned methods compare to other formats such as video or one-way verbal communication (i.e. audio recording) was not available due to these methods never having been trialled within this case. However, a significant area of interest to emerge was the use of photographs in enabling context understanding of historical events. For example, in incidences where the initial knowledge holder is no longer available to conduct two-way communication with the knowledge seeker, photographs were deemed as being extremely important in being able to convey an understanding of the context in which the knowledge was originally captured within. Consequently, this indicates that visual aids are more useful in this area than descriptive text. Combined with the time duration of writing out the description or having to read it, this method appears to align with the abovementioned need to abide by very strict time demands when locating knowledge.

As a result, this analysis has discovered that the most beneficial knowledge sharing technique is that of two-way communication between knowledge seeker and knowledge contributor. This does however expose the organisation to the vulnerable position of knowledge loss if the knowledge contributor leaves the organisation. Therefore, it would appear that the utilisation of a *'current'* knowledge sharing system through socialisation, combined with a *'historic'* knowledge sharing system through storing knowledge is preferential. Although this state could arguably be stated as currently being in place, there is a distinct lack of desire to utilise the historic knowledge store. Therefore, if this is not rectified, a scenario in which only current knowledge is utilised will materialise, thus inhibiting OL.

5.4.5 Current Resources

5.4.5.1 Information Technology

The technology adoption ethos adopted within the main contracting organisation appears to be somewhat confused. On one hand the CPM stated that they believed their ethos to be an industry leader and that they like to *"get in their first, try things out and implement them if they are right for the company."* However, they also evaluated their current technology base as *"nothing out of the ordinary* [as they have] *trialled PDAs but returned back to old systems."* This regression was discovered as being due to issues with their implementation strategies which were fraught with resistance to change. The CPM believes that this will naturally erode over the coming years as older generations that have been less exposed to technology start to retire and are replaced by a younger generation who have been brought up surrounded by technology.

Another significant issue was that of poor connection speed supplied to sites. This made access to project and company intranets a laborious task and was viewed as directly influencing the poor user rate of these supportive technologies. Technologies available on site and therefore reducing the resistances to change cited above include:

- Personal Computers;
- Laptops;
- Mobile Phones; and,
- Intranet.

5.4.5.2 Mobile Technologies

As stated above (see Section 5.5.5.2) the adoption of mobile technologies have been fraught with resistance. As a result, the ability to align knowledge feedback with current resources appears to direct towards avoiding the utilisation of mobile technologies. However, a dilemma to emerge is the evident direction of the industry in the future towards the widespread adoption of mobile technologies. Aligning with its current state of a lack of technology adoption is viewed as likely to gain a greater degree of acceptance; however, the longevity of that arrangement appears questionable.

5.4.5.3 Building Information Modelling

Both the design and construction organisations stated that BIM remains very much in an embryonic state. Neither senior representative has utilised BIM on any project as of yet. In terms of the construction organisation this was attributed to trialling it regionally before rolling it out nationwide. Therefore they are still waiting on the results of the trial before they learn to what extent and in what format BIM will be used in the future. This was followed by further confirmation that their technology adoption ethos is indeed reactive as BIM was said to be *“something that we're going to have to get up to speed on because* [their] *competitors definitely are”* (CPM). There also appeared to be no debate that it is a question of *when* rather than *if* BIM will be a fundamental aspect of construction projects.

This further supports research proposition 4a.1 (see Section 5.4.1.2), which projected that although BIM provides a potential platform for improved feedback between participants; it is currently too underdeveloped for this study to align with. This is due to the significant degree of uncertainty that surrounds its final makeup in terms of ownership framework, inter-organisational processes and legal requirements.

This was echoed from a design perspective also; with the LA stating that BIM would most definitely have been adopted sooner if the economic climate had not changed so suddenly. This restricted their ability to afford its implementation. However, an area of interest to was that of the characteristics of organisations that BIM is most likely to be used by in the future. These include;

- Large design organisations which can afford the high investment required;
- Organisations which already have an advanced IT hardware and expertise so that these do not need to be replaced and thus exasperate set up costs further; and,
- Organisations which are primarily involved in large infrastructure projects such as new healthcare facilities as the return on investment will more likely be realised.

5.4.6 Foreseen Difficulties and Potential Coping Strategies

5.4.6.1 Difficulty Nurturing Relationships

A profoundly important area of investigation for this case is the ability to nurture and maintain effective cross organisational working relationships from project to project through the utilisation of repetitive project teams. Consequently this was a key factor in this case's selection criteria (see Section 5.5.1).

By maintaining most of the same site team it *"massively helped"* operations due to being able to communicate effectively and in general, have a good understanding with external participants other than those of the contracting organisation (CPM). For example, the contracting organisation *"built a fantastic relationship with the client and capital planning team"* (CPM). This resulted in efficiency advantages such as not having to arrange formal meetings to discuss issues, but instead was able to approach members of the client's team to overcome issues immediately. This was attributed to the high degree of mutual trust that was generated as time progressed and as a result, the dynamics of the relationship was a lot different at the end of the sixth project than it was at the outset of the first.

The LA continued to suggest that in comparison to a traditional contracting arrangement, which can be *"quite confrontational,"* the move towards the D&B arrangement of the P21 procurement contract eliminated this *"adversarial approach."* The support of the need for effective working relationships between project parties was further cemented by stating that *"having good relationships is paramount"* (LA). Therefore nurturing effective working relationships with all parties leads to a smoother running project delivery and increases the likelihood that the objectives of the entire array of participants are satisfied.

The understanding and trust built as time progresses on a project generates multiple beneficial implications for a project. These have been identified to include;

- Enhanced efficiency;
- Reduced confrontations;
- Mutual understanding of each other's expectations; and,
- More idealistic solutions sought due to all party's contributing their experience.

Furthermore, it takes time to generate such effective working relationships. Therefore at the beginning of a project, these beneficial aspects are less apparent than they are towards the end of it. Accordingly, the repetitive project team arrangement enables such beneficial impacts to be implemented at a much earlier stage of the following project (i.e. its outset) rather than having to go through the cycle of relationship nurturing once more. Benefits of the repeat employment of a successful project team are viewed as including:

- Continual learning;
- Continuous improvement;
- Experiencing the positive effects of effective project relationships (see above) much earlier on; and,
- Greater assurances of the quality of work that external parties are able to offer, thus lowering the risk and uncertainty of a project.

For this to arise, design and construction organisations should seek to maintain key project teams where possible so that the relationships generated are not abolished instantly through dismantling the team. However, it is insufficient to simply maintain the same construction or design team separately. For the full benefits to materialise the fusion of the majority of the same key participants across organisational divides needs to occur, which indicated towards design and construction organisations seeking partnership alliances. Finally, the fulcrum of this equation relies upon a paradigm shift within the industry towards a greater acceptance of the D&B contract arrangement. This enables the development of such partnerships to emerge due to them being utilised more readily. Consequently, the above incurred beneficial effects of the repetition of successful teams should materialise. These findings have demonstrated irrefutable support for research propositions 7 and 7a (see Sections 5.4.1.2 and 5.5.1.2 respectfully).

This being said, the dilemma of what produces the greatest beneficial impact, the advantages of repetitive teams, or, disseminated project-based learning to other projects through employee reassignment, remains unanswered.

5.4.6.2 Resistance to Change and Receptivity of New Ideas

Resistance to change was viewed to extend further than the implementation of changes, such as new technologies, but to being unreceptive to new ideas in general. For example, the LA highlighted that the *"receptivity of the personnel involved"* could pose dramatic difficulties towards the ability to share knowledge. Therefore a further barrier to knowledge sharing has emerged in the form of a lack of receptivity to new ideas and knowledge. As such, where knowledge protection is a barrier posed by a potential sharer of knowledge, a lack of receptivity is a barrier posed by the potential receiver.

5.5 Summary of Findings

This section details how this chapter and the documented findings relate, confirm, reject or reinforce the research aim and objectives. Each objective is stated with related primary research findings discussed. Some research findings cross objective divides and are therefore only discussed in within the objective that they are most aligned with.

Objective 1: To examine existing literature relating to the need for and barriers against design-construction learning loops

It was discovered that there is a significant desire to learn from shared knowledge in preference for the belief that it will lead to over standardisation and restriction that was detected during the literature review. This suggests that some of the people related barriers noted (see Section 2.7.4) are not as prevalent as first thought, or are diminishing as a result of the changes in the competitive nature of the industry.

In terms of buildability problems, avoidable buildability issues, and, construction techniques / materials are both highly valued areas of buildability knowledge that was viewed as being desirable to share with other project participants. This is not currently occurring to a satisfactory level and therefore negative effects of buildability such as increased time and costs, maintenance difficulties, and a lack of value for money are continuously being experienced needlessly.

A further key finding in this area was that learning can be used as evidence of continuous improvement from previous projects, which therefore can form a unique selling point in bidding for new work. This coincides with the preceding finding, with it being noted that there is beginning to be a greater realisation that individual, organisational and industry benefits of learning outweigh the negative impressions that lead to barriers being formed.

Objective 2: To establish the potential and limitations of current knowledge management procedures

A significant deficiency of current practice is the distinct lack of knowledge capture / sharing activities being undertaken either live or in a timely manner. Over-reliance is being put on retrospective procedures such as PPE's which inherently result in knowledge loss. However, it was discovered that reviewing learning instances along the way through the currently undertaken process of conducting a DTM can act as a powerful tool to lessen the degree that they are forgotten. The subsequent PPE can therefore consolidate these issues and a greater attempt to capture more of the learning instance live is required.

In general, a high level of satisfaction was targeted towards current knowledge management processes as they were viewed as resulting in increased commitments with very little benefit being experienced. This was found to be mainly due to the knowledge perceived as being shared through such processes was not sufficient. In other words, not a lot was learnt through utilising the system which in turn led employees to believe time was best spent contributing to other activities. Accordingly, KM processes that move away from the explicit knowledge transfer within a FGKM approach towards that of socialisation within a SGKM approach was identified.

Objective 3: To establish the potential and limitations of current feedback loops designed to improve design quality

During the literature review it was identified that a key learning objective was beneficial over attempting to concentrate on an overly broad KM initiative. Therefore buildability was adopted as it complimented this objective of being a problem that can not only be improved through improved knowledge sharing, but in order to improve requires cross boundary knowledge sharing between design and construction.

This research phase found that it was evident that buildability issues arose throughout the project and were seen as inevitable. However, it was believed that efforts put in at the start of the project were fundamentally important in lessening the degree to which unexpected issues arose later. Limitations of current processes included the procurement method adopted in terms of whether it was a DBB or DB contract. DB contracts were seen to naturally integrate differing organisations and phases of the process much earlier on and therefore knowledge shared was improved.

However, regardless of the contract type, top level management has a significant impact on attaining learning goals. Through an increase in techniques such as measurement of attaining learning objectives it makes teams much more driven to attaining them. This being said, at present top level management are being measured themselves on other project related goals and therefore learning is being neglected by all levels.

Finally, an inherent barrier to learning posed by the project based nature of the industry is the lack of repetitive teams. Repetitive teams were viewed as being beneficial to maintain on-going learning as it reduces time taken to develop an effective team dynamic as early integration is naturally brought over from preceding projects. However, a finding of interest was that it is unclear whether this benefit outweighs that of repetitive teams potentially limiting the extent to which lessons learnt are shared with other areas of the organisation due to the reduction of reassignment of employees

Objective 4: Evaluate which technologies/techniques are most effective to assist learning activities

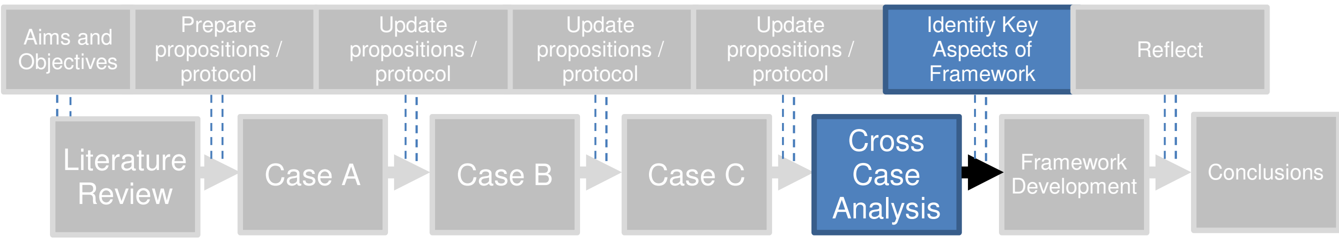
A key finding was that the efficiency of locating knowledge is of equal if not greater importance as the eventual transfer of knowledge effectiveness. Accordingly, this points to an area in which technologies can assist in the KM process, even if they are less desirable in being relied upon in isolation for the knowledge transfer process itself.

Furthermore, mobile technology solutions are the direction in which the industry is heading and therefore appear to pose less resistance towards their adoption within the KM process compared to previously due to them likely being sourced for alternative uses also and therefore limited resources would not apply, unlike if they were solely to be used for KM activities.

Objective 5: To improve cross-organisational boundary learning within infrastructure projects

As mentioned during the review of objective 2, early integration is the single biggest benefitting factor to a project in terms of developing understanding between all project participants. This improves the development of trust and familiarity between individuals and teams, which is key in overcoming resistances and tensions. Consequently it was observed that this can lead to heightened levels of openness, a willingness to share and a willingness to adopt new ideas. Therefore a framework that encourages integration throughout the project is viewed as a positive aspect.

It is however viewed that all of the findings documented above under more defined objectives inadvertently contribute to the satisfaction of this objective. For instance, live knowledge capture and sharing is a deficiency of current practice and is therefore a hurdle that is critical in overcoming in the development of improved processes.



6 Cross-Case Analysis and Discussion of Findings

The preceding chapter documented each case study. Each case study was conducted sequentially according to the case study methodology, to enable replication logic to be applied (see Section 4.6). This enabled the initial research propositions to be tested in the first case and adapted if necessary to produce theoretical replication, or alternatively, maintained to produce literal replication (Yin, 2009). This facilitated the development of theory to continuously progress.

In comparison, this chapter conducts a cross case synthesis, consisting of comparing and contrasting the findings of each case (Yin, 2009). However, to increase the robustness of the findings further, outcomes of independent studies are also analysed. Accordingly, the discussion of findings, are brought together within this chapter. This benefits the conclusions made due to them utilising a much wider source of evidence. As such, where similar characteristics are witnessed both across cases and beyond this study's boundaries, the generalisation of findings can be inferred (Yin, 2009).

6.1 Establishing the Need for a Knowledge Feedback Loop

6.1.1 Negative Effects of Buildability Issues

In all three cases the main effects of buildability issues were its negative impact on time and cost slippage. This was seen within Case A and B as being due to the need to perform some form of rework to overcome the problem before the built element could be completed (see Sections 5.3.2.1 and 5.4.2.1 respectively). Accordingly, this results in the need to conduct DTMs so that issues can be discussed and resolved before the design is reworked. In addition, Case C found that in instances where unnecessary complexities are not spotted, the process of constructing the overly complex solution is one that once more increases time and costs (see Section 5.5.2.1).

A further significant negative effect receiving a consensus of opinion was that of the ability for buildability issues to reduce the quality of the final product. This was also shown to result in the reduction of client satisfaction (see Section 5.4.2.1). This is especially worrying within a healthcare context due to other researchers finding that the quality of the facility itself directly impacts on the service provided within (Berry *et al.*, 2004; De Jager, 2007). Even though this has been found to be the case within other sectors also, for example the quality of commercial buildings impacting on the productivity levels of those working within them (Kampschroer and Heerwagen, 2005; Vischer, 2008; Sailer *et al.*, 2009); the seriousness of reducing the effectiveness of healthcare employees is far greater. For instance, it directly impacts the lives and well-being of those cared for within the facility, in comparison to the relatively immaterial profitability potential of a firm.

6.1.2 Need for Knowledge to be Pooled as Early on as Possible

There was an overwhelming consensus in favour for integrating teams much earlier on in the process so the above issues can be mitigated and/or avoided. For instance, in line with the views of (Russell *et al.*, 1994; Kartam and Askar, 1999; Palaneeswaran, 2006), all three case studies viewed buildability issues as avoidable, with both the greatest number of instances and the maximum opportunity to circumvent them being early on in the process (see Sections 5.3.6.1, 5.5.4.1: Site Observations and 5.5.2.2). The rationale for this was identified as being twofold. Firstly, a significant contributing factor for buildability instances to arise was a lack of understanding of each party's expectations, requirements and desires (see Sections 5.3.2.1, 5.3.2.2, 5.3.6.1, 5.4.2.1, 5.4.2.2, 5.4.4.3: Framework Collaboration and 5.5.6). This was greatest at the outset of a project (see Figure 5.4 Section 5.3.2.2). Therefore, through the second recognition of integrating all of the participants from the outset, it enables them to:

- Begin to generate an understanding of each other's needs and wants at a much earlier stage; and,
- Pool their accumulated knowledge and experience, thus making the most informed decisions possible.

Within healthcare this is naturally realised through the adoption of the P21+ framework, which resembles a D&B contract (see Section 5.3.4.3: Framework Collaboration). This is supported by Baiden *et al.* (2006) who discovered that the procurement route chosen for projects influences the degree of integration achieved, with D&B contracts demonstrating the most conducive environments for teams to work together. Furthermore, they found that within traditional contracts (i.e. DBB) teamwork was better achieved through repeated work.

Early integration is therefore viewed as enabling the pool of knowledge utilised at a project's outset to be swelled. However, key learning instances are still being lost. These tendencies include:

- Concentrating on mistakes and errors - thus neglecting learning from successes and manageable issues;
- Concentrating only on the most significant issues - thus neglecting the cumulative learning potential of smaller issues; and,
- Attempting to learn during the PPE - leading to knowledge deterioration/loss, but also the heightening of the barrier of knowledge protection due to it no longer being able to benefit the current project

Therefore, if the knowledge pool is to be increased further, learning throughout the project needs to be improved. Thus the impact of early integration is seen to be limited until this is achieved. Accordingly, the need for a feedback framework which shares project-based knowledge throughout its existence is still required.

Key Findings:

- Many buildability issues are reoccurring yet avoidable; and,
- Earlier integration between teams is key in enabling the greatest positive effect on buildability instances and thus the overall cost of the project to be achieved.

6.1.3 Enhancing Trust and Communication between Project Participants

It was highlighted in Case A that the retaining of key project teams has the ability to enhance the beneficial nature of early integration through relationships and trust being carried forward from preceding projects (see Section 5.3.6.1). These findings align with the opinions of numerous authors who bring attention to the negative effects temporary project teams can have on attaining on-going learning (Griffith and Sidwell, 1993; Shammas-Toma *et al.*, 1998; Love and Li, 2000; Jergeas and Van der Put, 2001; Yang *et al.*, 2003; Pulaski and Horman, 2005) (see Section 2.7).

This proposition was accordingly tested within Case Study B in which it was found that in harmony to the opinions of Shaw, (1994, c.f. Barlow and Jashapara, 1998) and Inkpen (1998), strategic alliances do create unique learning opportunities for the partnering firms involved. However, this assertion was discovered to be overly general, as in reality, partnering arrangements only lead to on-going learning and continual improvement where repetitive teams are maintained. This is due to the above mentioned prerequisite for learning being in the form of trust and understanding of each other's requirements and desires. Such a nurturing process was unreservedly described as having to get *"an old wheel moving again"* by the CPM of Case Study A, which demonstrates the laborious and time consuming task that it is. It was made apparent that only once this state was achieved would knowledge sharing occur effectively due to barriers to knowledge sharing such as knowledge protection and resistance to change remaining significant inhibitors (see Sections 5.3.6.1). Therefore, the relationships required for effective knowledge sharing were found to be apparent on an individual level and not an organisational one, thus signifying that a strategic partnership alone is insufficient (see Section 5.4.6.3).

Key Finding:

Repetitive teams heighten the ability to perform effective knowledge sharing; however, strategic alliances by themselves do not. This is due to the development of relationships, key to knowledge sharing, only being possible on an individual level and not an organisational one.

As can be seen in Figure 6.1, the time required to nurture a relationship with external and internal project participants is significant. As barriers are broken down a greater degree of knowledge sharing effectiveness (measured in the extent to which knowledge is shared freely between members) is achieved. In the early days of a new project this is difficult to and more time consuming; however, once parties begin to become familiar with the expectations of others, barriers to knowledge sharing are broken down and the process accordingly accelerates. Towards the end of a project when the level of understanding and trust is generally highest, effective knowledge transfer between partnering organisations takes place. This seamlessly reflects the avocation made by Maheshwari *et al.* (2006) that collaboration consists of a lifecycle of four phases:

- Foundation (decisions made leading up to forming a partnership/collaboration);
- Implementation (process of building relationships, physical assets and rules);
- Shakedown (coming to grips with working with others and establishing how to overcome differences so progress to normal working can be achieved); and,
- Onwards and Upwards (the stage between establishing normal working operations and the end of the project).

Accordingly, the protracted activity of progressing through this lifecycle was demonstrated through the statement made by the CPM of Case A, who declared that:

> *"It is hard to see from today, but if you were sat here at the start of the project, compared to now, the learning curve is massive; as we now know each other's*

skill sets, what we expect from each other, what we can do and that is why it is much slicker now, but in the early days it was not" (CPM).

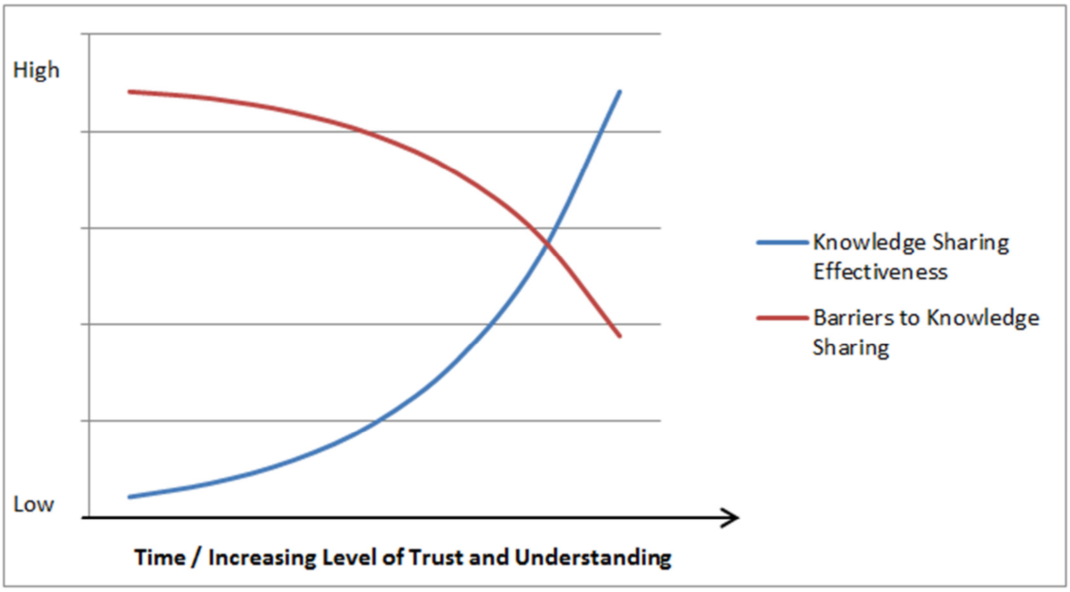


Figure 6.1: Impact of Trust and Understanding on Barriers to Share Knowledge and Effectiveness of Knowledge Transfer

The steepness of this curve is not uniform for all projects but depends on a variety of factors such as the effectiveness of the project manager in bringing together the team; openness of parties to trust others; and, their history of working together. Additionally, a key finding that enhances trust development, whilst signifying the urgent need for knowledge feedback and sharing throughout a project's duration was discovered and highlighted below.

Disbanding an effective team to work on new projects ultimately resets the levels of trust and understanding back to being none existent. This process then has to be undergone once more. In comparison, if an effective team could be retained to work on subsequent projects, the continuation of the working relationship would continue. This was partially seen through the findings of Case Study B (see Section 5.4.6.3), but cemented in Case Study C (see Section 5.5.6.1). This was in the form of not only leading to the natural continuation of effective knowledge sharing (eliminating the need to return to the trust nurturing stage), but enabling it to be continually improved also. Both of these scenarios are illustrated in Figure 6.2.

Likewise, projects in which construction integration occurs even later in the project (e.g. DBB contracts); the ability to influence costs has diminished further. Integration in this context is understood to be the 'act of intermixing people who were previously separated' (Oxford English Dictionary, 2011). It therefore refers to the point in time in which the construction team are introduced to the project and therefore can begin to develop a working relationship with other project participants and thus shape its course of action.

Key Finding:

Collaborative KM techniques such as DTMs greatly enhance the ability to generate trust and familiarity which thus result in a more supportive knowledge sharing culture to materialise. This indicates towards the need to conduct KM techniques throughput the duration of a project to enable effective project-based learning to take place. This is due to them consisting of activities such as the following, which build trust (Khalfan *et al.*, 2007):

- Experience - Working with people on a day-to-day basis;
- Problem solving - How sharing and solving problems helps communications;
- Shared goals - A joint understanding of the roles and aims of project work;
- Reciprocity - Team members supporting and rewarding each other's trusting behaviour; and,
- Reasonable behaviour - Working fairly and professionally with the people in the project team.

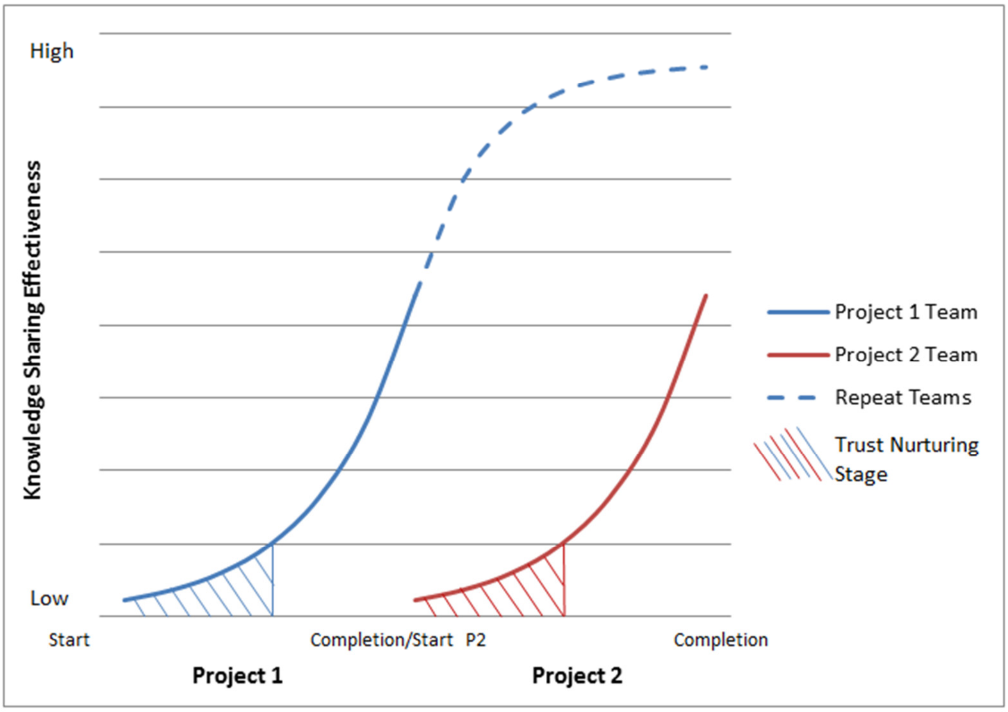


Figure 6.2: Knowledge Sharing Effectiveness of Repeat Teams in Comparison to Newly Formed Project teams

As such, it is apparent that the cost influence curve should not actually resemble a negative exponential curve as suggested initially by Lam *et al.* (2005) (see Figure 3.6: Section 3.2.4.3). Similarly, the consequential adaptation of this curve within this study, to illustrate the positive effect that D&B contracts provide (see Figure 5.11: Section 5.5.2.1), also requires modification. This is due to the need to make an allowance for the period of time that the project team is not sharing knowledge effectively because they remain in the trust nurturing stage (see Figure 6.3).

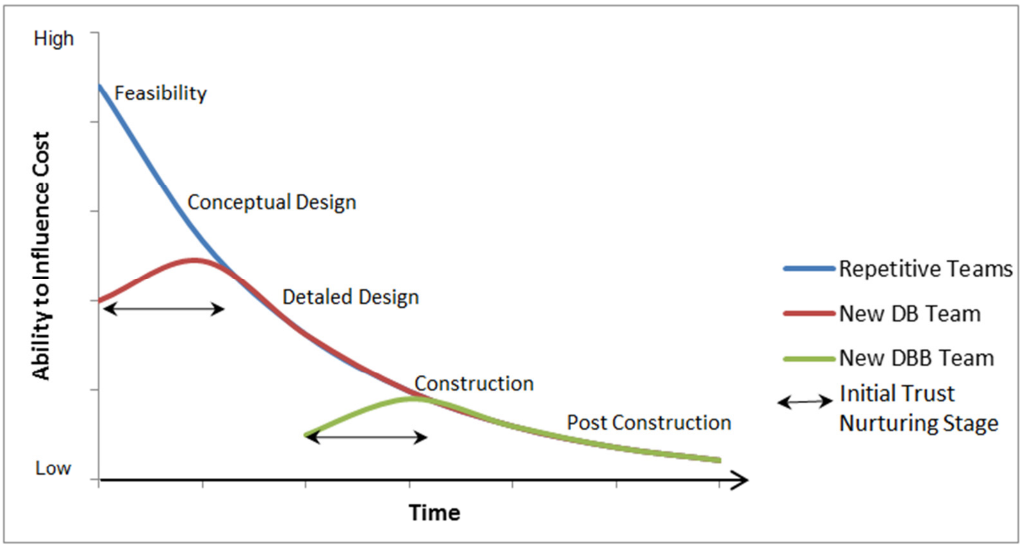


Figure 6.3: Cost Influence Curves of Repetitive Teams Compared to Newly Formed DB and DBB Teams

It was found that a repetitive team inherently brings forward a much greater degree of trust and understanding that they have previously nurtured. Therefore the consequential effective knowledge sharing that they have fostered is more apparent from a project' outset. Ultimately this leads to the ability to effectively affect buildability issues and thus the overall cost of the project from the outset (see Figure 6.3) and thus represents the scenario depicted by Lam *et al.* (2005) (see Figure 3.6: Section 3.2.4.3).

In comparison, a newly formed DB team has a reduced level of knowledge sharing potential from the outset of a project due to the need to firstly pass through the relationship nurturing stage. Therefore, during this nurturing process, the ability to fully influence the cost of the project is somewhat reduced. Once appropriate levels of trust and understanding develop, the team can affect the cost of the project according to the Pareto Principle. This is thus the same in terms of a newly formed DBB team also. However in line with the Pareto Principle, the integration of construction input later on in the project results in their ability to affect the cost having already diminished significantly (see Figure 6.3).

Key Findings:

- Newly formed teams have to pass through the arduous phase of trust building between project participants, which therefore delays the state of effective knowledge sharing compared to repetitive teams.

6.2 Types of Reusable Knowledge

Within each case, similar issues were repeatedly raised as important areas to focus attention in regards to capturing and sharing knowledge if the degree to which poor buildability is to be improved. The most consistently proposed issues (see Sections 5.3.3, 5.4.3 and 5.5.3) included:

- Detailing options of buildings;
- Construction Methods;
- Construction Materials;
- Access and Maintainability;
- Health and Safety; and,
- Failures and Rework

The differing cases also concurred in regards to the knowledge areas of buildability that would be the most beneficial if shared. These were:

- Adopted construction materials;
- Detailing of buildings; and,
- Construction methods used,

It was a mutual wish that the industry would focus more effort on heightening the importance of minimising the solutions that they produce. A growing frustration was targeted towards the lack of knowledge and information sharing within the industry as a whole, which they viewed if improved, would enable this desired state to more easily develop.

An alternative finding to previous research was seen through a declaration from the CPM of Case A. They stated that they extend the offenders of poor knowledge sharing beyond that of the traditional makeup of a project (i.e. clients, designers and construction teams) but to also include manufacturers of products (see Section 5.3.3). This was supported by the LA of Case Study A, who stated that if manufacturers conducted greater testing and case studies about their products, it would not only aid in the selection of the most appropriate materials, but also in lessening the degree to which the reinvention of the wheel occurs (see Section 5.3.4.3: Debriefing).

Key Findings:

To expand the beneficial impact of a knowledge feedback loop, knowledge sharing needs to extend further than the immediate participants of the project to also include manufacturers.

This finding has validated research propositions 1 and 2 (see Section 4.6.2). For example, Kartam and Askar (1999) illustrated the potential feedback loops in a project's lifecycle to consist of two buildability feedback loops (see Figure 3.7; Section 3.2.5). However, a revolutionary finding has arisen regarding the need to increase the feedback chain even further to include product manufacturers also. As a result, Kartam and Askar's illustration of the potential feedback loops in a construction project has been updated to include this finding (see Figure 6.4)

This outcome pulls together and progresses multiple preceding areas of knowledge. For example, it demonstrates that the tendency of the industry to reinvent the wheel unnecessarily (see Section 2.7.2.4) (Keegan and Turner, 2001; Carrillo, 2005; Tan *et al.*, 2006) is being exasperated by a lack of knowledge sharing. Similarly, the inclination of the industry to only appreciate the feedback benefits of POEs is not going to bring about the learning facilitated improvements required to achieve the efficiency targets set by Egan (1998) and Latham (1994).

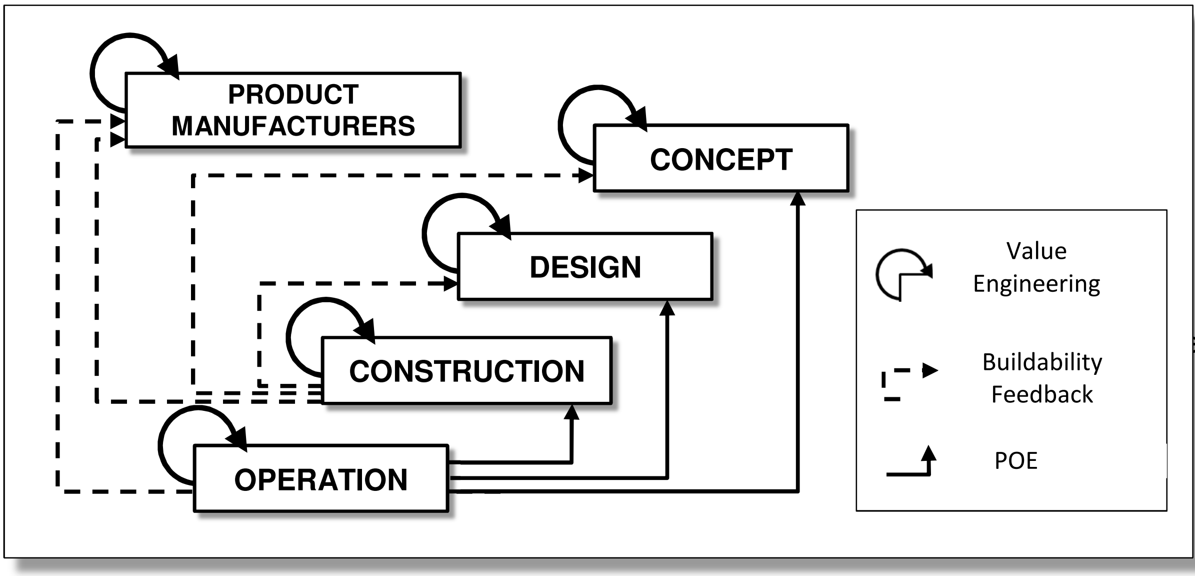


Figure 6.4: Feedback Loops in the Project Lifecycle. Adapted from Kartam and Askar (1999)

> **Key Findings:**
>
> There is a need for further research to investigate how knowledge sharing can transcend beyond the immediate project parties to also consist of product manufacturers who influence buildability inadvertently.

6.3 Current Knowledge Management Procedures

6.3.1 Current Lessons Learnt Capture Procedures

The main lessons learnt capture procedures utilised within the three cases were:

- PPEs;
- Site Observations;
- Case Writing;
- Evidence Gathering;
- DTMs; and,
- Cross Project Communication.

The most utilised method for the purpose of capturing knowledge was that of PPEs which was utilised throughout all three cases. Similarly, DTMs were also utilised in all three;

however, this method was not utilised effectively in any case to capture knowledge. Instead, its main objective was to enable solutions to problems to be generated (i.e. knowledge creation) but little or no attempt was made to fulfil the further stages of the KM lifecycle.

A by-product of this activity was the ability to generate and nurture more effective relationships and understanding with project participants outside of their own immediate discipline. This was discovered to benefit other cross-organisational lessons learnt capture procedures such as PPEs, due to it heightening the degree of trust and honesty between parties (Barlow and Jashapara, 1998).

Each of the above lessons learnt capture procedures were analysed within their respective settings (see Sections 5.3.4.1, 5.4.4.1 and 5.5.4.1). This has enabled an amalgamation of the benefits and drawbacks of each lesson capture procedure, as well as honing the ability to provide guidance upon how and when each method should be utilised (see Table 6.1).

Key Finding:

Not one lesson learnt capture procedure is without its limitations and therefore a multiple technique approach is required

6.3.2 Types of Issues Captured as Lessons Learnt

Desirable knowledge surrounding the detailing of buildings and construction materials / methods were viewed as being captured as lessons learnt to differing degrees (see Section 6.2). This section identifies and analyses additional knowledge areas that are captured as lessons learnt. These are:

- Failures and some successes;
- Most significant issues; and,
- KPI indicators.

Table 6.1: Overview of the Most Commonly Adopted Lessons Learnt Capture Procedures

Approach	Advantages	Drawbacks	Recommendations
Post Project Evaluation	• Does not impact on time demands during the project • Does not impact on labour resource demands during the project • Generally face to face, therefore allowing tacit knowledge transfer	• Instils the perception that on-going learning is not a high priority • Results in knowledge loss due to time lag between event and capture • Fear of openness • Tends to concentrate on project KPIs not buildability issues	• Utilise as a debriefing session and review of knowledge captured during the project through evidence gathering and DTMs • It requires a supportive culture that is open to continuously improving so the tendency to blame or protect knowledge is overcome
Site Observations	• Effective in transferring tacit knowledge • Enables a good understanding of context • Useful means to identify unique/ beneficial practices • Useful in transferring knowledge across projects	• Limited audience • Resource intensive • Does not ensure against past problems resurfacing	• Does not need to be limited to purely the start of projects • Need to ensure that learning is distributed to wider audience than those present (i.e. videoing the process) • Does not need to be limited to the same types of project (i.e. healthcare only)
Evidence Gathering	• Produces understanding of perspectives • Nurtures a supportive culture towards learning • Live knowledge capture enables more actionable knowledge to be captured • Can utilise a range of formats • Captures wider variety of knowledge than purely failures / larger issues	• Exasperates time and labour resource demands throughout the project • Must contend with short term / project related objectives	• Ensure that reasoning behind being asked to capture such evidence is well communicated to nurture a supportive and not restrictive culture • Demonstrate how the evidence is used and the benefits it brings
Design Team Meetings	• Relationship generation • Face to Face • Overcomes meaning and practice boundaries	• Remains in the heads of those present • Opportunity for obstruction / knowledge protection	• Need to raise awareness of why knowledge sharing is beneficial to all to nurture supportive culture
Cross Project Communicat-ion	• Effective means of sharing knowledge across projects • Demonstrates an appreciation of long term learning objectives • Wider pool of experience to call upon	• Resource intensive • Generally limited by sector (i.e. healthcare specific) and therefore limiting the distribution of learning	• Do not limit knowledge transfer sessions to specific sectors as a lot of lessons are transferable across sectors • Needs top level support to encourage / facilitate persons from differing sectors to get together to share knowledge will improve long-term communication channels
Case Writing	• Reduces knowledge loss from people leaving the organisation • Can be used to map the organisation's knowledge to see where gaps lie • Easy to store and share on the intranet system	• Currently conducted through looking back and recalling events which results in knowledge loss / deterioration • Cannot supplement with photos / videos etc. as time has lapsed	• Needs live knowledge capture to be conducted • Utilise multiple formats

6.3.2.1 Failures

In coherence with Hart (2005), failures were reflected upon to enable a criticism of ideas, theories and actions to be undertaken so that they can be improved. However, the procedures undertaken to capture failure related lessons is viewed as deficient as the act of reflection is rarely undertaken. As such, the learning cycle (see Section 7.2.1.1) is not being completed, leading to the reoccurrence of buildability issues. Figure 6.5 demonstrates that although feedback of a problem may be achieved through discussing it within a DTM, little if any further feedback is made regarding how successful the revised solution was. Opportunities for such feedback which remain absent are shown by cloud symbols within this and subsequent figures.

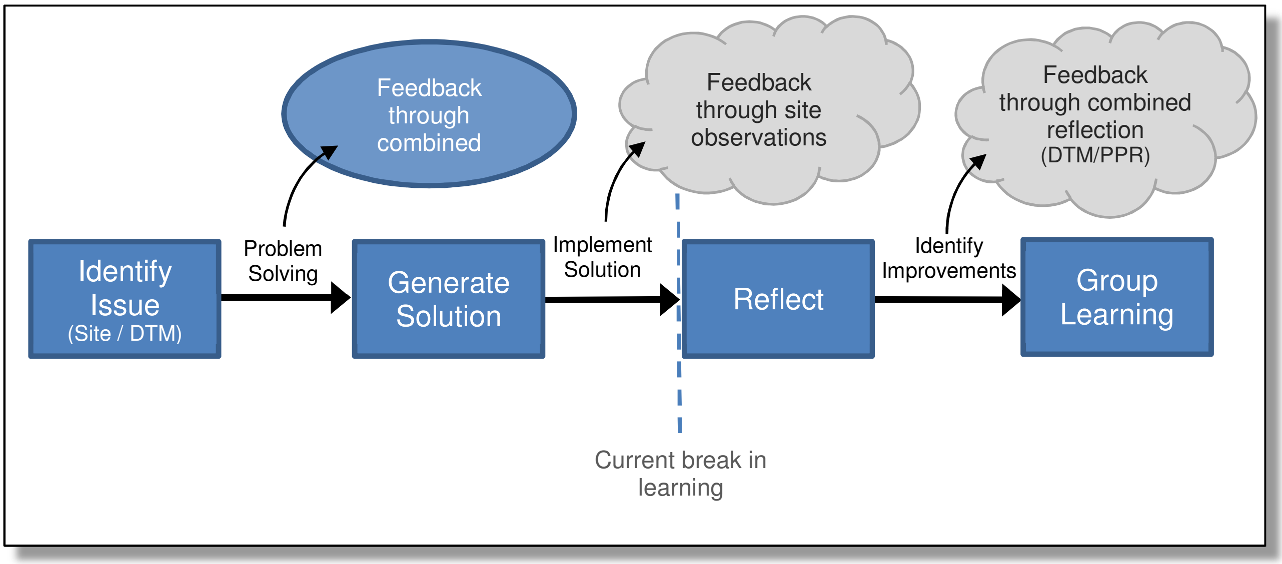


Figure 6.5: Omission of Learning from Buildability Issues

The lack of effective learning is compounded further through two further areas of learning which are absent, in the form of; knowledge created from overcoming manageable issues, and, successes. Manageable issues are seen to be those which are not so great that they require design rework but impact on buildability all the same. Whereas success are issues where their reflection could lead to the reinforcement of their future use or areas for further improvement.

Madsen and Desai (2010) contests Jung's (1950 c.f. Hart, 2005) assertion that little or nothing is learnt from successes, by stating that successes are additional critical learning opportunities. Failures are perhaps more obvious learning opportunities as they open the way to a deeper truth by forcing changes in views and methods whereas successes lead to the reinforcement of beliefs, values and actions (Jung, 1950 c.f. Hart, 2005). However, solely concentrating on failures is limiting the learning potential of each project. This was demonstrated through the AA of Case B stating that if aspects of good buildability are also reviewed then there is a strong possibility that they could become a standard solution. However, without physically building the element themselves, designers find it difficult to identify the most buildable solutions if feedback does not occur.

As the act of reflection is rarely undertaken regarding manageable buildability issues (see Figure 6.6) and successes (see Figure 6.7), breaks in the learning cycle occur. As such the opportunity to needlessly repeat inefficient and troublesome design solutions (in the case of manageable buildability issues), and reinvent the wheel instead of continuously improving (in the case of successes) is heightened.

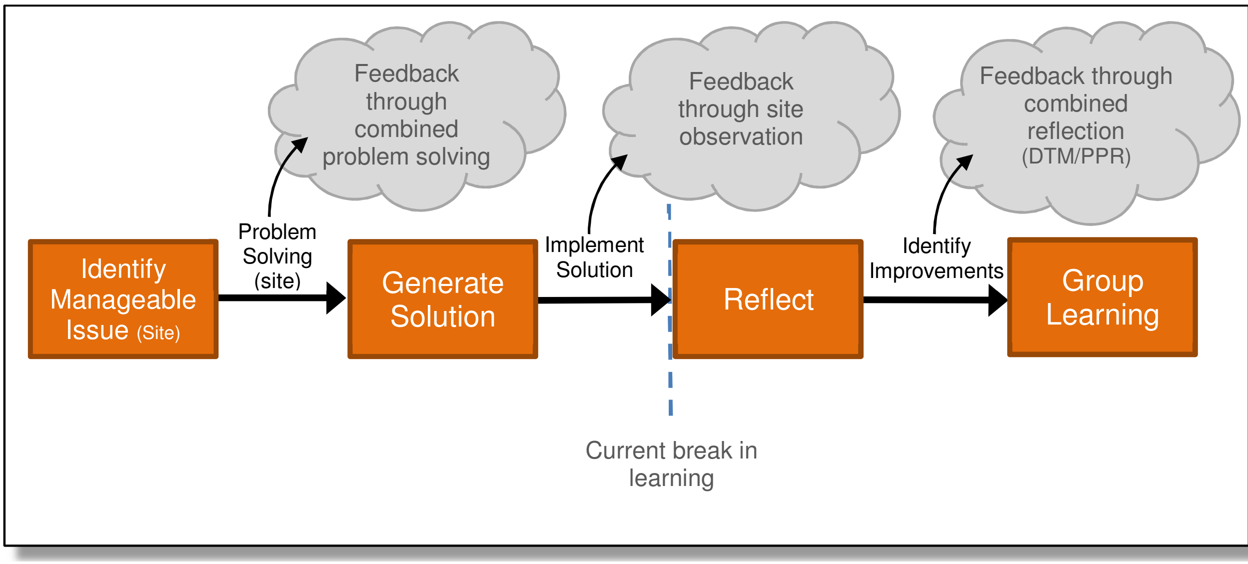


Figure 6.6: Omission of Learning from Manageable Buildability Issues

Instances of learning from successful solutions were detected, however these were generally limited to consisting of the most significant aspects of projects. Similarly this was the case for failures also. As a result vast degrees of learning instances are not being taken advantage of (see Figure 5.6: Section 5.3.4.3) and thus the learning potential experienced from each project is not being realised. For example, the number of manageable issues overcome by the construction team that do not have a detrimental effect to the project but result in minor negative consequences can be numerous. In comparison, the number of major issues to surface is expected to be fewer. Accordingly, the cumulative negative impact of all of the less noteworthy issues collectively impact on the project's performance.

Key Finding:

All three learning scenarios of; failures, success and manageable issues must be taken advantage of if the full extent of a project's learning is to be utilised

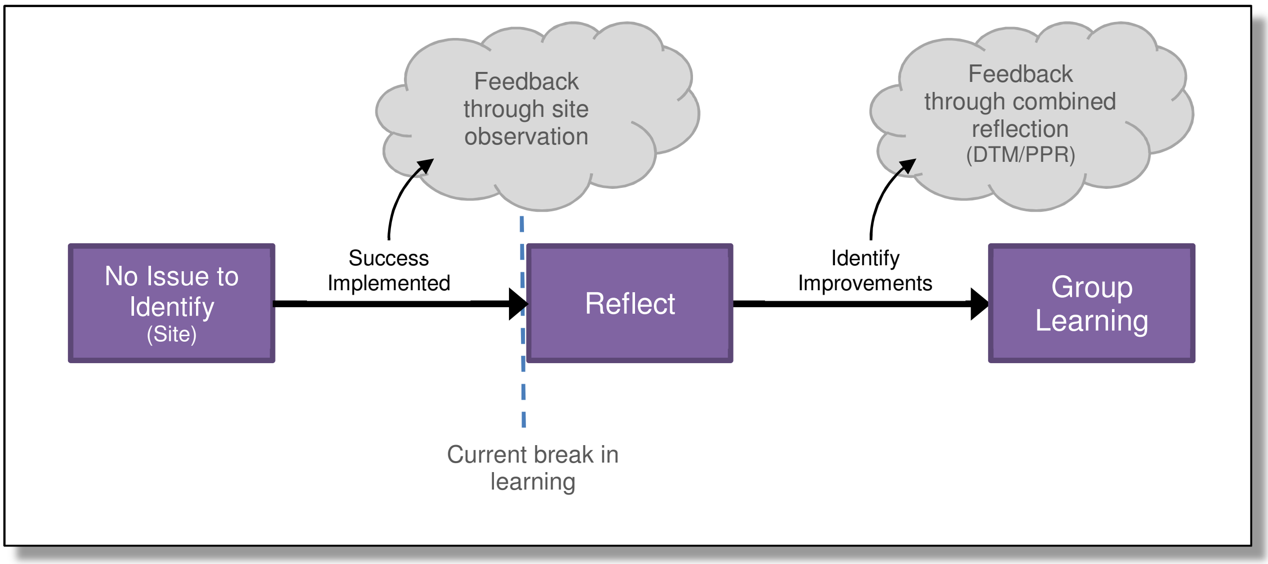


Figure 6.7: Omission of Learning from Design Successes

6.3.2.2 Key Performance Indicators

A further but rather unrelated area of lessons learnt to be captured consistently across the projects studied was that relating to KPIs. These included:

- Stakeholder relationships;
- Sustainability;
- Design team performance; and,
- Health and safety.

However, an emergent area of interest is the means to which the differing organisations experience a greater degree of success in capturing these, than is the case capturing technical related knowledge. This was identified as being due to project level management prioritising KPI related KM over that of buildability knowledge. Likewise the level of priority was observed as reflecting the measurability and benchmarking practices of the organisation as a whole, due to the results being a comparative measure of the project/individual. Due to health and safety instances being both measureable and highly prioritised by top level management these issues are given precedence by project level management. In comparison, buildability issues are much more subjective (see Sections 3.2.2 and 5.3.3); with no effective benchmarking frameworks currently available to measure progression in this area (see Section 3.2.3).

These findings indicate towards self and project-actualisation as sufficient incentives for improvements. For example, Tan *et al.* (2011) discovered that employees did not wish for monetary incentives in return for the increased additional workload and time spent on KM activities. Instead recognition from peers was desired, as well as efforts being taken into consideration during performance appraisal. Similarly, Vuori and Okkonen (2012) discovered that the motivation to share knowledge comes from the desire to help the organisation reach its goals and helping colleagues, not through financial rewards or advancing their own career.

Therefore, through the development of an effective benchmarking system, the ability to measure progress should result in natural improvements being made. Accordingly, a crucial area for further research has been identified in the form of the need to develop a buildability related benchmarking framework (see Section 8.4).

Key Findings:

- Raising the priority of buildability related lessons learnt would lead to this learning objective to be more fully satisfied.
- The identification of the critical need for further research in the area of developing a buildability related benchmarking framework

6.3.3 Supportive KM Techniques / Technologies Utilised

In harmony with the viewpoint of Kululanga *et al.* (2001), a noteworthy finding is the need for a multiple technique/technology approach to KM. This is demonstrated in Table 6.1 and illustrated in Figure 5.9 (see Section 5.4.4.1: Design Team Meetings); with both showing how not one single technique is devoid of drawbacks.

The findings of this study advance beyond simply alluding to this need, by providing both empirical and theoretical evidence to demonstrate serious ramifications if this guidance is obeyed in its most simplistic form. At present, all three cases implement a variety of KM techniques and technologies in line with Kululanga *et al.'s* (2001) recommendation. However, the structure of each resembles a KMS approach in which knowledge is regarded as codifiable and storable and not something that requires socialisation to be transferred (Visser, 2010).

This analysis therefore continues to investigate how attempts to adopt this dated perspective (see Section 2.2.4) plays out in reality, contrasting the findings to viewpoints advocating a move away from such practices.

All three cases emphatically showed dissatisfaction towards their KM intranet system. For example;

"No I do not use it at all. I do not think it is developed enough and that needs to change" (CPM – Case 1);

"I have not been on knowledge exchange for a while and I probably could not tell you the last time I went on it" (SPM – Case 2); and,

"I could go on [the intranet system] and find something out but instead I will phone somebody and shortcut the system" (CPM – Case 3).

A notable decrease in the level of satisfaction has been recognised as occurring from the point in which knowledge capture opportunity being identified, to its eventual reuse through the KM intranet system. This is due to highly prominent KM barriers in the form of short term objectives and limited resources resulting in the process of capturing knowledge being put off to a later point in time. As cautioned by Kamara *et al.* (2003), this leads to aspects of the knowledge situation to be forgotten or missed and ultimately a lower standard of knowledge being stored (see Figure 6.8). This is known as knowledge deterioration (Matlay, 2000; Von Krogh *et al.*, 2001).

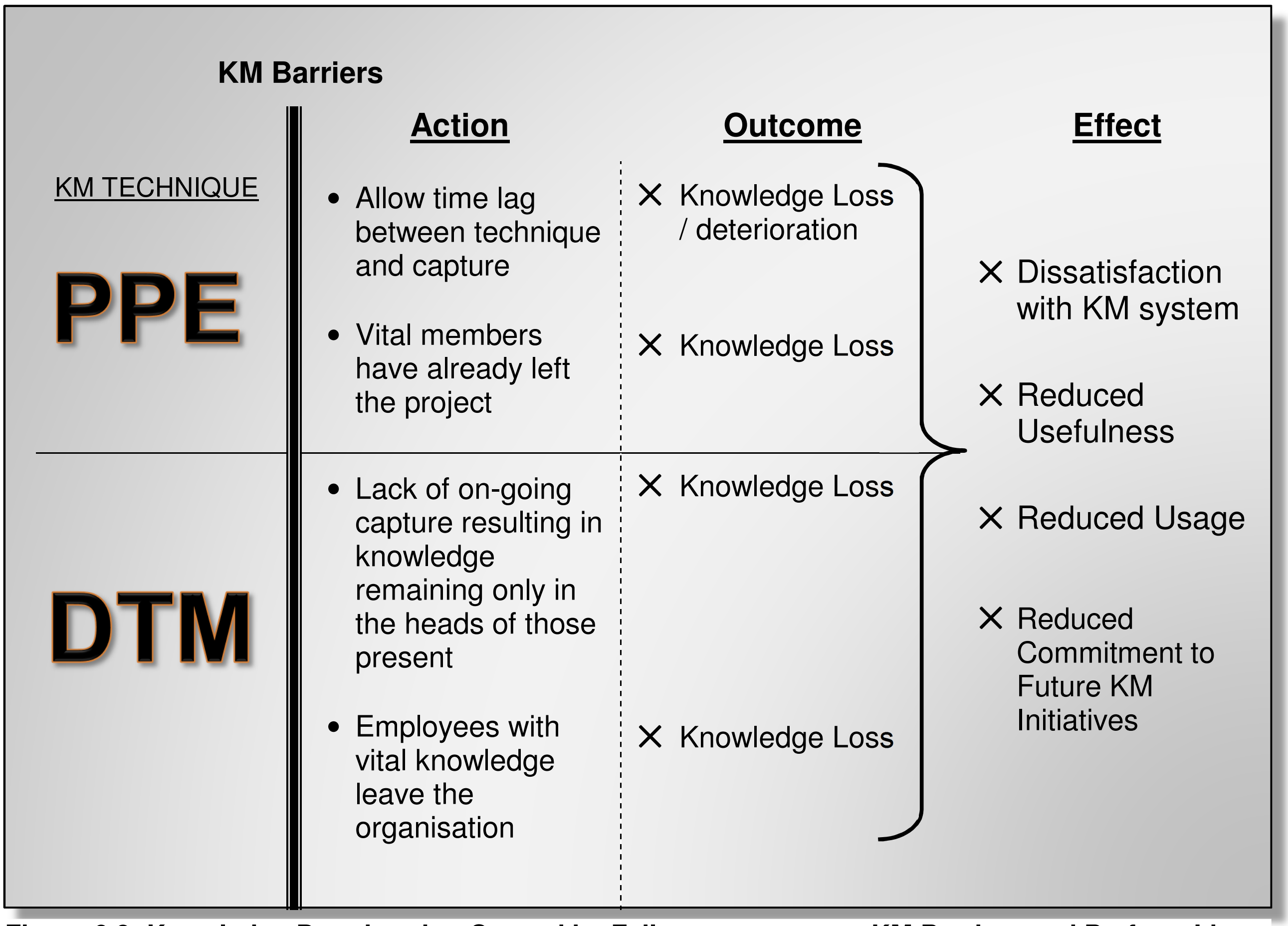


Figure 6.8: Knowledge Deterioration Caused by Failure to overcome KM Barriers and Perform Live Knowledge Capture

Key Finding:

The need for a multiple technique/technology KM arrangement is being satisfied; however it is not delivering desired results.

The influential impact of preceding stages / inputs of the KM lifecycle on subsequent stages / outputs has previously been alluded to by Agarwal and Poo (2006). They suggested that improved search and navigation should enhance the efficiency of the KMS and thus improve the satisfaction levels of knowledge finders. However, this did not extend as far as revealing the significant on-going psychological impacts this could have.

As will be discussed later in this chapter (see Section 6.3.4) further dissatisfaction is targeted at the format of stored knowledge, due to it resulting in poor knowledge transfer. These negative perceptions were seen as leading to a reinforcement of cynicism towards the system and KM processes in general. In turn this exasperates the extent to which poor quality of knowledge is captured and stored due to a lack of commitment towards such procedures. Figure 6.9 demonstrates this on-going sequence in what is to be termed *'The Knowledge Management Cycle of Disillusionment'.*

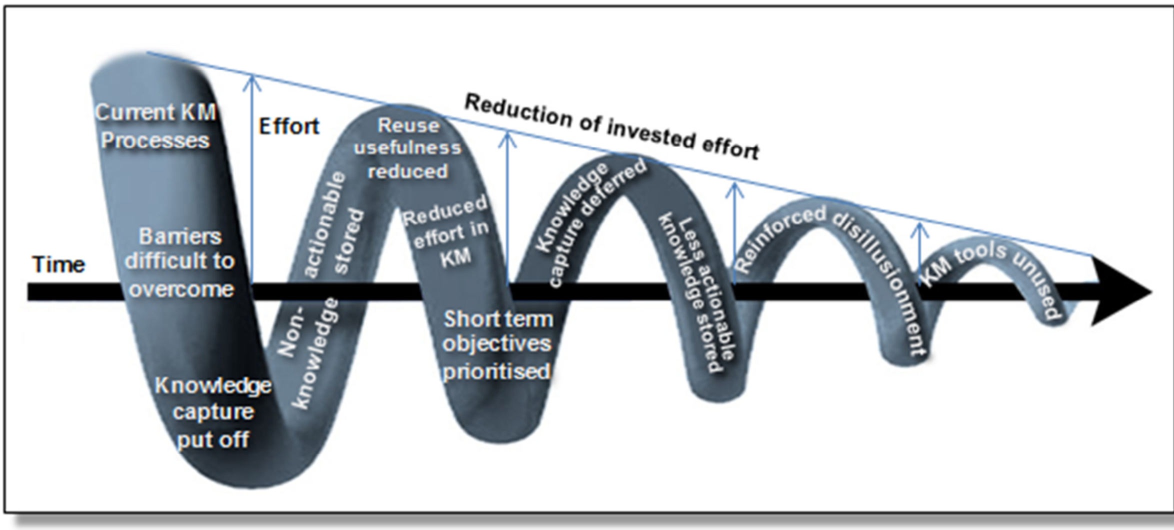


Figure 6.9: Knowledge Management Cycle of Disillusionment

In all three cases a high level of disillusionment was noted with all three systems being deemed as not being utilised to the extent to which they were designed. The reasoning for this was observed as the processes being appropriate in principle but being unable to obtain their desired goal. For instance, the goal of KM is to connect two nodes, knowledge owners and knowledge seekers, where the knowledge of one is transferred to the mind of another, so that a new decision can be made or situation handled (see Section 2.3). Therefore, the satisfaction levels of the potential users ultimately revolve around the effectiveness of the system in transferring knowledge, which at present is not being met.

Key Finding:

KM processes will experience a cycle of disillusionment and ultimately decline if knowledge sharing is not effectively achieved. This will result in a reduced lack of effort being applied to future KM processes thus causing a further reduction in knowledge quality and therefore an on-going cyclical decline of satisfaction/effort.

Figure 6.9 is unapologetically linear, as although it is recognised that insertions of resources such as; increased training and heightening its priority, would give a boost to effort applied, this is no more than an artificial life prolonging injection. Eventually, without continuously performing such evasive action a continuation of the linear decline will occur.

As a result, these findings have categorically demonstrated the importance of a move away from a *'first generation'* KM perspective (see Section 2.2.4). Alternatively, a move towards adopting a *'second generation'* KM perspective is needed. This sees knowledge transfer as a social endeavour, with knowledge being a relative, provisional and context-bound phenomenon socially embedded in communities and intimately tied to day-to-day practice (Visser, 2010). This highlights the need for any future KM framework to centre around the generation of a more social environment.

Key Finding:

A move away from a KMS strategy towards one that incorporates socialisation will lead to improved knowledge sharing and consequently heightened levels of satisfaction of the process.

6.3.4 Format of Knowledge Capture / Storage

Previous research such as that conducted by Goodman and Darr (1998), Nonaka (1994), Bessant and Tsekouras (2001), Ganah (2003), Lee and Egbu (2007) and Lin and Lee (2011) combined with the findings of this study (see Sections 5.3.4.5, 5.5.4.5, 5.4.4.5 and 6.3.4), provide clear evidence that the format in which knowledge is shared in impacts the degree of effectiveness to which knowledge is transferred. An overview of the inherent implications of each knowledge storage format is shown in Figure 6.10.

Figure 6.10: Inherent Implications of Each Knowledge Storage Format

The dissatisfaction that knowledge seekers experience (see Section 6.3.3) is caused by a poor understanding of the context of the learning situation being generated and thus low levels of tacit knowledge being transferred. Consequently, techniques incorporating greater degrees of socialisation and visualisation are required. This directs towards the conclusion that managing knowledge in a commodity sense (i.e. it can be extracted, stored, shared and managed using the formats illustrated in Figure 6.10) is a misconception and one that can be detrimental to KM efforts. For instance, this study has established a strong indication that such an approach simply leads to mediocre knowledge transfer at best (i.e. explicit knowledge), low levels of satisfaction towards the system and ultimately its demise on many occasions (see Section 6.3.3).

This points towards a change in mind set concerning KM systems being required from all involved. Top level management who invest time and resources into the development of such systems, and potential users who invest time and effort using them, need to lower their expectations of them. The storage of actual tacit knowledge is not possible until a computer system as advanced as the human brain is developed. Therefore the expectation that it can be the answer to an organisation's KM and subsequent transfer dilemma is unequivocally over optimistic.

Instead, the realisation that such systems are no more than a representation of an organisation's knowledge base is required, where such representations are utilised as signposts towards the most appropriate knowledge sources. For this to develop alterations to KM systems themselves should be made to not disguise themselves as knowledge transferal systems but instead knowledge locators. For instance, they should provide means to locate applicable and desirable knowledge, through identifying which knowledge owner(s) within the organisation/project are most suitable to discuss matters with. At this stage the appropriate level of socialisation can occur for effective tacit knowledge transfer.

This progresses recent attention within KM literature, which had similarly begun to move away from approaches overly centred on storing and transferring knowledge, towards ones that concentrates on 'actionable knowledge' (Bouwen *et al.*, 2009). This was discussed during the literature review as not only concentrating on the lessons learnt from a situation but also the context in which it occurred and the rationale behind the decision or action taken. As such, it was believed that captured knowledge needed to represent as close to the knower's real thinking as possible (see Section 2.3). However, the perspective derived from this study, signifies that these beneficial characteristics should be present within knowledge representations, but allied with socialisation in preference for a standalone knowledge 'store'.

As such, the findings regarding the most appropriate format to transfer knowledge remain important, especially when explicit knowledge is desired, because knowledge representations in some cases may be sufficient in transferring the knowledge sought. However, the effectiveness of each format can also be viewed as indicating towards the most beneficial formats to locate knowledge sources. This is due to some formats enabling a better understanding of the context and learning scenario than others, thus enabling a speedier location of appropriate knowledge to be conducted.

It may therefore be concluded that there is strong evidence that block text is an inefficient and ineffective format to locate knowledge, with verbal and visual aids being more strongly advocated. Therefore, in support of the viewpoint of Ruikar (2010), the incorporation of multimedia outputs, such as those facilitated by podcasts, enables a wide variety of learning abilities and styles to be satisfied.

Key Finding:

- It is a misconception that knowledge can be stored as a commodity. High levels of socialisation and visualisation are needed for effective tacit knowledge transfer.
- Multimedia knowledge representations lead to some knowledge transfer and more efficient knowledge locating than is the case through individual formats.

6.4 Current Resources

6.4.1 Information Technology and Mobile Technologies

An intensely apparent observation surrounding the technology adoption philosophies of the contracting organisations is that they use other organisations within the industry as benchmarks for themselves. If they believe that their technological resource base is sufficient in comparison to competitors' then it is viewed as satisfactory. For example, Case B and C assessed their adoption ethos as being one of the industry's leaders. However, their respective technological resource bases indicate that if these assessments are accurate, the industry as a whole is slow to adopt new technological advances. For example, PDA solutions were touted as being trialled within both of these '*leading'* companies. However, in the wider marketplace PDAs are already being superseded by smartphone and tablet computer alternatives due to them offering PDA functionality with additional telephone network connectivity capabilities (Goodrum and WACUG, 2011; Himmelsbach, 2012).

This demonstrates that the industry's slow technology adoption rate continues to be an obstacle in taking advantage of such progression (Anumba and Ruikar, 2002; Marsh and Flanagan, 2002; Nitithamyong and Skibniewski, 2004; Henderson and Ruikar, 2010). Caution therefore needs to be taken to ensure that a solution does not incorporate technologies that are either not already utilised or are not being planned for adopted in the near future. This is due to the recognition that resistance to change and limited resources have consistently been witnessed as substantial barriers to the proposed feedback loop (see Sections 2.7.4.1 and 2.7.3.3). The identified technological resource base that coincides with this above caution, including those determined as aligning with the near future direction of technology adoption within the industry are illustrated in Table 6.2.

Key Findings:

- Construction organisations are slow to adopt new technologies;
- The developed feedback framework must not incorporate resources that are not at the industry's disposal currently or planned in the near future, as this will cause significant resistance to its adoption.

6.4.2 Development of a Multiple KM Technique and Technology Strategy

Not one single KM technique or technology is capable of supporting the entire KM process (see Section 2.10.1). However, it is also not the case that an increase in the quantity of KM activities relates to better KM (see Section 2.10.1). The findings of this study have therefore provided more clarity into which techniques and technologies not only best support each stage of the KM lifecycle but also complement each other.

The most beneficial KM techniques and technologies to emerge have been tabulated according to the KM lifecycle phase that they best suit (see Table 6.2). The advantages and disadvantages identified of each in performing each phase are also provided. As such it is clear that where one technique/technology is lacking, another can fill the void. Accordingly, this has enabled a more effective KM technique/technology strategy to emerge in terms of the most complimentary arrangement of tools (see Figure 6.11). As can be seen, a distinct move away from the technological focused approaches advocated by many authors (see Section 2.5) has been made, in preference for an approach which incorporates a much higher degree of socialisation and visualisation.

Table 6.2: Available Technological Resource Base

Technology	Attributes	Drawbacks	KM Formats Supported
Personal Computers	• Large processing power • Wide familiarisation with software packages • Internet connectivity	• Not portable/ so the user has to return to site office to use	• Text, • Photographs, • Videos, • Audio
Laptops	• Portable • Remote internet connectivity • Wide familiarisation with software packages	• Cumbersome to transport around site • Not suited to site usage (durability etc.)	• Text, • Photographs, • Videos, • Audio
Mobile Phones	• Mobile • Possible remote internet connectivity • Compact communicative device • Relatively cheap	• Limited internet usability • Telephone network has limited connectivity • Writing text is cumbersome because small screen and buttons	• Limited text, • Photographs • Videos • Audio
PDAs	• Compact computing device • Remote internet connectivity • Suited for site based work using stylus or touch screen	• Lacks telephone communication capabilities • Being superseded by smartphones and tablet computers • Writing is cumbersome due to touch buttons	• Limited text, • Photographs • Videos • Audio
Intranet	• Enables remote access to stored knowledge • Offers multiple features such as video conferencing, CoPs, databases	• Often used for knowledge storage • More suited for passive forms of knowledge (e.g. reports)	• Text, • Photographs, • Videos, • Audio
Data Mining Tools	• Can search for documents on key text terms • Makes knowledge location more straightforward	• Mostly suited for text based documents • Cannot locate knowledge based on spoken language or video content (unless indexed using text)	• Majority text • Other formats also but they are secondary
Smartphones	• Compact computing and communicative device • Remote internet connectivity • Suited for site based work using stylus or touch screen	• Expensive • May already be owned personally • Touchscreens not always suitable for site use • Writing is cumbersome due to touch buttons	• Text, • Photographs, • Videos, • Audio
BIM	• Aligns with future direction of the industry • Powerful visualisation tool • Encourages collaborative project management	• Not mature enough to know in what form it will be utilised	• Text, • Photographs, • Videos, • Audio

Table 6.3: Most Beneficial KM Technology / Technique Arrangement Appraisal

Stage	KM Technique / Technology Appraisal
Identify	**Site Visits**
	+ Can identify what others are doing differently through discussion and demonstration / Two-way communication - Resource intensive / Not all encompassing / Only for a privileged few
	CoPs
	+ Can identify what others are doing differently through discussion / Two-way communication (generally when human based) - Generally need to be pre-arranged (time lag) / Only for a privileged few / Over reliance on text when computer based
	DTMs
	+ Identification of learning opportunity is brought forward in time / Natural event within a project (build on current processes) / Multi-discipline, face-to-face discussions - May be subject to fear of blame
Capture	**Mobile Technologies (PDAs / Smartphones/Tablets etc.)**
	+ Capture live (no time lag/knowledge deterioration) / Portable / Multimedia - Tendency to only capture static/non two way communication
	Site Visits
	+ Enables tacit knowledge transfer due to two-way communication (verbal) and demonstration (visual) / Cross project knowledge capture - Resource intensive / Not all encompassing / difficult to capture so tends to be only for a privileged few
	CoPs
	+ Effective in capturing tacit knowledge when human based Tends to only be effective to those present at the discussion / IT based alternative is predominantly restricted to text
	DTMs
	+ Effective in capturing tacit knowledge (two-way communication) / During a project so time lag between event and capture is reduced - Not live generally / Tends not to be captured resulting in remaining in minds of those present
Codify	**Multimedia Reports**
	+ Enables knowledge to be stored more effectively than in a purely text format / reduces knowledge loss if employees leave - Limits the degree of tacit knowledge transfer compared to socialisation
Storage	**Minds of Individuals**
	+ Tacit and explicit knowledge base / Brain is an effective knowledge location system - Difficult to locate the individual possessing the desired knowledge / Subject to knowledge loss if employee leaves the organisation
	Intranet
	+ Does not require locating the initial knowledge owner to access / Remote access / Multiple access at one time - Can be troublesome locating appropriate knowledge / more suited to explicit knowledge / dependant on the quality of knowledge captured

Reuse	**DTMs**
	+ Two-way communication possible / Visual, verbal and social aspects are available / Natural event within a project (build on current processes) / Cross discipline knowledge sharing - Dependant on the knowledge bases of those within a project setting
	Training and Mentoring
	+ Two-way communication possible / effective tacit knowledge transfer / protects against knowledge loss - Resource intensive
	Evidence of Learning
	+ Potential USP / Demonstrates to other the need to learn - Generally static / Explicit knowledge
	CoPs
	+ Can build upon knowledge base generated (e.g. evidence gathering) by discussing inputs with others / Spreads the knowledge base to wider avenues of the organisation / Two-way communication when human based - Tends to only be within the same phase of the supply chain / Technology based systems are slow and text based
	Site Visits
	+ Can compare current knowledge with what others are doing (reflection possible) / visual and verbal stimuli are satisfied for tacit knowledge reuse and sharing - Tends to be in an individual/localised manner
	General Discussion
	+ Enables tacit knowledge transfer through two-way communication / can clarify points / conducted in real time - Limited audience / May be difficult to locate knowledge owner
	Computers
	+ Can access the Intranet knowledge base remotely / Do not need to locate originator of knowledge - One-way communication leaves no opportunity to clarify understanding
Validate	**Computers**
	+ Can update the Intranet knowledge base - Preceding human based methods of validation are required first
	DTMs
	+ Cross discipline discussions to validate useful or obsolete knowledge / Real time validation of personal knowledge - Project based objectives lead to focus on current project and therefore does not lead to validating online knowledge base
	CoPs
	+ Enables two-way discussions to validate useful/obsolete knowledge / Real time validation of personal knowledge / Can validate online knowledge store also - Need to be prearranged / Project related pressures lead to these being put off
	Site Visits
	+ Can discuss/ see issues to validate useful or obsolete knowledge / Real time validation of personal knowledge - Project based objectives lead to focus on current project and therefore does not lead to validating online knowledge base / Resource Intensive

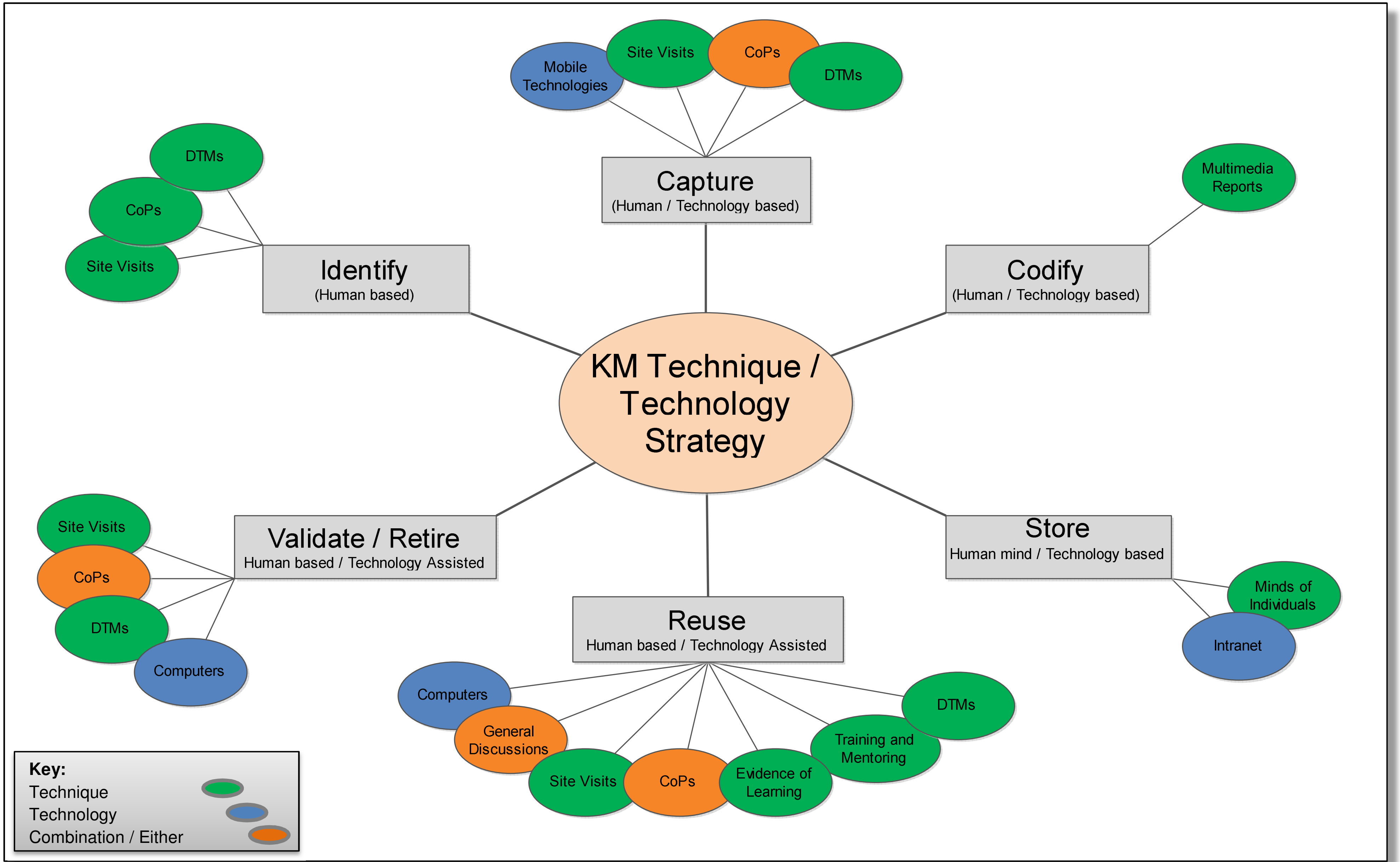


Figure 6.11: Arrangement of a More Beneficial KM Technique / Technology Strategy

6.5 Foreseen Difficulties and Potential Coping Strategies

6.5.1 Unsupportive Cultures

The most consistently recurring topic in KM literature is the importance of a supportive learning culture (see Section 2.7.3.2). The findings of this study support such perspectives as although the cultures of the respective organisations were viewed as gradually becoming more supportive, resistances to fully endorse the KM regimes were detected. For example, the SPM of Case B stated that the industry still requires a cultural change towards becoming more open and honest if buildability issues are to be highlighted and learnt from.

A key finding is the criticality of nurturing both supportive organisational and cross-organisational cultures. An effective knowledge sharing culture within the confines of an organisation's boundaries is significantly limited in achieving this goal in isolation.

The three most prominent culture related barriers are:

- Fear of Blame;
- Knowledge Protection / Hoarding; and,
- Resistance to Change

In terms of a fear of being blamed, this was demonstrated through not wanting to be openly honest about mistakes in the fear of being held responsible for negative aspects of a project. This is damaging the extent to which lessons can be learnt, as without acknowledging mistakes, they cannot be reflected upon and therefore learnt from. This was identified as being a barrier which is apparent both on a personal and organisational level. Personally, it may be viewed as a sign of weakness or a blemish on one's record if they admit to mistakes. On an organisational level it was feared that other parties may become defensive and therefore not be receptive of identified learning opportunities. For example, within Case C the CPM stated that through raising something that they believed could be improved upon in future, it can result in the receiving party becoming defensive and retaliate with an accusation of poor performance themselves (see Section 5.5.4.1 Post Project Evaluation).

Similarly, knowledge protection and hoarding was identified as remaining apparent. Differences between each case were more distinguishable regarding this issue, which has thus been tabulated to show the cross-case comparison (see Table 6.4).

Table 6.4: Cross-Case Comparison of Perceptions towards Sharing Knowledge

	Level	Perception to Knowledge Sharing	Implications
Case Study A	Personal	• Sign of weakness to share / ask for knowledge • May reduce their individual importance / worth	• Not learning from others to enhance the intellectual capital of the organisation • Potential for knowledge loss when somebody leaves
	Project	• Are open to sharing knowledge with other projects but they do not because not the opportunity to do so	• Becoming islands of knowledge • Other projects not benefitting from the learning of others
	Organisation	• Closed to knowledge sharing with outside organisations as it may assist competitors • Organisational knowledge is a powerful asset	• Experiencing repeat problems due to a lack of knowledge sharing and learning from other areas
Case Study B	Personal	• An open to sharing culture with very little fear of blame etc. detected	• A willingness to provide and absorb knowledge from others leading to a swelling of the knowledge resource base available • Less opportunity for knowledge loss when somebody leaves
	Project	• Knowledge sharing across projects through site visits shows a willingness to absorb ideas from other areas	• Other projects can benefit from the learning achieved in others • Repetitive issues can be reduced
	Organisation	• Open to share knowledge across organisational divides; however cautious to what knowledge is shared	• Some benefits of feedback will materialise • Areas in which the organisation is protective of knowledge will result in repeat issues occurring due to lack of feedback
Case Study C	Personal	• Are open to knowledge sharing amongst individuals; however the process do not support this effectively enough	• Can learn from other areas of the organisation • Limited at present due to ineffective processes
	Project	• Evidence gathering is conducted to share with individuals, projects and partners and this is well supported	• Other projects can benefit from the learning achieved in others • Repetitive issues can be reduced
	Organisation	• Most open to knowledge sharing across organisational divides especially where solid partnerships were developed	• Mutually beneficial knowledge sharing / learning • Repetitive projects reduced due to feedback of issues

Finally, in terms of resistance to change this barrier was more uniformly experienced across all three cases and not being dependent on the existence of a partnering agreement or not. This is due to resistance to change being a much more individualistic barrier (Burnes, 2004). What was discovered however is the perception that it is a characteristic of the older generation more so than employees entering the industry (see Sections 5.3.6.2 and 5.5.6.2).

This perspective is a formality, but is not one that will prove to ever become reality, as when the youth of today succeed their peers, they will also naturally develop the same human tendencies. This is due to more experienced employees having a much greater opportunity to become set in their ways and comfortable with processes that they have learnt. In comparison, the younger generation who have not yet become accustomed to set habits remain flexible and open to change whilst they discover their habituated routines. Once these have been set, they too will be inclined to resist change much more than they once did, thus resulting in the perception that the then older generation (the current youth of today) are more resistant to change than the youth of tomorrow. As a result, means to reduce resistance to change need to be sought at all levels and not simply hope that it will naturally decline as succession of employees occurs.

As such, Figure 6.12 illustrates an overview of these three most prominent barriers to knowledge sharing, as well as providing a summarisation of the coping strategies identified through this study.

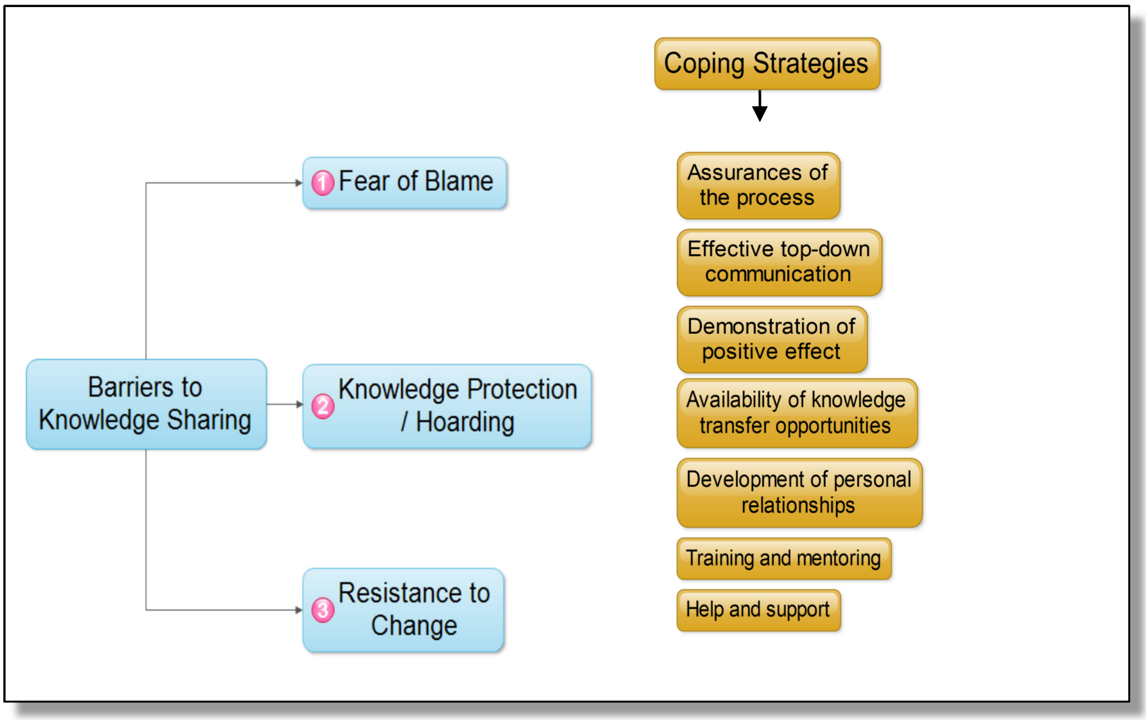


Figure 6.12: Barriers to Knowledge Sharing and Coping Strategies

6.5.2 Difficulty Nurturing Relationships

The greatest single beneficial alteration to the traditional procurement arrangement, in terms of knowledge sharing, is that of integrating teams as early on in the process (see Sections 2.6.2, 2.6.4.2, 3.2.4.1, 5.3.4.1: Framework Collaborations, 5.4.2.2 and 5.5.2.1). Accordingly, a move towards a procurement process which greater resembles a design and build contract such as the P21+ framework has been shown as presenting multiple benefits, including:

- Enabling construction knowledge to be integrated at the earliest possible stage;
- More buildable solutions;
- Relationship nurturing commencing much earlier on;
- Greater understanding of the needs and desires of the differing parties;
- Improved client satisfaction; and,
- Improved efficiency and quality of the built facility.

Furthermore, one of the most significant findings of this study is the ability to obtain such benefits inherently if effective project teams are maintained from one project to the next (see Sections 5.3.6.1, 5.4.6.3 and 5.5.6.1). This enables an even greater degree of continuous learning to be achieved as was demonstrated in Case C (see Section 5.5.6.1).

Accordingly, a move towards an early integrated repetitive team scenario can overcome some of the knowledge sharing and on-going learning difficulties apparent within the industry posed by inherent fragmentation (Gieskes and ten Broeke, 2000) (see Section 2.7.2.3). Figure 6.13 illustrates the differing project arrangements apparent in this study and their intrinsic advantages and drawbacks in relation to obtaining the aim of this study in the form of cross-organisational knowledge sharing. Also incorporated is the traditional and most common contracting arrangement of design-bid-build.

This measure is however limited due to current KM processes restricting the degree of learning that takes place within projects (see Section 6.1). These processes also do not possess the much needed support for knowledge sharing and feedback to other areas of the supply chain. Accordingly, a move towards a more integrated project delivery contract, combined with effective knowledge sharing procedures in the form of feedback to extended areas is undoubtedly needed.

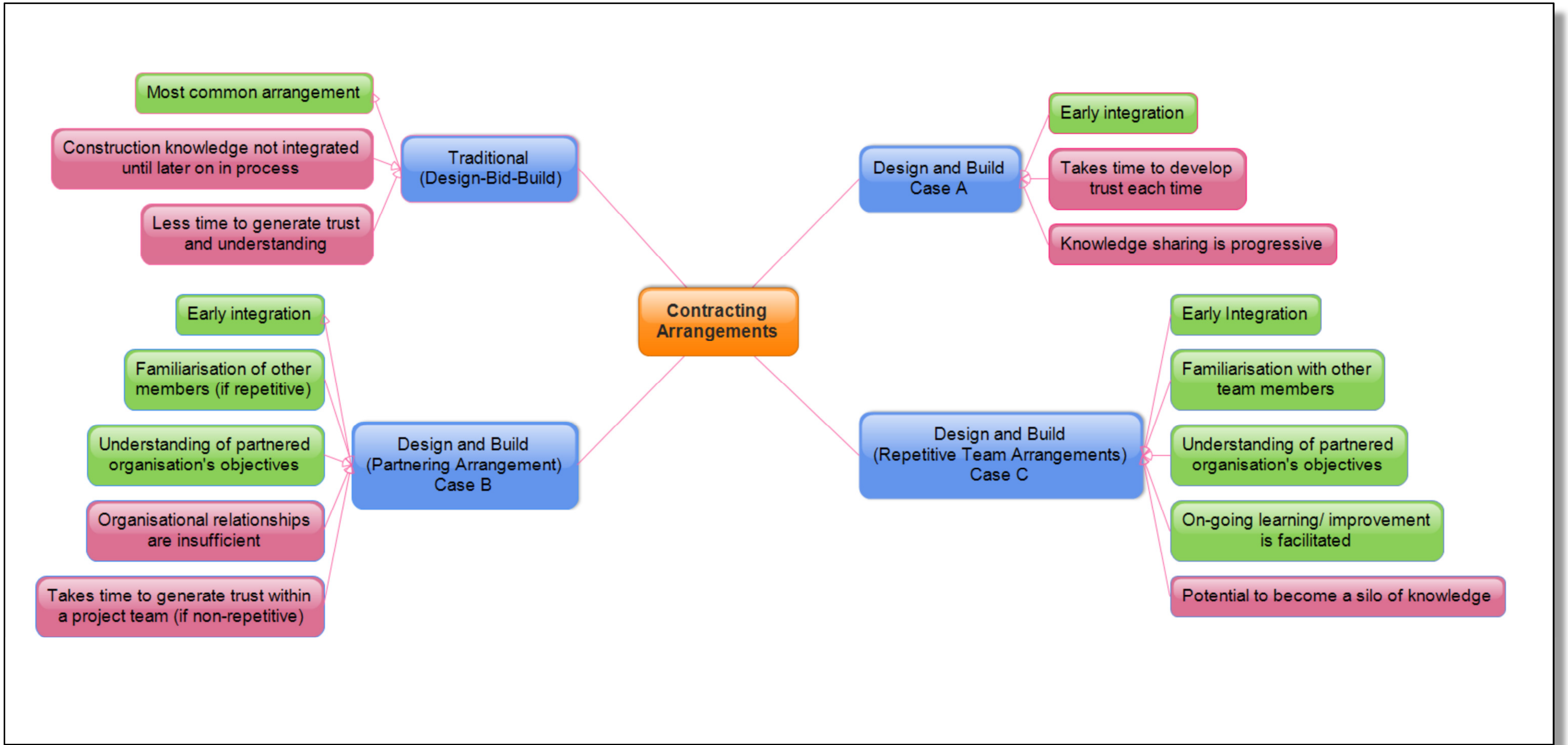
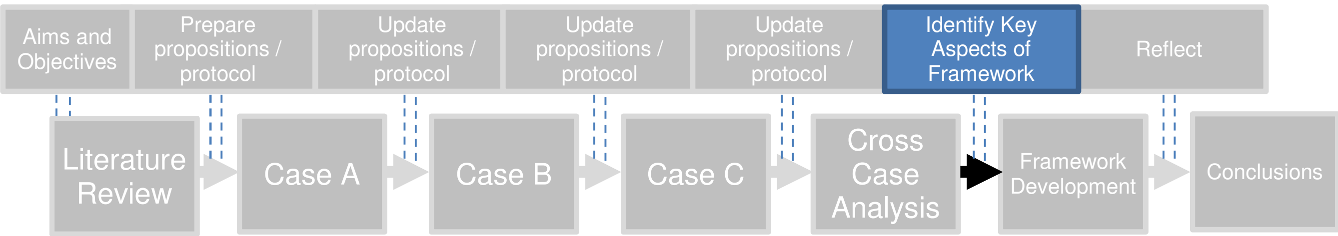


Figure 6.13: Comparative Analysis of Differing Contracting Arrangements in Enabling Knowledge Sharing



6.6 Summary of Findings Leading to Framework Development

This chapter has conducted an extensive cross-case analysis, drawing on the empirical findings derived as a result of the three case studies conducted within this research. To further substantiate these findings comparisons to related but independent studies have also been undertaken. Many key findings were highlighted throughout this chapter which are seen as having particular prevalence in focusing the continuation of this study. This is due to them being recognised as critical considerations to take into account for the subsequent development of the feedback framework. These will now be summarised to form a prelude to the following framework development.

Firstly, there is a distinct need to manage knowledge internally within the organisation and externally to those outside of the organisation boundaries (i.e. feedback of knowledge). This need is not currently being achieved on an internal or external basis. This calls for a greater appreciation of the need to share knowledge, which then is supported with improved processes to facilitate such. As a result this has pointed towards the need to communicate these findings through the utilisation of a potential framework which could offer such benefits and improvements to current practice.

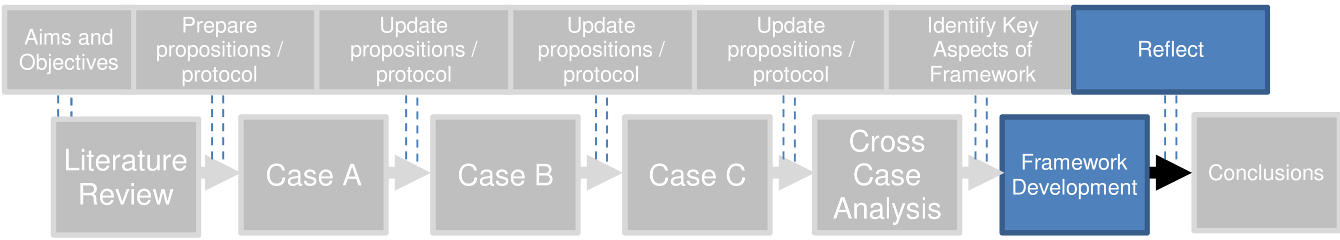
Further direction in terms of the makeup the framework was provided through the evident need to move away from a KMS strategy towards one that incorporates socialisation. This has been indicated as leading to improved knowledge sharing and heightened levels of satisfaction towards the process, instead of cycles of disillusionment. This has led to a significant increase in the opportunities to perform two-way communication within the advised framework. This is seen within both the live sharing of knowledge and internal usage of knowledge aspects of the framework (i.e. through building on currently adopted processes such as DTMs, CoPs and mentoring: see Sections 7.2.1.3 and 7.2.1.5 respectively).

The need for socialisation has also substantiated that it is a misconception that knowledge can be stored as a commodity. However, this has been expanded by the introduction that visualisation, in some cases, can be utilised to transfer tacit knowledge but this is dependent on the context and the learning experience being transferred. Accordingly, the move away from attempting to codify knowledge in text formats, towards attempting to capture the learning context through visual means such as video and photographs has been highlighted.

These findings have led to firstly the reframing of the use of knowledge stores, away from being the sole source of knowledge transfer to instead becoming a means to identify knowledgeable people (see Section 7.2.1.4). This reduces the extent to which the knowledge seeker will inevitably experience cycles of disillusionment as they have altered their expectations levels of what this resource is designed to achieve. Instead, they need to understand that it is a means to identify the most appropriate knowledge owner so that subsequent knowledge sharing techniques involving socialisation can take place (see Section 7.2.1.5). As well as this reframing, the knowledge 'store' itself has been viewed as being hindered further due to the over emphasis on text codification. Instead, the incorporation of heightened levels of visualisation has been viewed as potentially leading to sufficient levels of tacit knowledge to be shared. Accordingly, a multimedia knowledge storage format termed as a knowledge representation has been adopted (see Figure 7.3: Section 7.2.1.4).

At a higher level, a common theme emerged that due to project specific demands (see Section 2.7.2), it becomes the tendency to detect and correct problems and therefore fail to reflect on solutions and/or perform root cause analysis which can lead to learning and continuous improvement. Therefore, support for the full learning cycle (i.e. identification of the problem, generation of the solution and reflection of its implementation) needs to be incorporated and highlighted within the framework (see Section 7.2.1.1). Consequently this links to the need to perform knowledge capture activities at multiple stages of the learning cycle so that the full learning experience, and as a result, a greater extent of its context is captured. Accordingly, the learning cycle is the foundation to any knowledge management process and therefore the progression through these stages, as well as direction towards conducting live knowledge capture / sharing has become central to the feedback framework (see Section 7.2.1.1).

Finally, a general finding was that if the uptake of the improvements suggested through the framework was to be enhanced, the resources required to implement the suggestions need to be readily available. Accordingly, this framework is developed with a typical resource base in mind, taking into consideration typical processes such as DTMs also. This is expected to reduce the level of resistance towards its adoption or progression in further research. As such, this phase has enabled a clear direction regarding the formulation of the feedback framework to emerge. The following chapter firstly documents the development of the feedback framework and its key components. This is followed by conducting a testing and evaluation process on the eventual framework, which aims to verify whether it is fit for purpose, or requires further development. The aforementioned key characteristics are incorporated into this evaluation appropriately.



7 Development of the Research Informed Theoretical Framework

7.1 Introduction

The research activities undertaken and consequential findings have resulted in new ideas on how inter- and intra-organisational learning can be achieved within complex construction projects. These encompassed a wide array of key areas including improving live knowledge sharing, integration of project teams and moving away from utilising text as a sole knowledge transfer format, to name but a few. Some of these have been tackled in isolation in preceding studies to retain focus; however, a fundamental drawback of this isolation is that it neglects the effects it both inflicts and has inflicted on it by other more important aspects. For example, the concentration on attempting to improve the live capture of knowledge ignores what effect the inevitable codified knowledge has on the long-term learning potential and knowledge sharing of the organisation. Accordingly, a holistic view of this problem was taken.

It was also identified that a universal, implementable framework that was designed to meet all project contexts within all sectors of the industry was simply an unattainable goal. This is due to the shear variability that is apparent, including the individuals involved; the organisational processes; and, the project makeups and arrangements. Therefore as an aid to communicate these findings in a more coherent and usable manner, which assists the reader in understanding the adjusted concepts emerging from this research, a theoretical framework has been developed. This will allow the reader to associate their own context against the concepts discussed in this study to more easily be able to apply the ideas of how a combined first and second generation KM strategy can meet their needs.

This chapter therefore documents the development of the **EX**panding **C**onstruction **L**essons **L**earnt (EXCeLL) feedback framework, documenting how the findings from the preceding phases of research underpin its development and relate together. No attempt is made to provide guidance on its implementation outside of the discussion regarding the findings for its development. This provides a thorough understanding of the context in which these themes emerged, so that such knowledge can be adapted and applied within unrelated scenarios. Consequently, this framework is designed as a communicative tool to demonstrate more coherently *"how intra-inter project learning instances can be leveraged within highly serviced complex construction projects"* (i.e. the overarching research question of this study), by providing the necessary linkages between the key research themes to be communicated through the vehicle of an illustrative framework.

7.2 EXpanding Construction Learning Loops (EXCeLL) Framework

The EXCeLL framework (see Figure 7.1) is a project learning aid which highlights the key attributes required to perform effective cross-organisational project based learning within complex construction projects. It is not intended to be interpreted as a linear framework that is read from top to bottom. It is a high level framework which inherently incorporates low levels of prescription to enable adoption flexibility. Its main objective is to illustrate to construction organisations and project teams, the key facets that are essential for effective project-based learning to take place. If these components are not present, there is a high likelihood that effective learning will not take place, and consequently, detrimental cycles of disillusionment will inevitably occur (see Figure 6.9; Section 6.3.3).

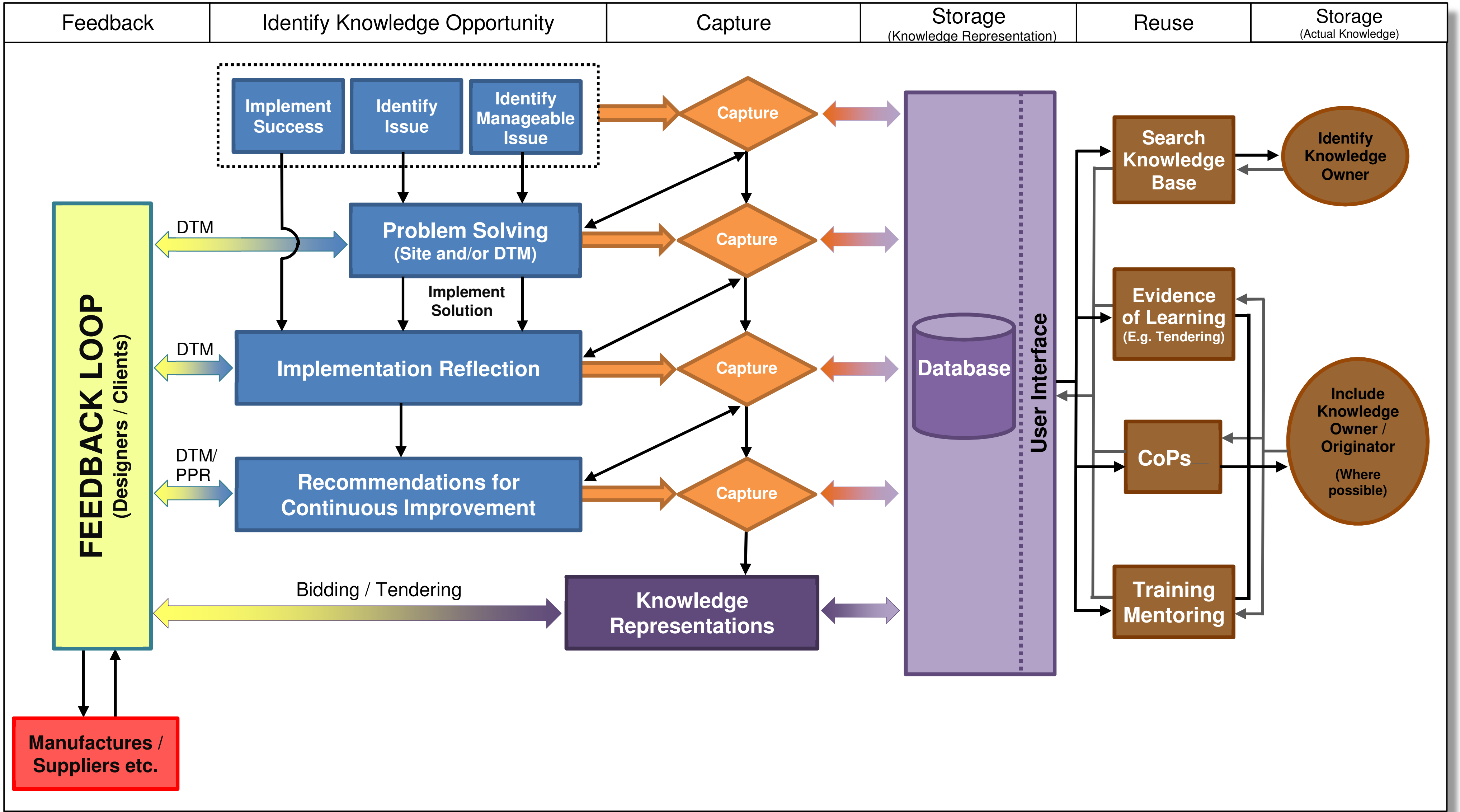


Figure 7.1: Design and Construction Feedback and Learning Loops (EXCeLL) Framework

7.2.1 Understanding the EXCeLL Framework

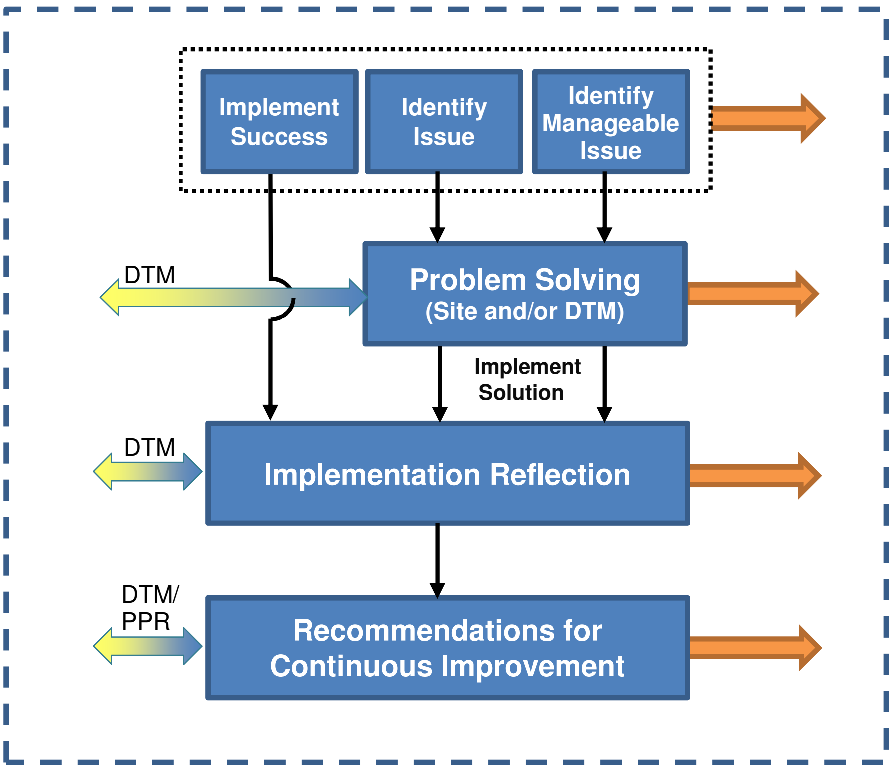
The EXCeLL framework has five main components. These include:

- The completion of the learning process (blue);
- Live and on-going capture of knowledge (orange);
- Live sharing of knowledge and learning throughout a project (yellow);
- Internal management of knowledge (purple); and,
- Internal usage of knowledge (brown).

This section continues to outline the key terms of each component and explains how the framework should be interpreted. More importantly it demonstrates how the findings of this study have formed the basis for the framework and how the framework itself overcomes detected KM issues.

7.2.1.1 Completion of the Learning Process (Blue)

This section describes how the EXCeLL framework highlights the necessity to complete the learning process (see Table 7.1); a scenario which was discovered as rarely being the case within practice (see Section 6.3.1). The overall learning process commences during the KM lifecycle phase of identifying a learning opportunity (see Figure 7.1).



Identifying a Learning Opportunity

The irreplaceable component of any KM framework is the requirement for a learning instance to take place. It is then its objective to facilitate the appropriate management of such knowledge. The EXCeLL framework therefore commences with a learning opportunity being identified. Regarding the issue of buildability, this was discovered (see Section 6.3.2.1) as being in one of three forms:

> **Successful implementation**: is a design feature that can be implemented without any need for rework or further discussion. At this stage there is very little learning to be captured as all that has been established is that an element of the design should be buildable. Consequently, no problem solving is required; however, the rationale behind formulating the conclusion that it is a buildable element could be captured and shared. At the very least, this would lead to wider members of the project team understanding the basis for such a decision, which is a form of learning that can be applied in future decision making processes.
>
> **Identification of an issue**: this occurs where a design element cannot be built as specified. There is a need for some form of rework or discussion to take place between differing parties to develop solutions by using the problem solving guidelines discussed in Problem Solving stage below.
>
> **Identification of a manageable issue**: manageable issues are those that construction personnel can overcome without the need for additional intervention from designers. The solution as planned was not the most desirable one, but it can be made to work due to the experience and skills of the construction team. These issues were discovered as very rarely shared, which results in designers being unaware that they occur (see Section 5.4.4.2). Consequently, such elements are deemed to be a relative success and therefore may be implemented once more in future projects (see Section 5.4.4.2). This is without the incorporation of additional construction knowledge, therefore leading to the absence of continuous improvement.

Problem Solving

The structure of the problem solving phase is dependent on which type of issue has been identified (see above). In the cases of a buildability issue that require rework on the part of designers, or a mutually agreed solution to a problem, this generally involves discussions between design, construction and sometimes client personnel within a DTM. This discussion instigates the questioning of norms in an attempt to identify root causes to establish how they can be overcome (i.e. learning). This development of new thinking is therefore an ideal knowledge capture opportunity, which is highlighted as a result of following the EXCeLL framework.

For a manageable issue that does not need external intervention, the problem solving stage can be conducted by the construction team. The EXCeLL framework brings to the construction team's attention the need to capture this problem solving activity so that it can be shared, before the implementation of the solution commences. For this activity to be prioritised, communication from top level management is required to inform employees how efforts towards these key learning instances can lead to significant industrial improvements if learnt from (see Section 5.4.4.2: Proposition 7a).

Implementation Reflection

Many authors have highlighted that a common downfall of learning practices within construction revolve around the omission of the act of reflection (Wood Daudelin, 1996; Barlow and Jashapara, 1998; Love *et al.*, 2000; Hart, 2005). This was supported through the finding that due to short term project related pressures, reflection is not completed sufficiently (see Section 6.3.2). What results is the detection and correction of problems without identifying their root causes or developing means for improvement and in effect not actually learning (see Section 6.3.2).

Previous KM framework attempts have failed to satisfy this problem fully, with either the problem solving stage being captured retrospectively (Kartam and Flood, 1997), or when it is attempted live (2006), it is done do in isolation and with no support of preceding or subsequent stages of the learning cycle (i.e. identifying learning opportunities or reflection).

Having identified this deficiency, the EXCeLL framework more clearly illustrates the need to fulfil the entire learning process, especially in regards to extending it further than the implementation of the solution (i.e. beyond detection and correction).

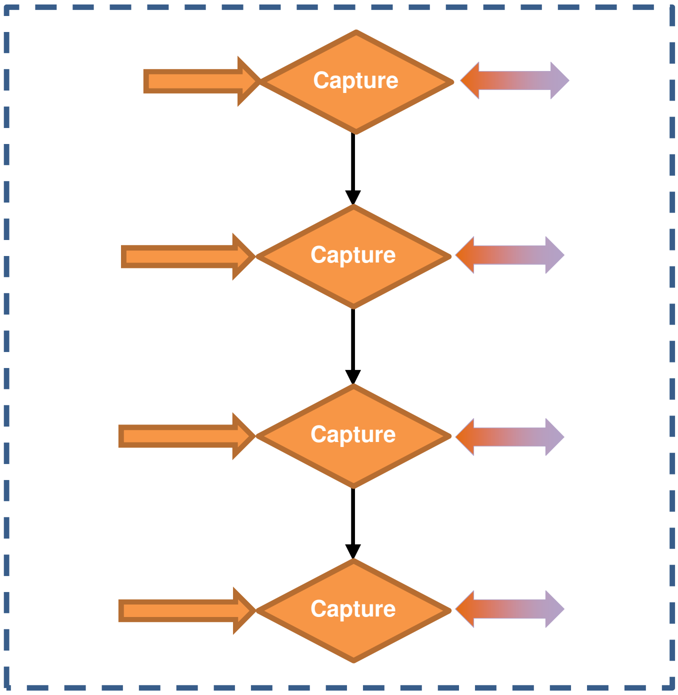
Table 7.1: How the 'Completion of the learning Process' Component of the EXCeLL Framework Addresses Inadequacies in Current Practice

EXCeLL Component	Evidence of Inadequacies in Current Practice	How EXCeLL Overcomes Issues
Identify Learning Opportunity	Knowledge deterioration if identification of learning opportunity is not 'live'.	Demonstrates that the identification stage should precede the problem solving and solution implementation stage and not recalled retrospectively.
	Concentration on most significant issues (generally failures).	Illustrates the need to learn from a range of issues (success, failures and manageable issues).
Problem Solving	It is a critical phase in the learning process as it results in questioning norms and creation of new learning. It occurs naturally in DTMs but it is rarely captured in practice.	Highlights that the DTM process is a significantly useful knowledge sharing technique. Also shows that the capture process should not be a one-off retrospective task, but be a step process in line with the learning cycle.
Implementation Reflection	Currently only conducted during PPE or POE. Misses opportunity to convey a greater degree of the context and results in knowledge loss / deterioration).	Brings the process forward in time to be completed during the implementation of the solution. Causes time between event and reflection to be minimised.
Recommendations for Continuous Improvement	Often conducted internally which limits the extent of continual improvement as no feedback to those that can ensure lessons are implemented in future (i.e. designers).	Incorporates the reflection process within DTMs which results in lessons being shared across organisational divides.
	Generally the entire KM process is conducted retrospectively at this stage.	The learning process is broken down into four phases, with capturing and sharing being highlighted as required throughout the progression through the cycle and not deferred until the end.

<u>Recommendations for Continuous Improvement</u>

Through mutually reflecting upon the implementation and results of a solution, designers and construction teams can develop appropriate recommendations for similar future issues. This results in a simultaneous move towards continuous improvement, whilst diverging from the traditional tendency to needlessly reinvent the wheel.

7.2.1.2 Live and On-going Capture of Learning Process



One of the most significant divergences of this framework compared to the output of preceding studies is the identification of the need to compliment first and second generation KM perspectives. Past studies have viewed these perspectives as mutually exclusive, with arguments surrounding which is preferred. However, this study has discovered that they can, and perhaps should, be harmonised. This consists of blending both systematic (first generation KM) and social (second generation KM) standpoints.

For instance, the move away from the aim to codify and manage knowledge systematically, towards the appreciation that socialisation is key for effective tacit knowledge transfer. However, there remains a significant desire from companies to produce a tangible *'knowledge store'* to defend against the risk of knowledge loss.

However, it has been observed that greater efforts are being made to satisfy the first generation (technological approach) (see Section 6.3.1). This over reliance on a knowledge store to transfer knowledge was seen to cause an on-going deterioration of the quality of stored 'knowledge', satisfaction levels of users, and inevitably level of usage (see Section 6.3.3). This has led to the conclusion that a knowledge store should be considered as no more than a representation of what knowledge is possessed within the organisation.

The EXCeLL framework therefore adapts the function of such a store, to become the basis for locating knowledge originators and sources of knowledge. In some cases the process of accessing such representations may be sufficient in conveying desired knowledge; however, in general it will require further socialisation based transfer techniques. These are discussed further in Section 7.2.1.5. The makeup and management of knowledge representations is discussed in Section 7.2.1.4.

Furthermore, the capture of knowledge representations was discovered to rarely be conducted live and throughout the learning cycle (see Section 6.3.1). This causes deterioration of knowledge and potentially knowledge loss (see Section 6.3.3). The EXCeLL framework emphasises the need for multiple points of live capture to reduce the extent of knowledge deterioration as far as reasonably possible. This improves the quality of knowledge representations stored on the system and thus heightens its ability to:

- Efficiently locate appropriate knowledge sources; or,
- Transfer knowledge without further action needing to be taken (i.e. arrange for further socialisation).

Table 7.2: How the 'Live and On-going Capture' Component of the EXCeLL Framework Addresses Inadequacies in Current Practice

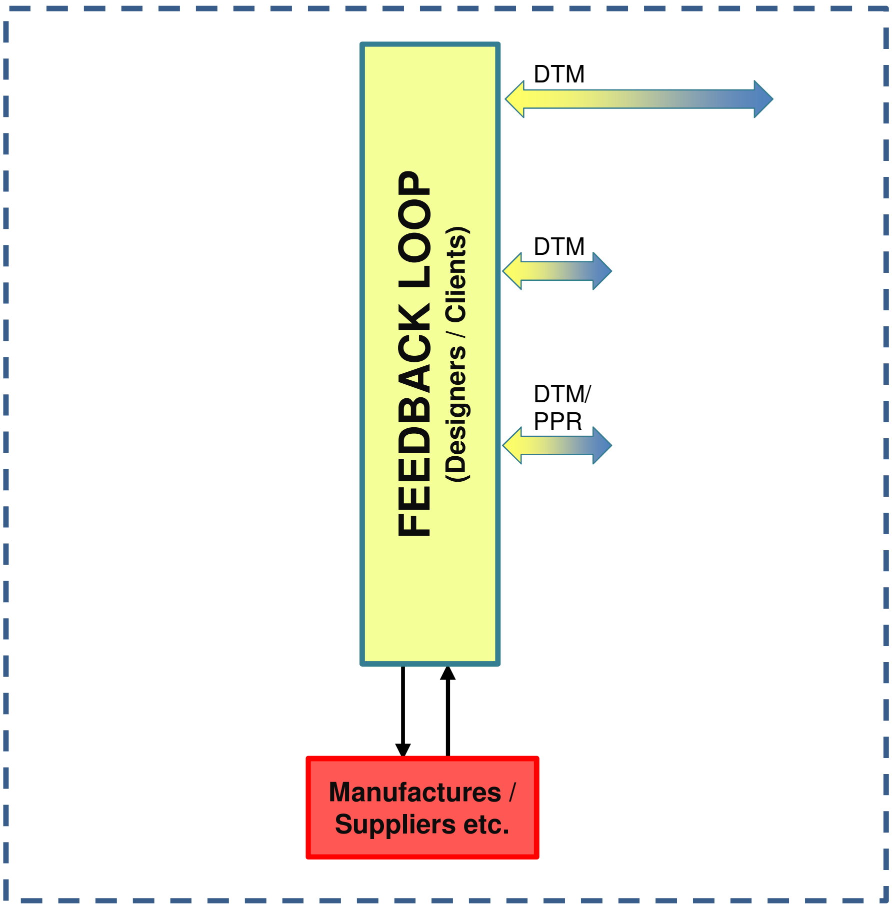
EXCeLL Component	Evidence of Inadequacies in Current Practice	How EXCeLL Overcomes Issues
Live Capture	Need for socialisation for tacit knowledge transfer.	Not overcome by this component (see Section 7.2.1.5).
	Demand for tangible 'knowledge' store.	Facilitates the capture of knowledge based on existing practices such as intranets and databases.
	Knowledge capture is not conducted live.	The quality of stored knowledge is enhanced through the introduction of live and continuous capture points, improving quality of stored knowledge and reducing knowledge loss.

It has been identified by previous authors such as Bessant and Tsekouras (2001) and Hari *et al.* (2005), and supported by the findings of this study that two-way communication is the most effective format for transferring tacit knowledge (see Sections 5.3.4.1, 5.3.4.3, 5.3.4.5, 5.4.4.3, 5.5.4.5 and 6.3.4). As such it was recognised that a regularly performed procedure that enables this form of knowledge transfer throughout a project is that of DTM's (see Section 6.3.1).

It is therefore understood that knowledge is being fed back informally through such measures. However, as highlighted in Section 6.3.2.1, only issues which require design input are fed back in this way. Manageable issues and successes are not, but should be if the most beneficial learning impact is going to be experienced. Therefore, the utilisation of DTM's to reflect upon major issues, manageable issues and successes, is fundamental.

DTMs can therefore act as live feedback loops of knowledge (see Figure 7.1) with very little added expenditure of time or effort. This is beneficial as utilising currently available resources and procedures was identified as a strategy that could significantly reduce barriers to knowledge transfer (see Section 5.3.4.1). Similarly, the benefits of capturing knowledge representations live apply to live feedback, which include a higher quality of knowledge and a better understanding of its original context.

7.2.1.3 Live Sharing of Knowledge and Learning throughout the Project



Current processes of reflection and learning at the end of a project were also seen to exasperate the issue of knowledge protection (see Section 5.4.6.4). This is due to the sharing of knowledge at this stage being viewed as likely to benefit competitors, as the design team moves to work on other projects with differing contractors. EXCeLL's incorporation of capture and sharing processes throughout the project lifecycle therefore presents a strategy that could reduce this barrier. This is due to the focus at these points remaining on the current project rather than future ones and therefore individuals are more likely to perceive their efforts as benefitting the current project to a greater extent than once it has been completed (see Table 7.3).

Table 7.3: How the 'Live Knowledge Sharing' Component of the EXCeLL Framework Addresses Inadequacies in Current Practice

EXCeLL Component	Evidence of Inadequacies in Current Practice	How EXCeLL Overcomes Issues
Live Knowledge Sharing	Knowledge is not always openly shared across organisational divides due to it being attempted at the end of a project.	Less emphasis is put on conducting knowledge sharing at the close-out of projects by formulising the knowledge sharing process throughout. This utilises DTM's to conduct live learning. It demonstrates that greater attempts need to be made to not only address upcoming issues but to also reflect on past issues so that learning is conducted during and not after the project.
	DTMs are an ideal and timely method for effective two-way communication / tacit knowledge transfer.	The framework utilises DTMs as a key cross organisational knowledge sharing/feedback method.
Knowledge feedback to Suppliers / Manufactures	Knowledge sharing between manufactures and construction/ design personnel is not conducted effectively in either direction leading to difficulties making appropriate decisions/ inability to continuously improve.	The need to improve knowledge sharing between construction projects and manufacturers is highlighted within the EXCeLL framework; however, further investigation into how this can materialise is acknowledged as being required (see Section 8.4).

A further aspect of the chain of knowledge which has emerged during this research and added to its originality is that of the need for the feedback of knowledge to not be limited to design and construction participants only. For actual continuous improvement to materialise, suppliers and manufacturers also need to be incorporated within the knowledge sharing framework (shown as red on Figure 7.1). If this is not the case, the extent to which learning can benefit the construction industry appears restricted due to the natural constraints placed on design and construction teams by the materials and the subsequent techniques that must be utilised. It is not clear through this study how such an addition would materialise in practice as it is out of the realm of its boundaries. However, this study has been fundamental in highlighting this desirable further research area.

Accordingly, a move towards the desired state of cross-organisational learning illustrated in Figure 7.2 can occur. The framework alters the focus of learning away from what can be learnt within the boundaries of an individual organisation. Instead the enhanced potential of cross-organisational learning can be achieved through the greater appreciation of the benefits of utilising the project to form a collaborative system.

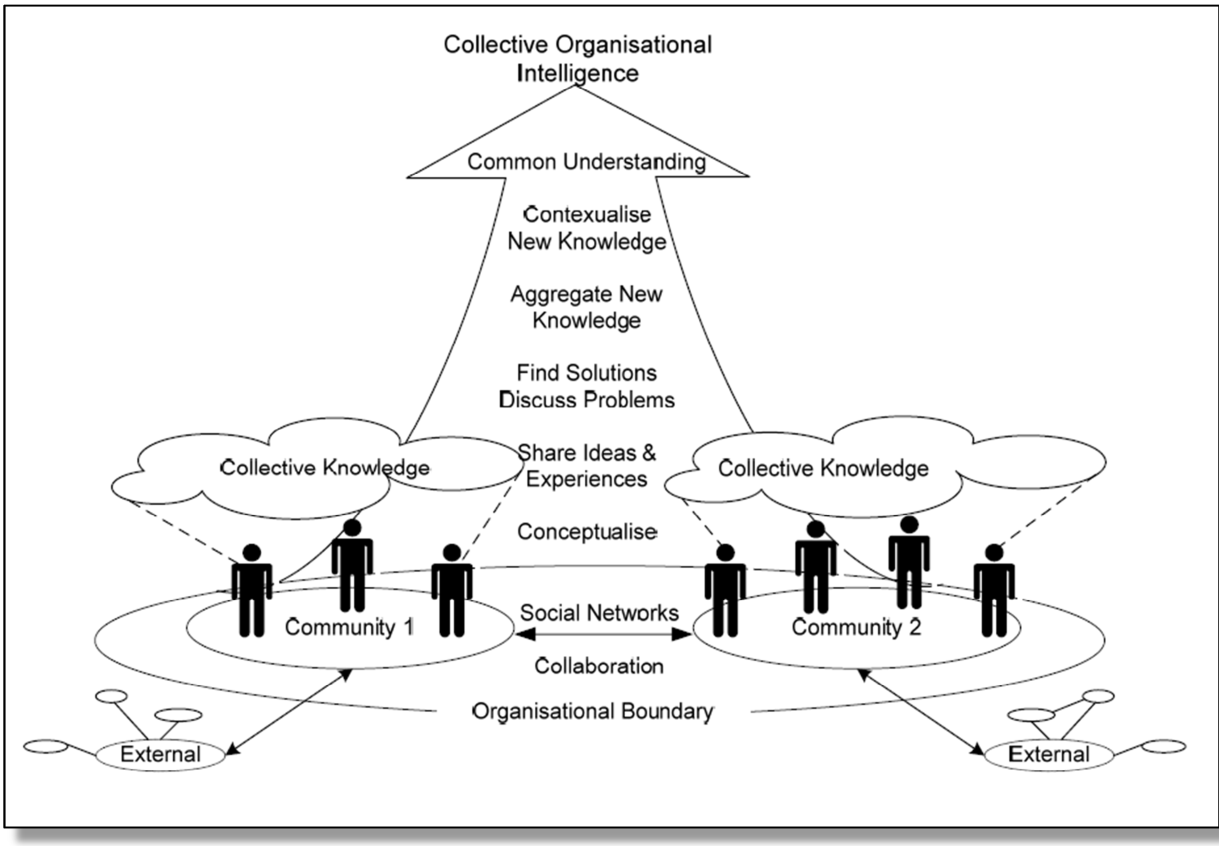
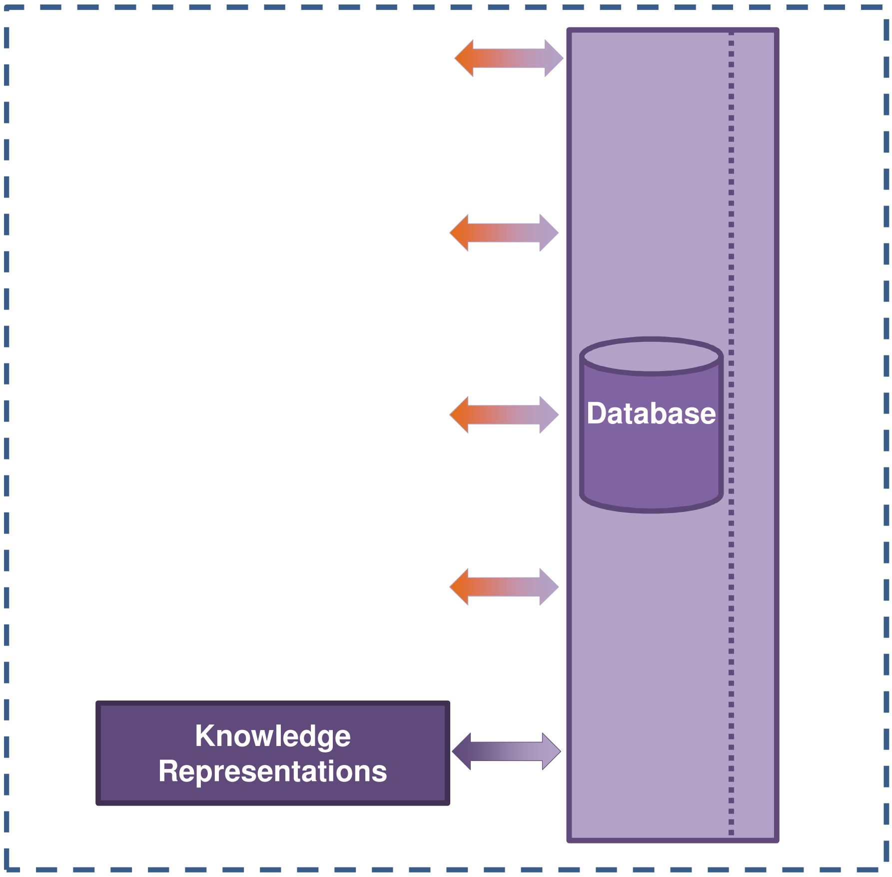


Figure 7.2: Contribution of Communities of Practice to Collective Organisational Intelligence. Source: Ruikar *et al.* (2009)

7.2.1.4 Internal Management of Knowledge Representations



Database and Intranet

To satisfy the aforementioned demand for a tangible knowledge store (see Section 7.2.1.2), the EXCeLL framework does not divert significantly away from current technologically based KM processes. Current intranet and user interfaces should be incorporated if appropriate (i.e. they are deemed as meeting this need), as an addition to the strategy to reduce the extent of resistance to change (see Section 5.3.4.1).

A critical area for organisations to address however is the need to change the perceptions and expectations of the users of such a knowledge store. Currently, it is expected to be intuitive, efficient, intelligent (in terms of understanding what knowledge is desirable) and effective in transferring explicit and tacit knowledge. However, its inability to provide all of these benefits has resulted in heightened levels of disillusionment (see Section 6.3.1). Accordingly, top level communication and retraining is required to reshape the expectations of users to align with its new purpose of being a capable knowledge location aid. This will enable users to become more tolerant of its inevitable downfalls due to being aware of them and understanding the processes in place to overcome them (i.e. availability of socialisation opportunities).

Format of Knowledge Representations

A critical area requiring alteration to existing processes is the need to adapt the format that knowledge representations are captured in (see Table 7.4). As has been noted throughout this study, varying formats are beneficial for numerous reasons (see Section 2.2.4, 5.3.4.5, 5.4.4.5 and 5.5.4.5). These include:

- Efficiency of capture/sharing;
- Ease of storage; and,
- Ability to transfer knowledge.

In particular, multimedia outputs are highly beneficial in satisfying the differing learning styles of visual, aural, read-write and kinaesthetic (VARK) as highlighted by Drago and Wagner (2004) (see Section 2.2.4). This is shown through Gardner's theory of multiple intelligences in which each human is capable of seven relatively independent forms of information processing, with each individual differing from another in the specific profile of intelligence that they exhibit Accordingly, a multiple format structure for knowledge representations is proposed to more appropriately satisfy these individualities within humans (see Figure 7.3).

Table 7.4: How the 'Internal Management of Knowledge Representations' Component of the EXCeLL Framework Addresses Inadequacies in Current Practice

EXCeLL Component	Evidence of Inadequacies in Current Practice	How EXCeLL Overcomes Issues
Database and Intranet	Knowledge stores are relied upon to share knowledge.	The purpose of the knowledge store has been altered to become more attainable thus reducing cycles of disillusionment. The aim of the store is to enable knowledge seekers to locate the most appropriate knowledge source.
Format of Knowledge Representations	Text is an over utilised format to store knowledge, which reduces its usefulness in conveying context and understanding.	Multiple formats are encouraged through it being easily identifiable if potential knowledge capture points are missed. This is in the form of there being gaps in the representation of knowledge if a variety of formats are not utilised.

This representation could be adapted to meet individual organisational needs, for instance with each stage being displayed on a separate page, allowing more room to display photographs. This could therefore aid in the ease of identifying the most appropriate representation of knowledge out of the variety of output retrieved from the search function. Figure 7.3 also shows how the story behind the creation of knowledge can be built up through the stages of the learning cycle; thus providing the knowledge seeker with a much more robust understanding of the context that it was created within (see Section 7.2.1.1).

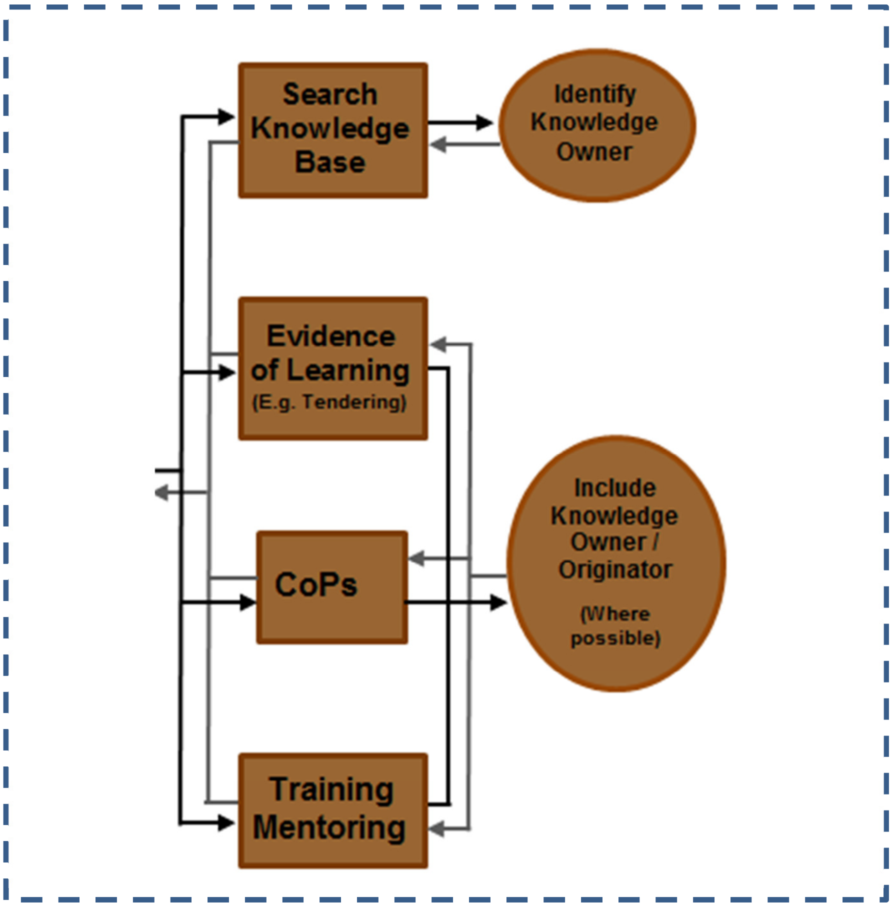
	Stage	Text	Photos/Graphs/ Drawings	Videos	Contacts
Success (Identify Success)	**Issue Identification** (Problem Identification)	Text summary • • • •			Hyperlinks to contact(s)' details
	Solution Generation (Problem Solving)	Text summary • • • •			Hyperlinks to contact(s)' details
	Reflection of Implementation (Reflection of Solution)	Text summary • • • •			Hyperlinks to contact(s)' details
	Learning (Learning outcome / recommendations)	Text summary • • • •			Hyperlinks to contact(s)' details

Figure 7.3: Knowledge Representation Format

A critical aspect of this structure is the creation of a social network of employees within the organisation through publishing the knowledge originators' contact details. This encourages knowledge seekers to communicate either physically (face-to-face) or verbally (via telephone) to transfer knowledge through the technique of two-way communication. Furthermore, a move towards such a social network can start to break down the damaging act of silos of knowledge and knowledge protection, which currently greatly limits the learning potential of the construction industry as a whole (see Section 5.3.4.3).

7.2.1.5 Internal Usage of Knowledge Representations

As knowledge representations do not dramatically differ from the processes or output of the KM approaches currently adopted (see Section 7.2.1.4), the uses of them also remain in line with those observed. These include; searching and locating knowledge, basis for communities of practice, training and mentoring, and evidence of learning (see Figure 7.1). However, it is anticipated that due to the change in expectations placed on their utilisation, the perceived beneficial impact will be greater, thus reducing cycles of disillusionment (see Section 6.3.1). Justification for this assertion will now be made in regards to each anticipated use.



Search / Locate Knowledge

As with current KM intranet systems, the store of knowledge representations can be sifted through to locate similar issues to those that the knowledge seeker is experiencing. This process has been enhanced due to it incorporating a much more intuitive story building process, multiple capture points and multiple formats. For example, it was observed that the use of visual aids such as photographs enable the viewer to interpret the situation much more swiftly than interpreting blocks of text, which is a key negative characteristic of existing processes (see Section 5.5.4.5).

By identifying and contacting appropriate knowledge owners through the supplied contact details in the knowledge representation format (see Figure 7.3); the knowledge seeker can overcome their problem and thus become a knowledgeable person themselves. As such they can either create a new contribution to the system or update the current knowledge representation with their own recommendations and learning outcomes. In particular, this should include updating their contact details to expand the social network of knowledge, which benefits both the organisation and future knowledge seekers by:

- Reducing the dependency on a small number of knowledge owners;
- Making it easier to locate knowledge owners; and,
- Reducing the chance that knowledge owners leave the organisation without being superseded (i.e. causing permanent knowledge loss).

Communities of Practices

A further example of how knowledge representations are currently utilised consistently across all cases, was that of forming the basis to create a CoP (see Section 5.3.4.3, 5.4.4.3 and 5.5.4.3). For instance, the knowledge situation (problem or success), its problem solving and implementation (if required) and the reflection of the outcome, can initiate the foundation of a CoP surrounding that knowledge area. During the analysis of the three cases, two forms of Cops were identified; technological and physical based CoPs.

A drawback of technologically based CoPs was that low levels of participation leads to a significant time delay between posting queries/pleas for assistance and actually receiving a response (see Section 5.3.4.3). The structure of the EXCeLL framework is viewed as reducing this drawback due to the ability to contact the knowledge owner directly due to contact details being published alongside the contribution. This can lead to the creation of an additional contribution if necessary, the updating of the original, or certainly increasing the social network of knowledge owners associated with each issue.

Physical CoPs also utilise the knowledge representation base due to them assisting organisations in identifying real life issues that have previously hurt the organisation. These are therefore discussed and communicated during monthly knowledge sharing sessions. The benefit of the EXCeLL framework over existing approaches is that a greater degree of the learning process is captured and therefore a greater extent of the context in which it was observed can be appreciated.

Training and Mentoring

Similarly to CoPs, the store of knowledge representations is sometimes used as examples of previous problems (see Section 5.5.4.2). EXCeLL increases in likelihood that key milestones of the learning process are captured by firstly highlighting the need to do so (through the framework process) and secondly, facilitating the ease of multiple capture points (through the format of knowledge capture) (see Table 7.5). Similarly to that discussed above (see CoPs) this is viewed as improving the ability to communicate knowledge through increasing the knowledge seeker's understanding of the original context.

Evidence of Learning (Tendering and Bidding)

Table 7.5: How the 'Internal Management of Knowledge Representations' Component of the EXCeLL Framework Addresses Inadequacies in Current Practice

EXCeLL Component	Evidence of Inadequacies in Current Practice	How EXCeLL Overcomes Issues
Search / Locate Knowledge	Difficult/ time consuming to locate desirable knowledge sources.	Building up a picture of how the knowledge was created (multiple capture points), and utilising multimedia formats reduces the emphasis on text. The user can therefore establish its appropriateness more efficiently.
	Lack of effective knowledge transfer results in knowledge loss.	More effective knowledge transfer through socialisation elements. Increase in the number of knowledge owners due to the social networking feature enabling the number of knowledge owners to be adapted as people leave the organisation / other persons become knowledgeable in this area.
CoPs	Time delay between appealing for assistance and receiving a response.	Ability to directly communicate with the originator of the contribution so response is immediate.
	Contributions are generally static in nature so become obsolete if the originator leaves the organisation.	New holders of knowledge can be added to the contribution which then more accurately represents the up to date knowledge base of the organisation.
Training and mentoring	Difficult to understand the context of learning instances through text based reports.	A fuller understanding of the originating context can be created through utilising multiple capture points throughout the learning cycle in multiple formats.
Evidence of Learning	Conducted retrospectively so does not capture the full learning instance.	Multiple capture points throughout the duration of the project.
	Often deferred indefinitely due to the reduction in its worth (if looking back) and limited resources.	Conducted within current procedures such as DTMs so relatively little additional effort compared to attempting to gather evidence retrospectively at the end of a project. Also conducted during the project when there are more resources at their disposal.

A use of knowledge representations which extends beyond the boundaries of the initial organisation is that of utilising it for evidence of learning. This emerged as something that clients value as it demonstrates attempts to continuously improve the products that are supplied by that company (see Section 5.5.4.1: Evidence Gathering). As such, Case C collects representations of knowledge to be used during the bidding and tendering stage of contracts to demonstrate a unique selling point.

This enables construction knowledge to be integrated early on in the project. The main reason for organisations to not conduct such a process, or not to the extent to which they would like, was due to the reduction in resources available at the end of the project (see Section 5.4.6.1). However, the EXCeLL framework encourages on-going and continuous knowledge capture throughout the project and accordingly reduces the pressure on restricted and dwindling resources that begin to be reallocated at the end of a project.

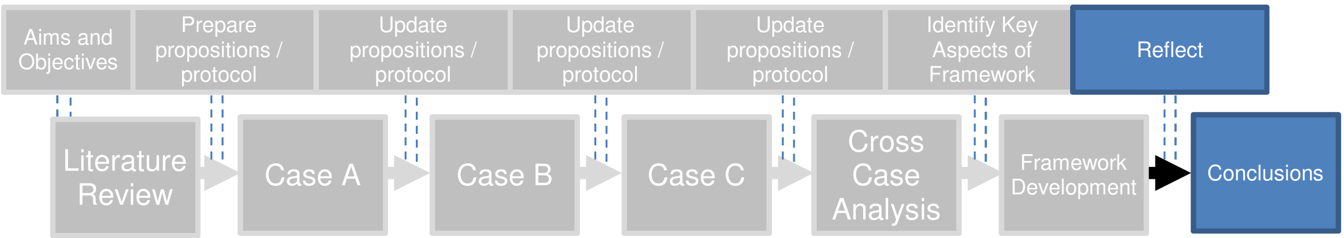
7.3 Overview

The EXCeLL framework therefore brings together the two major perspectives within KM literature in demonstrating that FGKM and SGKM ideas do not have to be abided to in isolation. Key reasons for the popular adoption of a FGKM approach within the organisations studied included, speed, cost and ability to produce a more tangible representation of knowledge available. This is despite the distinct dissatisfaction consistently voiced towards its ability to share knowledge.

Accordingly, in adapting the perceptions held towards the purpose of FGKM concepts such as codifying and storing knowledge electronically the benefits of speed, cost and tangibility can be utilised more appropriately. This will be achieved through the alteration that codified knowledge can be utilised as an effective tacit knowledge transfer technique and instead being the key source to locate knowledgeable colleagues, This can then result in the application of SGKM concepts which include the importance of socialisation to understand the contextualisation of the knowledge being shared.

7.4 Chapter Summary

This chapter has documented the development of the EXCeLL framework, providing an explanation of its key components. This is viewed an enabling the framework to be moulded within current construction organisation processes and surroundings. This viewpoint was evaluated which, through determining the positivity of results, has shown that the framework in its initial form was relatively successful in achieving its overall objectives. To further enhance its degree of satisfaction, additional development has been undertaken in areas identified through the evaluation process. The following chapter identifies recommendations for further research, acknowledges the limitations of this study and most importantly, outlines the key conclusions to be drawn from this study and its contribution to knowledge.



8 Conclusions and Recommendations

8.1 Realisation of Research Aim and Objectives

Specific objectives were set to fulfil this study's overarching aim (see Section 1.2). This section discusses how each has been fulfilled through research activities undertaken. This is subsequently followed by an articulation into the extent to which the attainment of these objectives has led to the fulfilment of the overarching research aim.

8.1.1 Objective 1: To examine existing literature relating to the need for and barriers against design-construction learning loops

It has been discovered that current failings and inefficiencies within the industry can be attributed to poor or a total lack of learning from previous experience. However, due to the fragmented nature of the industry, the improvement of learning from projects within a set organisation was observed as only leading to partial improvement. An even greater need is that of sharing learning across organisational divides throughout the supply chain.

An area of specific interest was that of buildability. This was recognised as an area in which learning from previous experience undoubtedly relied upon the sharing of experience and lessons learnt across discipline divides. This is due to the implications of decisions made during the design phase generally being experienced during the construction phase. Accordingly, feedback of experience is required to continually improve future decisions, but at present is not occurring sufficiently.

Although it was discovered that this need is understood within industry, each stage of this study (literature review and all three case studies) have all concluded that there are inherent barriers within the industry that make it difficult to achieve. These include; short term pressures, restricted resources, knowledge protection, unsupportive cultures and resistance to change to name just a few. A unique finding of this study identified how the perception of learning activities could lead to the intensification of a barrier in the form of a lack of faith towards it. This causes cycles of disillusionment to arise due to previous poor experiences. Within KM, this leads to a lack of future effort towards such activities, which thus reduces the worth of the KM infrastructure further. This results in an on-going cyclical decline that is detrimental to the KM initiative.

8.1.2 Objective 2: To establish the potential and limitations of current knowledge management procedures

It has been consistently found that current KM procedures are lacking in vital areas which are ultimately leading to them failing to achieve their goal of spreading knowledge throughout projects and organisations. In particular, the lack of appreciation and support for the context specificity of knowledge and the need for socialisation in order to understand its original context is leading to knowledge stores that consist of very little actionable knowledge.

It has been found however, that such knowledge stores can still serve a purpose if reframed in terms of their purpose. This is achieved by altering what they are designed to achieve, away from being the sole source of organisational knowledge, towards becoming a sign posting aid to relevant knowledgeable people. Accordingly, the location of relevant knowledge can be achieved efficiently, with real socialisation and context understanding being facilitated in addition, thus allowing tacit knowledge transfer to take place.

As such, the limitations of current practise, which predominantly adopted a FGKM approach, is viewed as be insufficient if cross project knowledge sharing is to take place. Furthermore, a purely SGKM approach was also seen as being difficult to achieve without the ability to locate knowledgeable sources. Accordingly, a hybrid approach has been proposed that draws on the benefits of each method, whilst bridging the limitations of the other.

8.1.3 Objective 3: To establish the potential and limitations of current feedback loops designed to improve design quality

Current feedback loops are predominantly conducted informally. Knowledge and experience are transferred unintentionally during activities such as discussions and problem solving with other project participants. However, the most informal method to feedback knowledge is through a post project evaluation. This was identified as being insufficient in meeting the above need to learn from projects due to it occurring at the end of the project. Firstly, this increases the opportunity for knowledge deterioration which occurs as time progresses from the event itself to the period in time in which it is recalled and shared. It also heightens the barrier of knowledge protection as the act of sharing knowledge at this stage is much less likely to benefit them and is more likely to benefit a competitor in a future project. In comparison, learning throughout the project not only minimises knowledge deterioration, but heightens the perception that shared knowledge still has a significant opportunity to benefit the existing project and therefore provides greater encouragement to overcome knowledge protection.

Internal feedback loops within the same organisation, which can result in cross-organisational knowledge sharing were even more fraught with drawbacks. They were identified as not concentrating on a wide enough array of learning instances, as they focus predominantly on failures. This not only ignores the opportunity to learn from manageable issues and successes, but also results in heightened barriers to feedback due to the development of a blame culture. All of these drawbacks are key ingredients that lead to the aforementioned cycles of disillusionment.

8.1.4 Objective 4: Evaluate which technologies/techniques are most effective to assist learning activities

It was observed that there is an industry wide tendency to attempt to satisfy the need to share knowledge through a first generation, technological approach. However, this greatly restricts its worth due to it being more suited to the transfer of explicit knowledge, ignoring the fundamental need for socialisation and predominantly depending on text as the capture and sharing format. This systems approach which incorporates a KM database accessed through an intranet was widely adopted. However, its inability to achieve effective knowledge transfer due to the above cited drawbacks lead to significant levels of cycles of disillusionment, which without intervention leads to its downfall.

The activity that provides the greatest cross-organisational knowledge sharing potential was discovered as being the design team meetings. These occur at regular intervals throughout the duration of a project and include personnel from differing disciplines. The main aim of these meetings is to overcome identified problems and therefore incorporate key phases of the learning cycle which include; identification of a learning opportunity, problem solving and solution generation. However, drawbacks of this process were still noted in the form of not learning from all issues (i.e. manageable issues and successes) and more importantly, not conducting appropriate reflection of solutions once implemented. This would enable future improvements to be developed and as such a move towards the desired state of continuous improvement.

The format in which knowledge is shared in has a direct impact on the technique or technology's usefulness. For instance, those that rely on text as the predominant format such as reports or KM databases are much less beneficial than those that incorporate high levels of two-way communication.

This being said, these more beneficial methods are generally more resource intensive. This led to perhaps the most significant finding of this study in the form that first and second generation approaches do not and should not be mutually exclusive. Although KM techniques are more suited to achieving effective knowledge transfer, the desire for organisations to create a tangible representation of their knowledge resource base remains. At the same time, these knowledge representations were found to be able to transfer a desirable amount of knowledge in some cases. The inclusion of technologies therefore reduces the reliance on KM techniques in isolation thus reducing its strain on resources.

8.1.5 Objective 5: To improve cross-organisational boundary learning within complex infrastructure projects

The above findings led to the formulation of the EXCeLL framework. This framework overcomes the downfalls of current practice in supporting the full duration of the learning cycle. It highlights the need to learn from a greater array of learning instances, as well as conducting live knowledge sharing (i.e. feedback) through the currently adopted process of DTMs. Live knowledge capture is also supported through the utilisation of KM technologies, in a multiple format / stage structure. This therefore meets the objectives of this research to improve cross-organisational learning, but also the objective of individual organisations to create tangible knowledge base representations.

8.2 Realisation of Research Aim

The aim of this research has been to develop a theoretical framework that enables knowledge to be transferred across organisational and discipline divisions between design and construction within large complex construction projects. This aim emerged from the call by Newell *et al.* (2006) to focus research in the area of seeking a KM initiative that draws on the positive aspects of both first and second generation methods in a hybrid approach (see Section 1.2).

The research activities undertaken were done so in a planned and robust manner which enabled a rigorous enquiry into the above interest area (i.e. surrounding each research objective). Accordingly, this led to an abundance of well-founded primary research findings that built upon and satisfied identified gaps in current knowledge. As a result, the EXCeLL framework demonstrates the key findings of this study in an illustrative manner and in particular the main conclusion to be brought from this study, that a hybrid approach to KM is not only possibly but desirable.

8.3 Limitations of Research

Although the main research question and its aims and objectives have been met through following a carefully planned methodology, this section outlines the unavoidable limitations of this research. These are as follows:

1. The framework has been developed appropriately for its purpose, which is to more clearly illustrate the findings of this study to the reader. It is intentionally designed to not be ready for practice but to probe thought into how a hybrid KM approach can manifest. A process of testing and validation within industry has not taken place and therefore it is acknowledged that for the purpose of improving industry confidence in its adoption, pilot projects in which it is implemented would be required. This stage was not possible during this study due to the restricted time and resource constraints. Such testing would enable a greater insight into further implementation guidance and improvements to emerge. This would require observation of its utilisation for the duration of a construction project to evaluate its use in sharing knowledge to subsequent projects. This therefore is outside the resource limits of this study, but has been identified as the potential basis for further research (see Section 8.4);

2. To narrow the focus of this research, the framework was developed to assist buildability. The framework therefore reflects the processes currently undertaken to detect, correct and learn from buildability issues. It is therefore acknowledged that this methodological consideration affects the overall impact of the research findings. This is due to the framework not being designed for a wider array of learning goals such as sustainability or health and safety. An area of interest therefore surrounds the extent to which it is applicable to satisfy other learning goals and to what extent and how it needs to be modified to meet alternative focuses.

3. As acknowledged previously (see Section 4.5.2), an inherent limitation of case study research is the reduced ability to generalise the findings beyond the small set of cases investigated. This was carefully considered during the contemplation of the most appropriate methodology to adopt. It was felt that the in depth nature of case studies outweighs this limitation due to its ability to offer a greater insight into the phenomenon investigated. In reflection this initial belief has been reaffirmed due to the case study approach enabling a much richer understanding of the problem than would be possible through alternative methods such as questionnaires. Accordingly, this allowed for an abductive research approach to be undertaken which thus led to more robust and continuous theory building to take place.

4. In connection with limitation three, the adoption of sequential case studies was a further methodological consideration that has had implications on the eventual ability to generalise the findings of this study beyond the small set of cases investigated. A three in-depth sequential case study approach was adopted in preference for a potentially higher number of simultaneous cases due to the perceived benefit the opportunity to update and adapt research propositions provided. This was seen by multiple propositions and sub-propositions arising or being adapted throughout conducting and analysing the cases (for example, propositions 2b.1, 3c, 4a.1, 6a, 7, 7.1, 8 and 8a). This led to being able to incorporate the testing of such emerging phenomena in following cases which would not have been facilitated if the cases were conducted concurrently. Accordingly, substantiation of findings could be achieved to a much greater extent. Consequently this strengthened the logic between the findings and the framework development.

5. As stated above, the methodological decision to embark on case study research naturally restricted the number of cases that could be observed. This resulted in three cases. However, linked to this restriction is the decision to then adopt comparable cases. Large healthcare projects were adopted as they were example cases of the main focus, high serviced complex construction projects. This was felt to reduce the significant number of explanatory variables that would be apparent if differing cases were adopted such as if one from the education, industrial power and healthcare had been adopted. Although this significantly assisted the analytic strategy for this study, it has implications for this study's generalizability.

8.4 Recommendations for Further Research

This section identifies areas in which further research can be conducted to progress these findings and subsequently build on the foundation provided. The breadth of this project's focus has needed to be wide to address the research problem holistically, rather than in a piecemeal fashion which has previously been the case. Therefore, in satisfying the research objectives and further demonstrating its contribution to knowledge, this study has unearthed a multitude of additional interest areas that require further research. These recommendations for further research are:

1. It was discovered that trust and understanding between project participants was the most substantial key ingredient for knowledge sharing to occur. Accordingly, a more in-depth investigation of the dynamic interfaces between construction and design

teams and how they interact and develop trust throughout projects is required. This is to enable greater insights into how trust and mutual knowledge sharing can arise in practice. Although investigated within the boundaries of this research, the scope of this topic area is so vast it could easily form its own standalone study. Therefore, through utilising the findings and guidance outlined in this study as a basis, more substantiated recommendations can be made so trust and interaction can be more freely generated;

2. Benchmarking practices were identified as a potentially powerful way to increase the interest and desire to achieve OL goals. However, at present there is no effective means to measure the extent of learning from individual projects due to the high levels of subjectivity that surrounds the subject. Therefore further research in this area would be highly beneficial in enabling such measurements and benchmarking practices to be incorporated into the EXCeLL framework;

3. It was discovered that the reallocation of employees facilitates knowledge distribution naturally. However, utilising repetitive teams was shown to present significant benefits in terms of enabling continuous learning. As these two strategies are seen as mutually exclusive, further investigation is required to establish the beneficial impact of both, thus allowing a more informed conclusion into the most desirable strategy to be formulated;

4. BIM has been found to be a likely fixture in the future makeup of the industry. However, due to this state not currently being evident, this study addressed its overarching research question without being dependant on certain tools being adopted or advances being made. Accordingly, further research is required to observe how BIM will impact on the EXCeLL framework both positively and negatively; and,

5. The learning objective of the KM lifecycle adopted in this study was to reduce repetitive buildability instances. This is attained through the EXCeLL framework. However, further research could lead to establishing the extent to whether other learning goals such as sustainability improvements can also be obtained through this framework. Once more this further progression of the framework is viewed possible through applying the framework in practice for the purpose of sharing knowledge relating to such additional learning objectives.

8.5 Contribution to Knowledge

This research has produced a theoretical framework that provides support to within- and cross-organisational learning from complex construction projects. It has therefore made a significant contribution to progressing research towards satisfying the need to improve the extent lessons are learnt from construction projects and applied in future projects. It moves research forward in attaining the desired state of continuous learning within construction whilst also changing the focus of learning away from within organisations, towards that of a collective system within a project. This encourages each organisational silo to think beyond their own boundaries by considering the beneficial impact they can provide to the project domain. This therefore fills the gap of knowledge that currently appears within projects due to the natural fragmentation of teams that possess differing knowledge bases.

A contribution of greater uniqueness and more specificity is that of responding to the call by Newell *et al.* (2006) for further work to be conducted in the area of investigating the

> *"interplay between ICT systems, work practices and the development of face-to-face and virtual communities within organizations as the dichotomy between existing approaches to knowledge management (Swan and Scarbrough, 2001) clearly fails to address important areas where 'pure' approaches may fail, but 'hybrid' approaches may succeed."*

Accordingly, this study has continued this premonition by producing conclusive evidence in support of the recognition that diverging KM perspectives within academia should in fact be converging if truly effective KM is to materialise. These two opposing perspectives have been termed as a first generation KMS perspective or a second generation socialisation approach. Previous attention had begun to see a shift in focus away from a first generation outlook, which viewed knowledge as a commodity that could be systematically captured, stored and retrieved. This was causing a move towards the adoption of a second generation perspective which sees knowledge as situated in practice and requiring human involvement if it is to be transferred effectively.

This study identified the need to continue towards adopting a second generation focus; however it shrewdly observed how both perspectives could be combined within one framework. Although moving away from a KMS approach, the need for organisations to generate a more tangible knowledge resource remains real. Accordingly, the KMS elements proposed focuses on generating heightened levels of natural socialisation. Through storing these learning encounters it is viewed as enabling further socialisation to be achieved as it facilitates a tangible representation of the organisation's knowledge resource base. Without such a resource, the current problem of locating knowledge sources (observed in practice) would continue to restrict organisational and project learning.

A further contribution to the KM field has been made by highlighting the need to approach KM holistically as improvements within specific aspects of the process are likely to impact on other areas inadvertently. For example, efforts made to improve live capture in isolation ignore the requirement for socialisation during the transfer phase. This has resulted in the increase in the codification of knowledge to enable it to be captured more easily and live, which inadvertently results in cycles of disillusionment due to the resultant knowledge sharing ultimately being limited by the process of making tacit knowledge explicit. Therefore through simplifying one aspect, it complicates and detracts the positive effect that can be achieved through following aspects. Accordingly, this research has demonstrated that a holistic view is possible and preferential compared to fire fighting localised problems.

8.6 Concluding Remarks

The need to learn from previous experience to move towards the goal of continuous improvement has been categorically substantiated within this study. The current inability to achieve desired levels of learning is seen as causing significant industry inefficiencies and reducing the value / quality of its outputs. However, this project has demonstrated that knowledge sharing outside of an organisation and project’s boundaries is not only beneficial, but obtainable. These findings are therefore viewed as a solid basis to originate future studies in continuation towards realising the state of continual learning within construction projects.

9 References

AAMODT, A. and NYGÅRD, M., 1995. Different roles and mutual dependencies of data, information, and knowledge — An AI perspective on their integration. *Data & Knowledge Engineering,* **16**(3), 191-222.

ABDOU, A., LEWIS, J. and RADAIDEH, M., 2003. An internet-based decision support system for healthcare project appraisal: a conceptual proposal. *Construction Innovation: Information, Process, Management,* **3**(3), 145-155.

AGARWAL, N.K. and POO, D.C.C., 2006. Meeting knowledge management challenges through effective search. *International Journal of Business Information Systems,* **1**(3), 292-309.

ALARCÓN, L.F. and MARDONES, D.A., 1998. Improving the design-construction interface, *Proceedings of the 6th Annual Conference of International Group for Lean Construction,* Guarujá, Brazil, 13-15 August. .

AL-GHAMDI, A.M., 2000. *Constructability at Design Offices & Contractors: Analysis and Recommendations.* Dhahran, Saudi Arabia: Collage of environmental design department of construction engineering and management.

AL-GHASSANI, A.M., ANUMBA, C.J., CARRILLO, P.M. and ROBINSON, H.S., 2005. Tools and techniques for knowledge management. In: C.J. ANUMBA, C. EGBU and P.M. CARRILLO, eds, *Knowledge Management in Construction.* Oxford, UK: Blackwell Science Publishing Ltd, pp. 83-102.

ALLISON, B., OWEN, A., ROTHWELL, A., O'SULLIVAN, T., RICE, J. and SAUNDERS, C., 1996. Research Skills for Students. London: Kogan Page.

ALSHAWI, M., 2007. Rethinking IT in construction and engineering: organisational readiness. Oxon, UK: Routledge.

ANDREEVA, T. and KIANTO, A., 2012. Does knowledge management really matter? Linking knowledge management practices, competitiveness and economic performance. *Journal of Knowledge Management,* **16**(4), 617-636.

ANDRIES, P. and WASTYN, A., 2012. Disentangling value-enhancing and cost-increasing effects of knowledge management (Accepted). *Journal of Knowledge Management,* .

ANUMBA, C.J., KAMARA, J.M. and CUTTING-DECELLE, A.F., 2006. Concurrent engineering in construction projects. Oxon, UK: Taylor & Francis.

ANUMBA, C. and RUIKAR, K., 2002. Electronic commerce in construction—trends and prospects. *Automation in Construction,* **11**(3), 265-275.

ARDERY, E.R., 1991. Constructability and constructability programs: White paper. *Journal of Construction Engineering and Management,* **117**(1), 67-89.

ARDITI, D., ELHASSAN, A. and TOKLU, Y.C., 2002. Constructability analysis in the design firm. *Journal of Construction Engineering and Management,* **128**(2), 117-126.

ARDITI, D. and GUNAYDIN, H.M., 1997. Total quality management in the construction process. *International Journal of Project Management,* **15**(4), 235-243.

ARGYRIS, C., 1993. Knowledge for Action: A Guide to Overcoming Barriers to Organizational Change. San Francisco: Jossey-Bass Inc.

ARGYRIS, C., 1992. On organizational learning. Oxford, England: Blackwell Scientific.

AUGENBROE, G. and VERHEIJ, H., 2002. Project web sites with design management extensions. *Engineering Construction and Architectural Management,* **9**(3), 259-271.

AYAS, K. and ZENIUK, N., 2001. Project-Based Learning: Building Communities of Reflective Practitioners. *Management Learning,* **32**(1), 61-76.

AYYAGARI, M., BECK, T. and DEMIRGÜÇ-KUNT, A., 2003. Small and medium enterprises across the globe: A new database. *World Bank Policy Research Working Paper No. 3127,* .

BAIDEN, B., PRICE, A. and DAINTY, A., 2006. The extent of team integration within construction projects. *International Journal of Project Management,* **24**(1), 13-23.

BARBOUR, R.S., 2007. Introducing qualitative research: a student's guide to the craft of doing qualitative research. London, UK: Sage Publications Ltd.

BARLOW, J., 2000. Innovation and learning in complex offshore construction projects. *Research Policy,* **29**(7-8), 973-989.

BARLOW, J. and JASHAPARA, A., 1998. Organisational learning and inter-firm partnering in the UK construction industry. *The Learning Organization,* **5**(2), 86-98.

BARSON, R.J., FOSTER, G., STRUCK, T., RATCHEV, S., PAWAR, K., WEBER, F. and WUNRAM, M., 2000. Inter-and intra-organisational barriers to sharing knowledge in the extended supply-chain, *Proceedings of the International Conference on e-Business and e-Work, Madrid, Spain,* October 18-20, IOS Press: Amsterdam pp367-373.

BECERIK-GERBER, B. and RICE, S., 2010. The perceived value of building information modelling in the US building industry. *Journal of Information Technology in Construction,* **15**, 185-201.

BELL, D., 1999. The axial age of technology foreword: 1999.

BENNETT, R. and GABRIEL, H., 1999. Organisational factors and knowledge management within large marketing departments: an empirical study. *Journal of knowledge management,* **3**(3), 212-225.

BERG, B.L., 2007. Qualitative research methods for the social sciences. 6th edn. USA: Pearson International.

BERRY, L.L., PARKER, D., COILE, R.C., HAMILTON, D.K., O NEILL, D.D. and SADLER, B.L., 2004. The business case for better buildings. *Frontiers of health services management,* **21**(1), 3-24.

BESSANT, J. and TSEKOURAS, G., 2001. Developing learning networks. *AI & Society,* **15**(1-2), 82-98.

BLAIR, D.C., 2002. Knowledge management: Hype, hope, or help? *Journal of the American Society for Information Science and Technology,* **53**(12), 1019-1028.

BOER, H., CAFFYN, S., CHAPMAN, R., CORSO, M., COUGHLAN, P., GIESKES, J., HYLAND, P., MAGNUSSON, M., PAVESI, S. and RONCHI, S., 2001. Continuous product innovation and knowledge management: the CIMA supporting methodology. *International Journal of Operations and Production Management,* **21**(4), 490-504.

BORDASS, B., 2003. Learning more from our buildings-or just forgetting less? *Building Research & Information,* **31**(5), 406-411.

BORDASS, B. and LEAMAN, A., 2005. Making feedback and post-occupancy evaluation routine 1: A portfolio of feedback techniques. *Building research and information,* **33**(4), 347-352.

BOUWEN, R., CRAPS, M., SIPS, K., TAILLIEU, T., TEMPST, W. and VAN ACKER, K., 2009. Diverging-Converging action strategies to generate actionable knowledge for sustainable material management, *Business as an Agent of World Benefit edition:2 Cleveland, Ohio, USA,* 2-5th June, 2009 .

BOWDEN, S., 2005. *Application of Mobile IT in Construction*, Loughborough University.

BOYD, D., EGBU, C., CHINYIO, E., XIAO, H. and LEE, C.C.T., 2004. Audio diary and debriefing for knowledge management in SMEs, *Proceedings of the twentieth Annual conference of ARCOM,* September 1-3 Heriot Watt University, UK, pp176-188.

BRAA, K. and VIDGEN, R., 1999. Interpretation, intervention, and reduction in the organizational laboratory: a framework for in-context information system research. *Accounting, Management and Information Technologies,* **9**(1), 25-47.

BRYMAN, A., 2008. Social research methods. 3rd edn. Oxford New York.

BRYMAN, A., 1988. Quantity and quality in social research. London: Unwin Hyman.

BRYMAN, A. and BELL, E., 2007. Business research methods. 2nd edn. USA: Oxford University Press.

BURNES, B., 2004. Managing change: A strategic approach to organisational dynamics. third edn. England: Prentice Hall.

CAMPANELLA, J., 1999. Principles of Quality Costs: principles, implementation and use. Third edn. Wisconsin, USA: Quality Press.

CARLILE, P.R., 2002. A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. *Organization Science,* **13**(4), 442-455.

CARRILLO, P.M., ANUMBA, C.J. and KAMARA, J.M., 2000. Knowledge management strategy for construction: key IT and contextual issues, *Proceedings of the Int. Conference on Construction Information Technology,* 28-30 June pp155-165.

CARRILLO, P.M., ROBINSON, H.S., ANUMBA, C.J. and AL-GHASSANI, A.M., 2003. IMPaKT: a framework for linking knowledge management to business performance. *Electronic Journal of Knowledge Management,* **1**(1), 1-12.

CARRILLO, P., 2005. Lessons learned practices in the engineering, procurement and construction sector. *Engineering, Construction and Architectural Management,* **12**(3), 236-250.

CARRILLO, P. and CHINOWSKY, P., 2006. Exploiting knowledge management: the engineering and construction perspective. *Journal of Management in Engineering,* **22**(1), 2-10.

CERF, 2000. Washington, DC.: CERF.

CHEN, S.E., MCGEORGE, W.D. and OSTWALD, M.J., 1993. The role of information management in the development of a strategic model of buildability, *Management of Information Technology for Construction Conference, Singapore.* .

CHEN, Y., 2008. *Using mobile computing for construction site information management*, Newcastle University.

CHOU, S.W., 2005. Knowledge creation: absorptive capacity, organizational mechanisms, and knowledge storage/retrieval capabilities. *Journal of Information Science,* **31**(6), 453-465.

CIRIA, 1983. *Buildability: an assessment.* Special Publication 26. London: Construction Industries Research and Information Association UK.

CLEVER, December, 1999-last update, cross-sectoral learning in the virtual environment Homepage of Loughborough University], [Online]. Available: http://info.lboro.ac.uk/departments/cv/projects/clever/index.html [16 November, 2010].

COMPTROLLER AND AUDITOR GENERAL, 2001. *Modernising Construction.* London: National Audit Office.

COWAN, R. and FORAY, D., 1997. The economics of codification and the diffusion of knowledge. *Industrial and corporate change,* **6**(3), 595-622.

CRESWELL, J.W., 2007. Qualitative inquiry & research design: Choosing among five approaches. 2nd edn. California: Sage Publications, Inc.

CRYER, J.D. and CHAN, K.S., 2008. Time series analysis: with applications in R. 2nd edn. Springer Verlag.

C-SAND, 2001-last update, creating, sustaining and disseminating knowledge for sustainable construction: tools, methods and architecture [Homepage of C-SanD Project], [Online]. Available: http://www.c-sand.org/) [November 15, 2010].

DAINTY, A.R.J., QIN, J. and CARRILLO, P.M., 2005. HRM Strategies for Promoting Knowledge Sharing within Construction Project Organisations. In: A.S. KAZI, ed, *Knowledge management in the construction industry: A sociotechnical perspective.* Hershey, Pa: Idea Group Publishing, pp. 18-33.

DAVENPORT, T.H., DE LONG, D.W. and BEERS, M.C., 1998. Successful Knowledge Management Projects. *Sloan management review,* (Winter).

DE JAGER, P., 2007. Toolkit for healthcare facility design evaluation-some case studies, *South African Federation of Hospital Engineering (SAFHE) and Clinical Engineering*

Association of South Africa (CEASA) national biennial conference and exhibition 2007, Port Elizabeth, South Africa, 17-19 October .

DEMAREST, M., 1997. Understanding knowledge management. *Long range planning,* **30**(3), 321-384.

DRAGO, W.A. and WAGNER, R.J., 2004. Vark preferred learning styles and online education. *Management Research News,* **27**(7), 1-13.

DRUCKER, P.F., 1988. THE COMING OF THE NEW ORGANIZATION. *Harvard business review,* **66**(1), 45-53.

DUBOIS, A. and GADDE, L.E., 2002. Systematic combining: an abductive approach to case research. *Journal of business research,* **55**(7), 553-560.

EASTMAN, C., TEICHOLZ, P., SACKS, R. and LISTON, K., 2008. BIM Handbook: A guide to building information modelling for owners, managers, designers, engineers, and contractors. New Jersey: John Wiley & Sons Inc.

EDUM-FOTWE, F., GIBB, A. and BENFORD-MILLER, M., 2004. Reconciling construction innovation and standardisation on major projects. *Engineering, Construction and Architectural Management,* **11**(5), 366-372.

EGAN, J., 1998. *Rethinking construction, report of the construction task force on the scope for improving the quality and efficiency of UK construction.* Department of the Environment, Transport and the Regions, London, UK.

EGBU, C.O. and BOTTERILL, C., 2002. Information technologies for knowledge management: their usage and effectiveness. *Electronic Journal of Information Technology in Construction (ITcon),* **7**, 125-136.

EISENHARDT, K.M., 1989. Building theories from case study research. *Academy of management review,* **14**(4), 532-550.

FAIRCLOUGH, N., 2005. Peripheral vision: Discourse analysis in organization studies: The case for critical realism. *Organization Studies,* **26**(6), 915.

FELLOWS, R. and LIU, A., 2008. Research methods for construction. 3rd edn. Oxford: Wiley-Blackwell.

FERGUSON, I., 1989. Buildability in Practice. London: Mitchell Publishing Company Limited.

FERNIE, S., GREEN, S.D., WELLER, S.J. and NEWCOMBE, R., 2003. Knowledge sharing: context, confusion and controversy. *International Journal of Project Management,* **21**(3), 177-187.

FIOL, C.M. and LYLES, M.A., 1985. Organizational learning. *The Academy of Management Review,* **10**(4), 803-813.

FIRESTONE, J.M. and MCELROY, M.W., 2004. Organizational learning and knowledge management: the relationship. *Learning Organization, The,* **11**(2), 177-184.

FISCHER, G. and HERRMANN, T., 2011. Socio-Technical Systems. *International Journal of Sociotechnology and Knowledge Development,* (1), 33.

FISCHER, M. and TATUM, C.B., 1997. Characteristics of design-relevant constructability knowledge. *Journal of Construction Engineering and Management,* **123**(3), 253-260.

FISCHER, M.A., 1993. Automating constructability reasoning with a geometrical and topological project model. *Computing Systems in Engineering,* **4**(2-3), 179-192.

FITZGERALD, B. and HOWCROFT, D., 1998. Competing dichotomies in IS research and possible strategies for resolution, *Proceedings of the international conference on Information systems,* pp155-164.

FLEETWOOD, S., 2005. Ontology in organization and management studies: A critical realist perspective. *Organization,* **12**(2), 197-222.

FONG, P.S.W., 2005. Building a Knowledge-Sharing Culture in Construction Project Teams. In: C.J. ANUMBA, C.O. EGBU and P.M. CARILLO, eds, *Knowledge management in construction.* Oxford, UK: Wiley-Blackwell, pp. 195-212.

FRANCO, L.A., CUSHMAN, M. and ROSENHEAD, J., 2004. Project review and learning in the construction industry: Embedding a problem structuring method within a partnership context. *European Journal of Operational Research,* **152**(3), 586-601.

GALLUPE, B., 2001. Knowledge management systems: surveying the landscape. *International Journal of Management Reviews,* **3**(1), 61-77.

GAMBATESE, J.A., POCOCK, J.B. and DUNSTON, P.S., 2007. Constructability concepts and practice. Virginia, USA: American Society of Civil Engineers.

GANAH, A.A.M., 2003. *Computer Visualisation Support for Buildability*, Loughborough University.

GARVIN, D.A., 1993. Building a learning organization. *Harvard business review,* **July-August**, 78-91.

GAVRILOVA, T. and ANDREEVA, T., 2012. Knowledge elicitation techniques in a knowledge management context. *Journal of Knowledge Management,* **16**(4), 523-537.

GEORG, S. and TRYGGESTAD, K., 2009. On the emergence of roles in construction: the qualculative role of project management. *Construction Management and Economics,* **27**(10), 969-981.

GERRING, J., 2007. Case study research: principles and practices. New York, USA: Cambridge University Press.

GIBBERT, M., RUIGROK, W. and WICKI, B., 2008. What passes as a rigorous case study? *Strategic Management Journal,* **29**(13), 1465-1474.

GIESKES, J. and TEN BROEKE, A.M., 2000. Infrastructure under construction: continuous improvement and learning in projects. *Integrated Manufacturing Systems,* **11**(3), 188-198.

GOODMAN, P.S. and DARR, E.D., 1998. Computer-aided systems and communities: mechanisms for organizational learning in distributed environments. *Mis Quarterly,* **22**(4), 417-440.

GOODRUM, G. and WACUG, P., 2011. The Cursor.

GRAHAM, B. and THOMAS, K., 2007. The development of an integrated knowledge management model for construction.

GRASIC, B. and PODGORELEC, V., 2011. Developing knowledge management systems: approaches, technologies and methods, *Proceedings of the 2011 American conference on applied mathematics and the 5th WSEAS international conference on Computer engineering and applications,* World Scientific and Engineering Academy and Society (WSEAS) pp207-212.

GRIFFITH, A. and SIDWELL, A.C., 1993. Development of constructability concepts, principles and practices. *Engineering, Construction and Architectural Management,* **4**(4), 295-310.

GRIFFITH, A. and SIDWELL, A.C., 1995. Constructability in building and engineering projects. Hampshire, UK: Macmillan Press LTD.

GRIMSEY, D. and LEWIS, M.K., 2005. Are Public Private Partnerships value for money?: Evaluating alternative approaches and comparing academic and practitioner views, *Accounting forum,* Elsevier pp345-378.

GU, N. and LONDON, K., 2010. Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction,* **19**, 988-999.

GUBA, E.G. and LINCOLN, Y.S., 1994. Competing paradigms in qualitative research. In: N.K. DENZIN and Y.S. LINCOLN, eds, *Handbook of qualitative research.* Thousand Oaks, CA: Sage, pp. 105-117.

GUO, Z. and SHEFFIELD, J., 2006. A paradigmatic and methodological examination of KM research: 2000 to 2004. *Decision Support Systems,* **44**, 673-688.

HAKIM, C., 1987. Research design: Strategies and choices in the design of social research. London: Allen and Unwin.

HALL, P.A., 2003. Aligning ontology and methodology in comparative research. In: J. MAHONEY and D. RUESCHEMEYER, eds, *Comparative historical analysis in the social sciences.* Cambridge: Cambridge University Press, pp. 373-404.

HAMILTON, D.K., 2003. The four levels of evidence based practice. *Healthcare Design,* **3**(4), 18–26.

HANLON, E.J. and SANVIDO, V.E., 1995. Constructability information classification scheme. *Journal of Construction Engineering and Management,* **121**(4), 337-345.

HARI, S., EGBU, C. and KUMAR, B., 2005. A knowledge capture awareness tool. *Engineering, Construction and Architectural Management,* **12**(6), 533-567.

HARRIS, S., 2004. Public private partnerships: delivering better infrastructure services, *Inter-American Development Bank, Washington, D.C.,* February .

HART, D.N., 2005. Information systems foundations: constructing and criticising. Austria: ANU E Press.

HARTY, C., 2005. Innovation in construction: a sociology of technology approach. *Building Research & Information,* **33**(6), 512-522.

HEALY, M. and PERRY, C., 2000. Comprehensive criteria to judge validity and reliability of qualitative research within the realism paradigm. *Qualitative Market Research: An International Journal,* **3**(3), 118-126.

HEFT, T., PRICE, L. and HARPER, T., 2012. Addressing Healthcare Concerns during Construction and Renovation. *Journal of Obstetric, Gynaecologic, & Neonatal Nursing,* **41**(s1), S97-S97.

HENDERSON, J.R., 2009. *Technology Implementation Strategies for Construction Organisations*, Loughborough University.

HENDERSON, J.R. and RUIKAR, K., 2010. Technology implementation strategies for construction organisations. *Engineering, Construction and Architectural Management,* **17**(3), 309-327.

HENNINK, M.M., HUTTER, I. and BAILEY, A., 2011. Qualitative research methods. London, UK: Sage Publications Ltd.

HIGNETT, S. and LU, J., 2009. An investigation of the use of health building notes by UK healthcare building designers. *Applied Ergonomics,* **40**(4), 608-616.

HIMMELSBACH, T., 2012. A Survey on Today's Smartphone Usage. GRIN Verlag.

HOLZER, D., 2007. Are you talking to me? Why BIM alone is not the answer, *The Proceedings of the Fourth International Conference of the Association of Architecture Schools of Australasia,* .

HORGA, V., HORGA, M. and HORGA, M.G., 2011. Information technology in supporting knowledge management, *Proceedings of the 10th WSEAS international conference on Artificial intelligence, knowledge engineering and data bases,* World Scientific and Engineering Academy and Society (WSEAS) pp283-287.

HUBER, G.P., 1991. Organizational Learning: The Contributing Processes and the Literatures. *Organization Science,* **2**(1, Special Issue: Organizational Learning: Papers in Honor of (and by) James G. March), 88-115.

HYDE, R., 1993. Buildability as a design concept for architects: a case study of laboratory buildings. *Engineering, Construction and Architectural Management,* **2**(1), 45-56.

ILLINGWORTH, J.R., 2000. Construction Methods and Planning. 2nd edn. London: E & FN Spon.

INKPEN, A., 1998. Learning, Knowledge Acquisition, and Strategic Alliances. *European Management Journal,* **16**(2), 223-229.

JACKSON, M.C., 1999. Towards coherent pluralism in management science. *Journal of the Operational Research Society,* **50**(1), 12-22.

JARRAR, Y.F., 2002. Knowledge management: learning for organisational experience. *Managerial Auditing Journal,* **17**(6), 322-328.

JASHAPARA, A., 1993. The Competitive Learning Organization: A Quest For The Holy Grail. *Management Decision,* **31**(8), 52-62.

JERGEAS, G. and VAN DER PUT, J., 2001. Benefits of constructability on construction projects. *Journal of Construction Engineering and Management,* **127**(4), 281-290.

KAGIOGLOU, M. and TZORTZOPOULOS, P., 2010. Improving Healthcare Through Built Environment Infrastructure. Sussex, UK: Wiley-Blackwell.

KALE, S. and KARAMAN, A.E., 2012. Benchmarking the Knowledge Management Practices of Construction Firms. *Journal of Civil Engineering and Management,* **18**(3), 335-344.

KAMARA, J.M., ANUMBA, C.J., CARRILLO, P.M. and BOUCHLAGHEM, N., 2003. Conceptual framework for live capture and reuse of project knowledge, *International Conference on Information Technology for Construction,* 23-25 April pp178-185.

KAMARA, J.M., AUGENBROE, G., ANUMBA, C.J. and CARRILLO, P.M., 2002. Knowledge management in the architecture, engineering and construction industry. *Construction Innovation,* **2**(1), 53-67.

KAMPSCHROER, K. and HEERWAGEN, J., 2005. The strategic workplace: development and evaluation. *Building research and information,* **33**(4), 326-337.

KARTAM, N. and ASKAR, H., 1999. Constructability knowledge-intensive database system. *Eighth International Conference on Durability of Building Materials and Components, Vancouver, Canada,* 30 May - 3 June pp2498-2506.

KARTAM, N. and FLOOD, I., 1997. Constructability feedback systems: Issues and illustrative prototype. *Journal of Performance of Constructed Facilities,* **11**(4), 178-183.

KEEGAN, A. and TURNER, J.R., 2001. Quantity versus quality in project-based learning practices. *Management Learning,* **32**(1), 77-98.

KHALFAN, M.M.A., MCDERMOTT, P. and SWAN, W., 2007. Building trust in construction projects. *Supply Chain Management: An International Journal,* **12**(6), 385-391.

KIM, D.H., 1993. The link between individual and organizational learning. *Sloan Management Review,* **35**(1), 37-50.

KIMOTO, K., ENDO, K., IWASHITA, S. and FUJIWARA, M., 2005. The Application of PDA as Mobile Computing System on Construction Management. *Automation in Construction,* **14**(4), 500-511.

KING, W.R., CHUNG, T.R. and HANEY, M.H., 2008. Knowledge management and organizational learning. *Omega,* **36**(2), 167-172.

KIVRAK, S., ARSLAN, G., DIKMEN, I. and BIRGONUL, M.T., 2008. Capturing knowledge in construction projects: knowledge platform for contractors. *Journal of Management in Engineering,* **24**(2), 87-95.

KOCH, C., 2003. Knowledge management in consulting engineering-joining IT and human resources to support the production of knowledge. *Engineering Construction and Architectural Management,* **10**(6), 391-401.

KULULANGA, G.K., MCCAFFER, R., PRICE, A.D.F. and EDUM-FOTWE, F., 1999. Learning mechanisms employed by construction contractors. *Journal of Construction Engineering and Management,* **125**(4), 215-223.

KULULANGA, G., EDUM-FOTWE, F. and MCCAFFER, R., 2001. Measuring construction contractors' organizational learning. *Building research and information,* **29**(1), 21-29.

LAM, P.T.I., CHAN, A.P.C., WONG, F.K.W. and WONG, F.W.H., 2007. Constructability rankings of construction systems based on the analytical hierarchy process. *Journal of Architectural Engineering,* **13**(1), 36-43.

LAM, P.T.I. and WONG, F.W.H., 2009. Improving building project performance: how buildability benchmarking can help. *Construction Management and Economics,* **27**(1), 41-52.

LAM, P.T.I., WONG, F.W.H. and CHAN, A.P.C., 2006. Contributions of designers to improving buildability and constructability. *Design Studies,* **27**(4), 457-479.

LATHAM, M., 1994. *Constructing the team: final report of the government/industry review of procurement and contractual arrangements in the UK construction industry.* London: HMSO.

LEE, C.C. and EGBU, C.O., 2007. Information technology tools for capturing and communicating learning and experiences in construction SMEs in developed and developing countries, *ITcon 12,* pp167-180.

LEEDY, P.D. and ORMROD, J.E., 2001. Practical research: Planning and design. 7th edn. New Jersey: Merrill Prentice Hall.

LEONG, E.K.F., EWING, M.T. and PITT, L.F., 2004. Analysing competitors' online persuasive themes with text mining. *Marketing Intelligence & Planning,* **22**(2), 187-200.

LIN, Y.C. and LEE, H.Y., 2011. Developing project communities of practice-based knowledge management system in construction. *Automation in Construction,* .

LOPEZ, R. and LOVE, P.E.D., 2011. Design Error Costs in Construction Projects. *Journal of Construction Engineering and Management,* **1**, 330.

LÓPEZ-NICOLÁS, C. and MEROŅO-CERDÁN, Á.L., 2011. Strategic knowledge management, innovation and performance. *International Journal of Information Management,* .

LORD, M.D. and RANFT, A.L., 2000. Organizational Learning about New International Markets: Exploring the Internal Transfer of Local Market Knowledge. *Journal of International Business Studies,* **31**(4), 573-589.

LOVE, P.E.D., LI, H., IRANI, Z. and FANIRAN, O., 2000. Total quality management and the learning organization: a dialogue for change in construction. *Construction Management and Economics,* **18**(3), 321-330.

LOVE, P.E.D., HUANG, J.C., EDWARDS, D.J. and IRANI, Z., 2004. Nurturing a learning organization in construction: a focus on strategic shift, organizational transformation, customer orientation and quality centered learning. *Construction Innovation: Information, Process, Management,* **4**(2), 113-126.

LOVE, P.E.D. and LI, H., 2000. Quantifying the causes and costs of rework in construction. *Construction Management and Economics,* **18**(4), 479-489.

LOW, S.P., 2001. Quantifying the relationships between buildability, structural quality and productivity in construction. *Structural Survey,* **19**(2), 106-112.

MA, T.Y.F., LAM, P.T.I. and CHAN, A.R.C., 2001. Barriers to the implementation of constructability in project procurement. In: A. SINGH, ed, *Creative systems in structural and construction engineering.* Rotterdam: Taylor & Francis, pp. 95-100.

MACVAUGH, J. and AUTY, S., 2008. Proactive knowledge management: an independent enabler of New Product Development success? *International Journal of Technology Intelligence and Planning,* **4**(3), 347-363.

MADSEN, P.M. and DESAI, V., 2010. Failing to learn? The effects of failure and success on organizational learning in the global orbital launch vehicle industry. *The Academy of Management Journal (AMJ),* **53**(3), 451-476.

MAHESHWARI, B., KUMAR, V. and KUMAR, U., 2006. Optimizing success in supply chain partnerships. *Journal of Enterprise Information Management,* **19**(3), 277-291.

MANNING, R. and MESSNER, J., 2008. Case studies in BIM implementation for programming of healthcare facilities. *Journal of Information Technology in Construction,* **13**, 446-457.

MAQSOOD, T., FINEGAN, A.D. and WALKER, D.H.T., 2010. Extending knowledge management across the supply chains in the construction industry: knowledge sharing in construction supply chains, *Second International Conference on Construction in the 21st Century (CITC-II), Sustainability and Innovation in Management and Technology, Hong Kong.* 10–12 December CRC for Construction Innovation.

MARKUS, M.L., 2001. Toward a theory of knowledge reuse: Types of knowledge reuse situations and factors in reuse success. *Journal of Management Information Systems,* **18**(1), 57-93.

MARSH, L. and FLANAGAN, R., 2002. Measuring the costs and benefits of information technology in construction. *Engineering Construction and Architectural Management,* **7**(4), 423-435.

MARTENSSON, M., 2000. A critical review of knowledge management as a management tool. *Journal of Knowledge Management,* **4**(3), 204-216.

MATLAY, H., 2000. Organisational learning in small learning organisations: an empirical overview. *Education Training,* **42**(4/5), 202-211.

MCADAM, R. and REID, R., 2001. SME and large organisation perceptions of knowledge management: comparisons and contrasts. *Journal of Knowledge Management,* **5**(3), 231-241.

MCCULLOUGH, C., 2010. Evidence-Based Design for Healthcare Facilities. USA: Renee Wilmeth.

MCDERMOTT, R., 1999. Why information technology inspired but cannot deliver knowledge management. *California management review,* **41**(4), 103-117.

MCELROY, M.W., 2000. Integrating complexity theory, knowledge management and organizational learning. *Journal of knowledge management,* **4**(3), 195-203.

MCQUEEN, R.A. and KNUSSEN, C., 2002. Research methods for social science: a practical introduction. Essex: Pearson Education.

MICHAEL, S.C. and PALANDJIAN, T.P., 2004. Organizational learning and new product introductions. *Journal of Product Innovation Management,* **21**(4), 268-276.

MILLS, G.R.,PHIRI, M.,AUSTIN, S.,PRICE, A.D.F. and LAWSON, B. 2009Innovation in Facility Design and Construction Processes - Nurturing an Evidence-Based Learning Environment which supports the Innovative Design of Healthcare Facilities or similar. Research Proposal edn.

MINGERS, J., 2004. Real-izing information systems: critical realism as an underpinning philosophy for information systems. *Information and organization,* **14**(2), 87-103.

MINGERS, J., 2001. Combining IS research methods: towards a pluralist methodology. *Information Systems Research,* **12**(3), 240-259.

MINGERS, J., 1997. Multi-paradigm Multimethodology. In: J. MINGERS and T. GILL, eds, *Multimethodology: the theory and practice of combining management science methodologies.* Chichester: England: John Wiley & Sons Inc, pp. 1-23.

MOHAMED, S.F., 2006. *Improving Construction Site Management Practices Through Knowledge Management*, Loughborough University.

MOORE, D., 1993. Buildability assessment and the development of an automated design aid for managing the transfer of construction process knowledge. *Engineering, Construction and Architectural Management,* **3**(1/2), 29-46.

NAOUM, S.G., 2007. Dissertation research and writing for construction students. Oxford: Elsevier Butterworth-Heinemann.

NEUMAN, W.L., 2007. Basics of social research: Qualitative and quantitative approaches. 2nd Ed. edn. USA: Pearson Education Inc.

NEUMAN, W.L., 2003. Social research methods: Qualitative and quantitative approaches. Allyn and Bacon.

NEWELL, S., ROBERTSON, M., SCARBROUGH, H. and SWAN, J., 2009. Managing knowledge work and innovation. second edn. New York: Palgrave Macmillan.

NEWELL, S., BRESNEN, M., EDELMAN, L., SCARBROUGH, H. and SWAN, J., 2006. Sharing Knowledge Across Projects Limits to ICT-led Project Review Practices. *Management Learning,* **37**(2), 167-185.

NEWMAN, I. and BENZ, C.R., 1998. Qualitative-quantitative research methodology: Exploring the interactive continuum. Carbondale: Illinois: Southern Illinois University Press.

NGOWI, A., 2001. The competition aspect of construction alliances. *Logistics Information Management,* **14**(4), 242-249.

NHS, 2011-last update, Procure21+. Available: http://www.procure21plus.nhs.uk/ [03/25, 2011].

NIMA, M.A. and ABDUL-KADIR, M.R., 1999. Evaluation of the engineer's personnel's role in enhancing the project constructability. *Facilities,* **17**(11), 423-430.

NISBET, N. and DINESEN, B., 2010. *Constructing the business case - Building information modelling.* ISBN 978 0 580 70935 7. London, UK: British Standards Institution.

NISSEN, M., KAMEL, M. and SENGUPTA, K., 2000. Integrated analysis and design of knowledge systems and processes. *Information Resources Management Journal,* **13**(1), 24-43.

NITITHAMYONG, P. and SKIBNIEWSKI, M.J., 2004. Web-based construction project management systems: how to make them successful? *Automation in Construction,* **13**(4), 491-506.

NONAKA, I., 1994. A dynamic theory of organizational knowledge creation. *Organization Science,* **5**(1), 14-37.

NONAKA, I. and TAKEUCHI, H., 1995. The knowledge-creating company: how Japanese companies create the dynamics of innovation. Oxford, UK: Oxford University Press.

O'LEARY, D.E., 1998. Using AI in knowledge management: Knowledge bases and ontologies. *Intelligent Systems and their Applications, IEEE,* **13**(3), 34-39.

ORANGE, G., BURKE, A. and CUSHMAN, M., 1999a. An approach to support reflection and organisation learning within the UK construction industry. *BITWorld'99,* .

ORANGE, G., CUSHMAN, M. and BURKE, A., 1999b. COLA: a cross organisational learning approach within UK industry, *4th international conference on networking entities (Neties'99), Donau-Universität, Krems, Austria.* 18-19 March, 1999 .

ORANGE, G., ONIONS, P., BURKE, A. and COLLEDGE, B., 2010. Knowledge Management: Facilitating Organizational Learning Within the Construction Industry. *Leeds Metropolitan University, School of Information Management Discussion Paper Series,* .

ORANGE, G., ONIONS, P., BURKE, A. and COLLEDGE, B., 2005. Knowledge management: Facilitating organisational learning within the construction industry. In: C.J. ANUMBA, C.O. EGBU and P.M. CARILLO, eds, *Knowledge management in the construction industry: A sociotechnical perspective.* Hershey, Pa: Idea Group Publishing, pp. 130-149.

ORLIKOWSKI, W.J. and BAROUDI, J.J., 1991. Studying information technology in organizations: Research approaches and assumptions. *Information systems research,* **2**(1), 1-28.

OXFORD ENGLISH DICTIONARY, 2011. 12 edn. OUP Oxford.

PALANEESWARAN, E., 2006. Reducing rework to enhance project performance levels, *Proceedings of the one day seminar on recent developments in project management in Hong Kong,* May 12 .

PANDAY, P.P., 2009. Simplifying podcasting. *International Journal of Teaching and Learning in Higher Education,* **20**(2), 251-261.

PARANAGAMAGE, P., CARRILLO, P., RUIKAR, K. and FULLER, P., 2012. Lessons learned practices in the UK construction sector: current practice and proposed improvements. *Engineering Project Organization Journal,* **(iFirst)**, 1-15.

PATEL, M.B., MCCARTHY, T.J., MORRIS, P.W.G. and ELHAG, T.M.S., 2000. The role of IT in capturing and managing knowledge for organisational learning on construction projects, *Proceedings of the International Conference on Construction Information Technology (CIT2000),* 28-30 June pp674-685.

PATTON, M.Q., 2002. Qualitative research and evaluation methods. 3rd edn. Thousand Oaks, California: Sage Publications, Inc.

PEDLER, M., BURGOYNE, J.G. and BOYDELL, T., 1996. The learning company: a strategy for sustainable development; The learning company: a strategy for sustainable development. Maidenhead: McGraw-Hill.

PFAFF, C.C. and HASAN, H., 2011. Wiki-Based Knowledge Management Systems for more Democratic Organizations . *Journal of Computer Information Systems,* **52**(2), 73-82.

PHENG, L.S. and HWA, G.K., 1994. Construction Quality Assurance: Problems of Implementation at Infancy Stage in Singapore. *International Journal of Quality and Reliability Management,* **11**(1), 22-37.

POCOCK, J.B., KUENNEN, S.T., GAMBATESE, J. and RAUSCHKOLB, J., 2006. Constructability state of practice report. *Journal of Construction Engineering and Management,* **132**(4), 373-383.

PRENCIPE, A. and TELL, F., 2001. Inter-project learning: processes and outcomes of knowledge codification in project-based firms. *Research Policy,* **30**(9), 1373-1394.

PULASKI, M.H. and HORMAN, M.J., 2005. Organizing constructability knowledge for design. *Journal of Construction Engineering and Management,* **131**(8), 911-919.

REZGUI, Y., ZARLI, A., BOURDEAU, M. and COOPER, G., 2000. Inter-Enterprise Information Management in Dynamic Virtual Environments: The OSMOS Approach, *Proceedings of CIT2000–The CIB-W78, IABSE, EGSEA-AI International Conference on Construction Information Technology,* pp28-30.

RHODES, B. and SMALLWOOD, J.J., 2002. Defects and rework in South African construction projects, *COBRA 2002 Conference,* 5-6 September .

RICS, 1988. SMM7 Standard Method of Measurement of Building Works. 7th edn. London: The Royal Institution of Chartered Surveyors.

RIFKIN, W. and FULOP, L., 1997. A review and case study on learning organizations. *The Learning Organization,* **4**(4), 135-148.

ROBERTS, J., 2000. From know-how to show-how? Questioning the role of information and communication technologies in knowledge transfer. *Technology Analysis & Strategic Management,* **12**(4), 429-443.

ROBERTSON, M. and SWAN, J., 2001. Survival of the leanest: intensive knowledge work and groupware adaptation. *Information Technology & People,* **14**(4), 334-352.

ROBINSON, H.S., CARRILLO, P.M., ANUMBA, C.J. and AL-GHASSANI, A.M., 2001. Perceptions and barriers in implementing knowledge management strategies in large construction organisations, *Proceedings of RICS Foundation Construction and Building Research Conference (COBRA),* Glasgow Caledonian University pp451-460.

RUIKAR, K., 2010. Podcasting in Project-based Learning environments: Findings of a Pilot Study, *6th International Conference of Innovation in Architecture Engineering and Construction (AEC),* The Pennsylvania State University, USA, 11th June 2010 pp314-323.

RUIKAR, K., 2006. Business process implications of e-commerce in construction organisations.

RUIKAR, K., ANUMBA, C.J. and EGBU, C., 2007. Integrated use of technologies and techniques for construction knowledge management. *Knowledge Management Research & Practice,* **5**(4), 297-311.

RUIKAR, K., KOSKELA, L. and SEXTON, M., 2009. Communities of practice in construction case study organisations. *Construction Innovation,* **9**(4), 434-448.

RUSSELL, J.S., SWIGGUM, K.E., SHAPIRO, J.M. and ALAYDRUS, A.F., 1994. Constructability related to TQM, value engineering, and cost/benefits. *Journal of Performance of Constructed Facilities,* **8**(1), 31-45.

SAILER, K., BUDGEN, A., LONSDALE, N., TURNER, A. and PENN, A., 2009. Evidence-based design: theoretical and practical reflections of an emerging approach in office architecture, *Undisciplined! Proceedings of the Design Research Society Conference 2008. Sheffield, UK.* July 16-19 .

SANCHEZ, R., 2005. Knowledge Management and Organizational Learning. *Fundamental Concepts for Theory and Practice,* .

SCARBROUGH, H., SWAN, J., LAURENT, S., BRESNEN, M., EDELMAN, L. and NEWELL, S., 2004. Project-Based Learning and the Role of Learning Boundaries. *Organization Studies,* **25**(9), 1579-1600.

SCHEIN, E.H., ed, 1985. *Organizational leadership and culture.* San Francisco, CA: Jossey-Bass,.

SEALE, C., GOBO, G., GUBRIUM, J.F. and SILVERMAN, D., 2004. Qualitative research practice. London, UK: Sage Publications Ltd.

SENGE, P.M., 1993. The Fifth Discipline: The Art and Practice of the Learning Organization. *Consulting Psychology Journal: Practice and Research,* **45**(4), 31-32.

SHAMMAS-TOMA, M., SEYMOUR, D. and CLARK, L., 1998. Obstacles to implementing total quality management in the UK construction industry. *Construction Management and Economics,* **16**(2), 177-192.

SHETH, A.Z., PRICE, A.D.F. and GLASS, J., 2010. BIM and refurbishment of existing healthcare facilities, C. EGBU, ed. In: *Proceedings of the 26th Annual ARCOM Conference, Leeds, United Kingdom,* 6-8 September, 2010 vol. 2, pp.1497-1506.

SIMONE, C., ACKERMAN, M. and WULF, V., 2012. Knowledge Management in Practice: A Special Issue. *Computer Supported Cooperative Work (CSCW),* , 1-2.

SMYTH, H. and EDKINS, A., 2007. Relationship management in the management of PFI/PPP projects in the UK. *International Journal of Project Management,* **25**(3), 232-240.

SNELL, R. and CHAK, A.M.K., 1998. The learning organization: learning and empowerment for whom? *Management Learning,* **29**(3), 337-365.

SNYDER, W.M. and CUMMINGS, T.G., 1998. Organization learning disorders: conceptual model and intervention hypotheses. *Human Relations,* **51**(7), 873-895.

SPACKMAN, M., 2002. Public–private partnerships: lessons from the British approach. *Economic Systems,* **26**(3), 283-301.

SPECTOR, J.M. and DAVIDSEN, P.I., 2006. How can organizational learning be modelled and measured? *Evaluation and program planning,* **29**(1), 63-69.

STANKOS, M. and SCHWARZ, B., 2007. Evidence-based design in healthcare: a theoretical dilemma. *Interdisciplinary Design and Research e-Journal,* **1**(1), 1-15.

STENMARK, D., 2002. Information vs. Knowledge: The Role of intranets in Knowledge Management, IEEE PRESS, ed. In: *Proceedings of the 35th Hawaii International Conference on System Sciences,* Jan 7-10 .

STEWART, T.A., 1997. Intellectual capital. Doubleday New York.

STONEHOUSE, G.H. and PEMBERTON, J.D., 1999. Learning and knowledge management in the intelligent organisation. *International Journal,* **7**(5), 131-144.

SUBASHINI, R., RITA, S. and VIVEK, M., 2012. The Role of ICTs in Knowledge Management (KM) for Organizational Effectiveness. *Global Trends in Information Systems and Software Applications,* , 542-549.

SUCCAR, B., 2009. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction,* **18**(3), 357-375.

SUERMANN, P. and ISSA, R., 2009. Evaluating industry perceptions of building information modelling (BIM) impact on construction.

SUTTON, D., 2001. What is knowledge and can it be managed? *European Journal of Information Systems,* **10**(2), 80-88.

SWAN, J., SCARBROUGH, H. and NEWELL, S., 2010. Why don't (or do) organizations learn from projects? *Management Learning,* **41**(3), 325-344.

SWAN, J., NEWELL, S., SCARBROUGH, H. and HISLOP, D., 1999. Knowledge management and innovation: networks and networking. *Journal of Knowledge management,* **3**(4), 262-275.

TAN, H.C., 2006. *A Methodology for the Live Capture and Reuse of Project Knowledge in Construction*, Loughborough University.

TAN, H.C., CARRILLO, P., ANUMBA, C., KAMARA, J.M., BOUCHLAGHEM, D. and UDEAJA, C., 2006. Live capture and reuse of project knowledge in construction organisations. *Knowledge Management Research & Practice,* **4**(2), 149-161.

TAN, H.C., CARRILLO, P.M. and ANUMBA, C.J., 2011. Case Study of Knowledge Management Implementation in a Medium-Sized Construction Sector Firm. *Journal of Management in Engineering,* **1**, 71.

TAN, H.C., CARRILLO, P., ANUMBA, C.J., BOUCHLAGHEM, N., KAMARA, J. and UDEAJA, C., 2005. Approaches to the Capture of Reusable Project Knowledge in Construction, *Proceedings of CIB W102 Conference on Information and Knowledge in a Global Economy,* 12-20 May pp577-586.

TASHAKKORI, A. and TEDDLIE, C., 1998. Mixed methodology: Combining qualitative and quantitative approaches. Thousand Oaks, CA: Sage Publications.

THABET, W., 2000. *Design/Construction Integration thru Virtual Construction for Improved Constructability.* Berkley-Stanford CEM Workshop, August 1999, Stanford CA.: .

THOBEN, K.D., WEBER, F. and WUNRAM, M., 2002. Barriers in Knowledge Management and Pragmatic Approaches. *Studies in Informatics and Control,* **11**(1), 7-16.

THURBIN, P.J., 1995. Leveraging knowledge: 17 day programme for a learning organization. London: Pitman.

TRIGUNARSYAH, B., BAKTI, E.S. and MAJID, M.Z.A., 2007. Constructability innovation in piperack design for refinery project, *Construction Management and Economics: past, present and future,* 16-18 July, 2007 Taylor & Francis.

TSE, T.K., WONG, K.A. and WONG, K., 2005. The utilisation of building information models in nD modelling: A study of data interfacing and adoption barriers. *ITcon,* **10**(Special Issue From 3D to nD modelling), 85-110.

TSERNG, H.P.J. and LIN, Y., 2005. A knowledge management portal system for construction projects using knowledge map. Hershey, Pa: Idea Group Pub, pp. 299-322.

UGWU, O.O., ANUMBA, C.J. and THORPE, A., 2004. The development of cognitive models for constructability assessment in steel frame structures. *Advances in Engineering Software,* **35**(3-4), 191-203.

UHLIK, F.T. and LORES, G.V., 1998. Assessment of constructability practices among general contractors. *Journal of Architectural Engineering,* **4**(3), 113-123.

ULRICH, R.S., 2006. Evidence-based health-care architecture. *The Lancet,* **368**(Supplement 1), S38-S39.

VAKOLA, M. and REZGUI, Y., 2000. Organisational learning and innovation in the construction industry. *The Learning Organization,* **7**(4), 174-184.

VISCHER, J.C., 2008. Towards an environmental psychology of workspace: how people are affected by environments for work. *Architectural Science Review,* **51**(2), 97-108.

VISSER, M., 2010. Constructing organisational learning and knowledge socially: an interactional perspective. *International Journal of Knowledge and Learning,* **6**(4), 285-294.

VON KROGH, G., NONAKA, I. and ABEN, M., 2001. Making the most of your company's knowledge: a strategic framework. *Long range planning,* **34**(4), 421-439.

VUORI, V. and OKKONEN, J., 2012. Knowledge sharing motivational factors of using an intra-organizational social media platform. *Journal of Knowledge Management,* **16**(4), 592-603.

WALLIMAN, N., 2006. Social research methods. London: Sage Publications Ltd.

WILLIS, T.H. and WILLIS, W.D., 1996. A quality performance management system for industrial construction engineering projects. *International Journal of Quality & Reliability Management,* **13**(9), 38-48.

WITHERS, I. and MATTHEWS, D., 2011. All government projects to use BIM within five years. *Building Magazine,* (20th May 2011), pp. 11.

WOLSTENHOLME, A., AUSTIN, S.A., BAIRSTOW, M., BLUMENTHAL, A., LORIMER, J., MCGUCKIN, S., WARD, D., WHYSALL, D., LE GRAND, Z. and GUTHRIE, W., 2009. *Never waste a good crisis: a review of progress since Rethinking Construction and thoughts for our future.* Constructing Excellence.

WONG, F.W.H., LAM, P.T.I., CHAN, E.H.W. and SHEN, L.Y., 2007. A study of measures to improve constructability. *International Journal of Quality & Reliability Management,* **24**(6), 586-601.

WOOD DAUDELIN, M., 1996. Learning from experience through reflection. *Organizational dynamics,* **24**(3), 36-48.

WUNRAM, M., FOSTER, G. and MOTTAGHIAN, S., 2000. Deliverable D06–Identification of Barriers. Result from the project CORMA-Practical Methods and Tools for Corporate Knowledge Management. Projekt Nr. IST-1999-12685. Unpublished.

YAN, H. and DAMIAN, P., 2008. Benefits and Barriers of Building Information Modelling, *12th International Conference on Computing in Civil and Building Engineering, Beijing, China*.

YANG, Y.Q., WANG, S.Q., DULAIMI, M. and LOW, S.P., 2003. A fuzzy quality function deployment system for buildable design decision-makings. *Automation in Construction,* **12**(4), 381-393.

YIN, R.K., 2009. Case study research: design and methods, Applied Social Research Methods Series, vol. 5. 4th edn. Thousand Oaks, California: Sage Publications.

YU, W.D., WEI, Y.T., LIU, S.J. and CHANG, P.L., 2008. Preliminary study on the automatic lessons-learned file generator, *Proceedings of International Symposium on Automation and Robotics in Construction 2008,* 26-29 June 2008 pp422-428.

ZARRAGA-OBERTY, C. and DE SAÁ-PÉREZ, P., 2006. *European Business Review,* **18**(1), 60-76.

ZHAO, J.L., 1998. Knowledge management and organizational learning in workflow systems, *Proceedings of 1998 Americas Conference on Information Systems,* August 14-16.

10 Appendices

Appendix A – Adopted Research Methods to Satisfy Research Objectives

Table 10.1: Research methods utilised to address research questions

Primary Method	
Secondary Method	

Research Objectives	Questions Provoked	Current Knowledge (established through literature review)	Literature Review	Case Study
Identify the need/drivers for a design-construction quality loop	What are the benefits that arise as a result of learning from the construction stage?	• Client related - improved communications, enhanced formalisation of responsibilities/authority, improved requirement specifications, enhanced innovation, early detection of potentially costly errors, failures and expensive remedial works, reduced costs and time overruns, enhanced quality and more accurate solutions being provided. • Design related – enhanced constructability and quality, reduced costs and schedules, enhanced designer knowledge base, improved levels of innovation. • Construction related – competitive advantage, reduction in reoccurring problems and mistakes. • Mutual benefits – reduced levels of rework, evidence of fit for purpose, enhanced intellectual capital.		
Identify the barriers of creating a design-construction quality loop	What are the challenges apparent that prevent learning from taking place?	• Technology barriers – legacy systems, lack of supportive technologies. • Industrial barriers – short term objectives, project mentality / focus, temporary project partnerships, belief that learning leads to over standardisation. • Organisational barriers – inability to capture tacit knowledge, unsupportive culture, limited resources, makeup of construction organisations being SMEs. • People barriers – resistance to change, lack of faith, idea theft.		
	What coping strategies are used to overcome such barriers?	• Various barriers exist and there is no one coping mechanism that is capable to overcome them in their entirety. However they can be lessened through effective communication, support and general good top level management to develop a supportive culture.		
Investigate current practices (if any) designed to improve the feedback of design quality	What knowledge is currently fed back to the design stage?	Predominantly knowledge collated through post occupancy evaluations and walk through tours.		
	How are current feedback frameworks structured?	The most widely used source of feedback is through post occupancy evaluations. Within healthcare infrastructure there are two main forms; AEDET (Achieving Excellence Design Evaluation Toolkit) and ASPECT (A Staff and Patient Environment Calibration Tool). AEDET		

improvements (in terms of enhance buildability)		evaluates a design through assessing each facility's build quality and functionality according to differing statements. ASPECT assesses staff and patient satisfaction levels surrounding the health outcomes of patients and staff performance.		
	How successful are these in practice and how could they be improved?	They are not leading to the desired levels of benefits.		
Investigate what knowledge would be beneficial if captured and fed back to the design stage	What knowledge is currently being captured?	Rework related knowledge captured during processes such as snagging and inspections. Health and safety, sustainability and innovation are also highly regarded knowledge capture areas.		
	How useful would it be if this information was fed back to the design stage?	Literature review indicates that this knowledge would benefit future projects. Most significantly it should reduce the instances of rework / reinvention of the wheel, provide greater value for money, and reduce costs and schedules. However such knowledge is more appropriate to be used within the construction stage itself in order to improve quality and defects in construction. A more appropriate learning objective appears to lie in that of buildability issues, which tend to originate during the design stage but become evident during construction. Therefore buildability related knowledge appears to be well suited to be shared between construction and design. It is still to be investigated how 'useable' this construction captured knowledge actually is and how it may be captured in a mutually beneficial way.		
	In what format is the knowledge best captured and transferred?	Tacit knowledge is of greater value than explicit knowledge. Therefore it has been indicated that the more tacit knowledge and context that can be captured and fed back to designers, the more use the knowledge will be to them. It is not clear however in which format this is best achieved.		
Explore the relevant techniques and technologies that could assist the delivery of a design-construction quality loop	What techniques/ technologies are currently used for KM and OL?	• Techniques – collaborative (partnering, alliances, joint-venturing and framework agreements), network learning (communities of practice), in-house learning (after action review and lessons learnt, post project evaluation, benchmarking, debriefing), individual learning (diaries, recruitment, mentoring / training, reassignment, empowerment, incentives). • Technologies – mobile technologies (PDAs, ultra mobiles, tablets), intranets and groupware, project extranets, case based reasoning, data and text mining.		
	What are the most successful techniques and technologies for knowledge transfer?	Literature review suggests that no one technique or technology is capable of fulfilling the requirement s for the entire knowledge management cycle. It is also indicated that a multiple / combined approach of various techniques and technologies should provide the best results in preference for a solely technological or technique based approach.		
Formulate a design-construction quality loop framework	What knowledge needs to be captured?	It was identified that it is important to identify one key learning objective rather than attempt to capture an overly comprehensive knowledge base as it is highly unlikely that there will be the resource base to support such. Consequently this research has identified that knowledge relating to how buildability of design can be enhanced is of significant importance in improving design		

		quality and therefore the capture of this will be sought. It is also noted that tacit knowledge is of much greater value than explicit knowledge.		
	How should knowledge be captured?	A greater extent of explicit knowledge and its context can be captured when the time between the event and the capture is minimised. Therefore where possible, live capture should be prioritised.		
	How should knowledge be stored?	A contentious issue as some view knowledge as being codifiable (the transformation of tacit knowledge into explicit knowledge) and suggest that this is beneficial as it enables links between cause and effects to be established more easily. However, others believe that codifying knowledge leads to rules and rigidity. It was also discovered that designers benefit from direction but not imposed rigidity and therefore a compromising medium should be sought.		
	How should knowledge be maintained?	Knowledge can be stored in a variety of ways; however, the documentation of knowledge through the use of reports is not seen as an effective method. A knowledge store should be easily accessible to those authorised to access it. It should also be easily searchable in order to locate the relevant knowledge quickly and easily without having to rummage through countless documents.		
	How should the knowledge be shared?	In order for the captured knowledge to be of use it must be shared with those that can utilise it the most. In the case of the learning objective of this research (buildability related instances) such knowledge needs to be shared with future designers in order to prevent its reoccurrence. There are technological means to achieve this in the form of groupware, intranets, extranets, cased based reasoning and data mining. There are also non technological means in the form of reports, training and communities of practice to name a few.		
	What is the business case for the design-construction loop to be adopted?	There appears to be undoubted benefits on the basis of the literature review in the form of; improved design quality, reduced costs and schedules, increased innovation to name a few. However, the development of a feedback framework within a healthcare context is faced with substantial complexities and barriers. Therefore the extent to which a business case for the design-construction loop can be developed appears to hinge on the degree to which these complexities can be broken down and overcome, whilst still leveraging the cited benefits that such a framework is said to provide.		
To provide recommendations for the effective implementation of the proposed framework in healthcare infrastructure projects	How can the developed framework be implemented successfully?	The main barriers and some coping strategies have been identified above; however more effective means to overcome these will be further investigated in the case study research phase		

Appendix B – Supplementary Case Study Information

B.1 Development Logic of Case Study Research Propositions

Table 10.2: Development Logic Database of Case Study Research Propositions

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
Initial Project Outline (Section 1)	Focused	• How the capture and feedback of knowledge can create a learning culture to improve the quality of healthcare facility designs	• Literature review plan to review OL and KM, as well as learning within healthcare infrastructure projects,		
Initial Literature Review (Sections 2 and 3)	Broad	• OL and KM - KM process - KM techniques / technologies • Learning within healthcare infrastructure projects	• Lack of learning from the construction stage of healthcare projects • Post occupancy evaluation is the only structured form of feedback loop (therefore learning from finished buildings was already over represented in the literature compared to learning from the construction of buildings	**3.2.5** **3.2.5**	**Proposition 1 -** A feedback loop between the construction and design stages could improve the level of vital learning from each healthcare project
			• Buildability knowledge resides in the construction stage which has the potential to impact on the overall cost, quality and time of healthcare infrastructure projects thus attaining the learning improvement desired in the initial project outline.	**2.6.4** **3.2**	**Proposition 2 -** the capture and feedback of buildability instances to designers can improve design quality, reduce costs and time.

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
Initial Literature Review (cont.) (Sections 2 and 3)	Broad	• OL and KM - KM process - KM techniques / technologies • Learning within healthcare infrastructure projects	• Review of the KM lifecycle, as well as techniques and technologies to support it • Live capture of knowledge is difficult due to resource constraints but improves the quality of the knowledge captured	**2.5.4**	**Proposition 2a –** the usefulness of the knowledge captured is improved the nearer to the learning event occurring, the eventual capture takes place.
			• A purely technological or technique based feedback framework is unlikely to be successful due to techniques/technologies overcoming the weaknesses each other, as well as not one technique / technology being ideally suited to any of the stages of the KM lifecycle	**2.5, 2.10.1**	**Proposition 3** – A socio-technical systems approach can overcome the downfalls of purely technique or technology centred KM approaches
			• Knowledge capture within construction projects is rarely captured live. This leads to knowledge deterioration and/or knowledge loss.	**2.5, 2.10.1**	**Proposition 4-** mobile technologies can be utilised to assist the live capture of learning instances onsite
			• A variety of knowledge capture formats are required to transfer tacit knowledge in preference for purely text	**2.2.4**	**Proposition 2b** – Vital tacit knowledge can be fed back to designers if a variety of capture formats are utilised.
			• Poor knowledge capture, storage and validation procedures are causing a lack of actionable knowledge/lessons learnt to be stored in KM systems • Poor quality of knowledge (i.e. non-actionable knowledge) leads to the dissatisfaction of knowledge reuse which ultimately leads to KM systems becoming obsolete.	**2.10**	**Proposition 6** – The improvement of knowledge capture and storage will have an automatic positive impact on the knowledge reuse

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
Buildability Literature Review (Section 3.2)	Focused on proposition 2	• What constitutes buildability • Benefits / drivers to improve buildability • Barriers against improving buildability • Factors of buildability • How KM can improve buildability • Comparative studies in the capture and feedback of buildability instances and other related studies	• **Reinforcement of proposition 1 and 2** – The capture and feedback of lessons learnt during the construction stage could greatly benefit the design quality of future projects • Buildability instances need to be fed back to designers to avoid their reoccurrence. • No research to date satisfies the entire range of research objectives set within this study (see Section 3.3)	**3.2.3, 3.2.5** **3.2.5** **3.3**	**Proposition 4a** – BIM provides a potential platform for the feedback framework
Further Building Information Modelling Literature Review (Section 2.9.5)	Focused on proposition 4	• What is BIM • Benefits of BIM • Current adoption of BIM • Suitability of BIM to meet the needs of this study • Drawbacks/ challenges of BIM	• **Reinforcement of proposition 4a -** BIM appears to be an appropriate platform to enable knowledge capture, storage and sharing amongst project participants • The alignment with BIM could increase the longevity of this study's findings/ developments	**2.9.5**	
Further Mobile Technology Literature Review (Section 2.9)	Focused on proposition 6	• Review of mobile technologies to assist in the capture of learning instances onsite • Review of current adoption levels of mobile technology	• Mobile technology advances of late make them a much more viable option than in the past • Successful KM programs require social interaction also • **Reinforcement of proposition 3 and 4**	**2.3.5**	
Case Study Investigation (Case Study A)	Focused on proposition testing	• Establishing the need for a knowledge feedback loop • Types of reusable knowledge • Currently adopted KM	• A more open flow of construction knowledge integrated as early as possible within projects would lead to improved levels of learning, thus reducing future mistakes, improve design quality and ultimately improve the	**5.3.2.3**	

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
Section 0 Case Study Investigation (Case Study A cont.) Section 0		processes • Buildability specific KM processes • Resources currently held by organisations that can be utilised within the knowledge feedback loop • The requirements of a knowledge feedback loop • Difficulties foreseen and coping strategies • Establishing the need for a knowledge feedback loop • Types of reusable knowledge • Currently adopted KM processes • Buildability specific KM processes • Resources currently held by organisations that can be utilised within the knowledge feedback loop • The requirements of a knowledge feedback loop • Difficulties foreseen and coping strategies	value of the delivered facility - **Reinforcement of proposition 1**		
			• The failure to capture and openly share knowledge is resulting in both the reoccurrence of avoidable buildability issues and the tendency to reinvent the wheel - **Reinforcement of proposition 1 and 2**	**5.3.3**	
			• Lessons learnt are not highly prioritised by top level management compared to project related goals and environmental success factors.	**5.3.4.1, 5.3.4.2**	**Proposition 7** - a heightened priority given to lessons learnt from top level management would lead to more time and effort being allocated to the on-going activity throughout the project.
			• Text is the most dominantly used format for knowledge capture, codification, storage and sharing; however it was viewed by many as not being effective in enabling knowledge to be shared - **Reinforcement of proposition 2b**	**5.3.4.5**	
			• The *quality* of the knowledge held within KM systems affects the extent to which they are utilised. If the knowledge captured and stored is not viewed as valuable enough to seek out then the system will become disused - **Reinforcement of proposition 5**	**5.3.4.4**	

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
			• The widespread use of BIM appears to be approaching but it is not the case as yet. It is also not apparent in what form BIM will take and therefore it is too embryonic to be able to align the development of a feedback loop to effectively - **Reinforcement and Rejection of proposition 4a**	**5.3.4.4**	**Proposition 4a.1** - The potential of BIM provides a probable platform to share knowledge between project participants; however at present it is too premature to predict in what form this will emerge.
			• The utilisation of cross organisational project teams enables learning to naturally take place and thus achieve continuous improvement. Not incorporating on-going teams results in relationships and understandings having to be nurtured at the start of each project	**5.3.6.1**	**Proposition 8** - Utilising repetitive core teams leads to learning to naturally take place and thus enables continual improvement more readily than contrived methods of KM.
Case Study Investigation (Case Study B) Section 0	Focused on proposition testing	• Establishing the need for a knowledge feedback loop • Types of reusable knowledge • Currently adopted KM processes • Buildability specific KM processes • Resources currently held by organisations that can be utilised within the knowledge feedback loop	• Greater feedback, communicative channels and knowledge sharing between project parties is needed to continuously improve the quality of facilities built and in particular, reducing buildability issues – **Reinforcement of propositions 1 and 2**	**5.4.2.1** **5.4.3**	
			• The repetition of the same project team enables understanding between key organisations to be in place prior to the project commencing, reduces conflicts and leads to continuous learning **Reinforcement of proposition 8**	**5.4.2.2** **5.4.2.3** **5.4.3** **5.4.4.2** **5.4.6.3**	

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
Case Study Investigation (Case Study B cont.) Section 0	Focused on proposition testing	• The requirements of a knowledge feedback loop • Difficulties foreseen and coping strategies	• Heightened levels of communication, feedback and in general, knowledge sharing assist in overcoming buildability issues – **Reinforcement of propositions 1 and 2**	**5.4.2.2** **5.4.2.3**	
			• Need to raise the awareness of conducting lessons learnt and feedback to as wide an audience of project participants as possible to achieve industry improvements – **Reinforcement of propositions 1 and 6**	**5.4.3**	
			• Not one singular KM technique or technology is ideally suited to support the full KM lifecycle in isolation therefore multiple KM techniques / technologies are required within a socio-technical arrangement. However careful consideration is required as increased quantity does not equate to increased quality – **Reinforcement of proposition 3**	**2.10.1** **5.4.4.2** **5.4.4.3** **5.4.4.4**	
			• Greater reassurances and support from top level management surrounding the process of conducting lessons learnt and in particular the identification of mistakes is essential	**5.4.4.2**	**Proposition 6.a –** greater assurances and communication from top level management of the KM process would lead to a reduction in the fear of reflecting upon mistakes

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
Case Study Investigation (Case Study B cont.) Section 0	Focused on proposition testing	• Establishing the need for a knowledge feedback loop • Types of reusable knowledge • Currently adopted KM processes • Buildability specific KM	• Vital lessons arising during the construction phase are not being fed back to those who could best utilise the resultant knowledge (i.e. designers). **Strong reinforcement of propositions 1 and 2.**		
			• Other issues such as health and safety and sustainability are prioritised more highly than buildability and technical issues due to client demands. A heightened priority for buildability lessons learnt from top management would lead to more effort being applied to this activity but this is only likely if it is client led	**5.4.4.2**	**Proposition 7.1** - a heightened priority given to lessons learnt from clients and / or top level management would lead to more time and effort being allocated to the on-going activity throughout the project
			• Tacit knowledge is transferred through two-way communication – **Discrediting of proposition 2b**	**5.4.4.3**	
			• Mobile technologies are able to widen the learning potential of highly effective but resource intensive KM techniques such as site visits or mentoring and training – **Reinforcement of proposition 4**	**5.4.4.4**	
			• Vital tacit knowledge can be transferred if a variety of capture formats are utilised especially through formats that use visual elements (i.e. not text) – **Reinforcement of proposition 2b**	**5.4.4.5**	**Proposition 2b.1** - Vital tacit knowledge can be captured and fed back to designers through the utilisation of oral and/or visually based formats.

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
			• BIM, although a likely KM supportive platform in the future is at too an embryonic stage at present – **Reinforcement of proposition 4a.1** •	**5.4.5.3**	
			• Partnering can lead to natural on-going learning between its members to be achieved (**reinforcement of proposition 8**); however, its benefits are limited unless the personnel remain consistent.	**5.4.6.3**	**Proposition 8a** – Effective relationships that enable knowledge transfer and learning are personal and not organisational, so for on-going natural learning to emerge from partnering, repetitive personnel is essential.
Case Study Investigation (Case Study C)	Focused on proposition testing	• Establishing the need for a knowledge feedback loop • Types of reusable knowledge • Currently adopted KM processes • Buildability specific KM processes • Resources currently held by organisations that can be utilised within the knowledge feedback loop • The requirements of a knowledge feedback loop • Difficulties foreseen and coping strategies	Within traditional design-bid-build contracts the need for a knowledge feedback loop is unquestionable; however, due to design-build contracts enabling natural feedback through integration, the need for such a formal loop is lessened – **Consideration for proposition 1**	**5.5.2.2**	
			• Buildability issues are viewed as avoidable if knowledge is captured, reflected upon and reused – **Reinforcement of proposition 1 and 2** • Construction techniques and materials are an area in which could benefit from feedback between construction and design **– Reinforcement of proposition 1**	**5.5.3.1** **5.5.3.2**	
			• Top level support and communication is required if a supportive knowledge sharing culture is to be nurtured – **Reinforcement of proposition 7a**	**5.5.4.1**	

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
Case Study Investigation (Case Study C) (cont.)	Focused on proposition testing		• The establishment of trust and understanding between project participants is fundamentally important if a philosophy of openness is to be fostered. • On-going trust and openness can be safeguarded if the same project teams are maintained from project to project. • **Reinforcement of propositions 7 and 7a**	**5.5.4.1**	
			• Two-way communication is beneficial in transferring tacit knowledge – **Weakening of proposition 2b and 2b.1**	**5.5.4.1**	
			• Ability to demonstrate a high regard for learning from previous buildability issues can be a contributing factor in gaining contracts for the subsequent work if clients appreciate its worth – **Reinforcement of proposition 6.1**	**5.3.4.1**	
			• Top level management priority of other knowledge capture areas such as those related to KPIs ensure that time is allocated to the activity – **Reinforcement of proposition 6.1**	**5.5.4.2**	
			• Repetitive teams eliminate the ability to benefit from natural knowledge dissemination techniques such as reassignment of employees – **Consideration for proposition 7 and reinforcement of propositions 3 and 3b**	**5.5.4.3**	
			• Two-way communication enables the opportunity to request for further information or to clarify details, which is absent through the text based report method.	**5.5.4.5**	**Proposition 3c** - two-way communication is needed to provide efficient location of appropriate knowledge and effective knowledge transfer

Activity	Scope of Enquiry	Areas of Interest	Output / Results	Cross Reference	Emerging Research Propositions
Case Study Investigation (Case Study C)	Focused on proposition testing	(see above)	• A significant degree of uncertainty remains surrounding in what form BIM will be adopted in terms of ownership framework, inter-organisational processes and legal requirements – **Reinforcement of proposition 4.1**	**5.5.5.3**	
			• Design and construction organisations should seek to maintain key project teams where possible so that the relationships generated are not abolished instantly through dismantling the team • However it is insufficient to simply maintain the same construction or design team separately • For full benefits to materialise the fusion of the majority of the same key participants across organisational divides needs to occur where possible. • Relationships are personnel and not organisational • **Reinforcement of propositions 7 and 7a**	**5.5.6.1**	

B.2 Case Study Protocol

Case Study Protocol

1) Establish Initial Contact

- Identify large contracting organisations from their experience in working within the P21+ framework as well as traditional contracts for healthcare infrastructure projects;
- Contact healthcare framework managers or equivalent from large contracting organisations; and,
- Make contact via email explaining the research conducted to date, the desired direction and outputs of the study (aim and objectives), the need to discuss the opportunity to visit a current project to act as a case study, and the intention to keep all participants completely anonymous.

2) Conduct Discussion with Framework Manager (or equivalent)

- Discuss findings to date from the literature review to illustrate how the aim and objectives of the study have been formed;
- Discuss the research propositions that have arisen throughout and gain feedback on the senior personnel's viewpoints;
- Establish how the research objectives align with the organisation's objectives and interests (i.e. continual learning is a mutual objectives);
- Discuss what data collection opportunities (i.e. current healthcare infrastructure projects) the organisation may be able to offer;
- Identify the most idealistic project in terms of being complimentary to the aim and objectives and propositions, as well as back-up projects as contingencies;
- Request that the framework manager makes initial contact with the project manager requesting assistance and cooperation with the study; and,
- Make contact with the project manager and arrange a convenient time to meet and arrange data collection timetable.

3) Desired Data Sources

- Project manager;
- Additional key managerial staff;
- Experienced and influential design team representative; and
- Supplementary data:
  - Observations – design team meetings etc.
  - Evidence gathering – buildability presentations, KM outputs, photographic evidence of buildability issues.

4) Interview Protocol

This section details the main interview protocol followed. It is structured thematically in sections outlining the aim of each section, the information sought and the sources of information. Two similar but distinguished interview protocols were followed depending on the source of information (construction or design related).

Organisational and Personal History (Construction / Design)

MAIN AIM: To assess what position the interviewee is in to comment about the knowledge capture and sharing and therefore establish to what extent they fulfil the sampling criteria.

Information Sought:

Organisation:

- The size of the organisation; and,
- The phase of the construction process they specialise in.

Individual:

- What their position / job title within the organisation is;
- What their job description/ roles are;
- What their experience in healthcare specific projects is; and,
- What their general construction experience is.

SOURCES OF INFORMATION: Project manager, additional key managerial staff, experienced and influential design team representative

Current Situation (Construction / Design)

MAIN AIM: To gain an understanding of what the current problems are regarding the buildability of designs, how reoccurring they are and to assess whether an increase in feedback is likely to improve the situation. Therefore the information desired to establish the need for a knowledge feedback framework is.

Information Sought:

- How big an issue design buildability is;
- What are the negative consequences of a lack of buildability in a design;
- Which issues are the most reoccurring and/or preventable; and
- What construction related knowledge would assist in designing out buildability issues in the future?

SOURCES OF INFORMATION: Project manager, additional key managerial staff, experienced and influential design team representative, design team meeting observation, evidence gathering

Current Practises (Construction / Design)

MAIN AIM: To understand how buildability issues are overcome. Establish what procedures (if any) are in place to feedback information. Identify strengths and weaknesses in current procedures to build/ improve upon.

Information Sought:

- How knowledge is currently captured, stored, and shared;
- Analyse how effective these practices are;
- Investigate how they may be improved;
- Outline what feedback mechanisms (if any) are in place, and what their strengths / weaknesses are;
- What knowledge is currently captured;
- What knowledge needs to be captured to improve the situation;
- In what format is knowledge captured, stored and shared;
- How effective is this and is there formats better suited for this need

SOURCES OF INFORMATION: Project manager, additional key managerial staff, experienced and influential design team representative, design team meeting observation, evidence gathering

Current Resources (Construction / Design)

MAIN AIM: To establish what current resources (in particular regarding currently adopted mobile technologies) the organisations has in order to build/ improve upon them rather than attempting to enforce new technologies/ procedures which would be fraught with resistance.

Information Sought:

- What the organisation's technology strategy / ethos is;
- What mobile technology the organisation currently utilises;
- What other tasks currently use mobile technology;
- What the main difficulties are implementing new resources; and,
- How these difficulties are overcome.

SOURCES OF INFORMATION: Project manager, additional key managerial staff, experienced and influential design team representative.

Building Information Modelling (Construction / Design)

MAIN AIM: To assess whether the application of BIM is an appropriate platform to build the proposed feedback loop upon.

Information Sought:

- How widespread the adoption of BIM currently is on healthcare projects;
- What the future direction of BIM is;
- How it may be adapted to incorporate the capture and sharing of knowledge;
- What the drivers and barriers against utilising this technology are compared with alternatives such as standalone KM practices; and,
- What the additional processes may be to enable the effective adoption of the proposed feedback loop within this environment.

SOURCES OF INFORMATION: Project manager, additional key managerial staff, experienced and influential design team representative.

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Way Forward (Construction / Design)

MAIN AIM: To present the interviewee with the opportunity to indicate how they believe the need to manage knowledge and in particular, buildability instances would be best achieved.

Information Sought:

- How they foresee the best way to capture knowledge is;
- How they foresee the best way to manage and disseminate knowledge is; and,
- Identify what the key credentials the proposed feedback loop would have to possess to heighten its chances of success.

SOURCES OF INFORMATION: Project manager, additional key managerial staff, experienced and influential design team representative.

Coping Strategies (Construction / Design)

MAIN AIM: To assess the prevalence of the cited barriers and drivers obtained from the literature review. Assess how these could be overcome or reduced through the formulation of mitigation strategies.

Information Sought:

- What the main barriers are towards achieving effective knowledge feedback;
- How these barriers may be overcome or reduced;
- How additional barriers (cited in the literature) could be overcome or reduced.

SOURCES OF INFORMATION: Project manager, additional key managerial staff, experienced and influential design team representative.

Further Comments (Construction / Design)

MAIN AIM: To present the opportunity to add any additional comments that they believe may be relevant and have been missed through the process.

Information Sought:
Any relevant information regarding the research topic which has been missed.

SOURCES OF INFORMATION: Project manager, additional key managerial staff, experienced and influential design team representative.

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5) Data Collection and Management Procedures

- Voice record all data collection (that permission is granted for);
- Make notes throughout data collection;
- Ask additional probing questions to extract further information and explore intriguing avenues;
- Transcribe all data recordings in text form for easier within-case and cross-case analysis;
- Maintain a log and backup of all data collected; and,
- Identify follow up questions needing to be answered as a result of:
    - Data gathered being insufficient, or,
    - Data gathered identifying additional avenues to explore.
- Arrange follow up interviews if required.

6) Data Analysis

- Write-up case-study report;
- Conduct within-case study analysis;
- Identify emerging research propositions;
- Restate research propositions;
- Alter the interview protocol as necessary to test emerging research propositions within the subsequent case studies;
- Repeat steps 1-6 for secondary case study and so on for any additional case studies to be carried out;
- Once all case studies and follow up data collection has been completed, perform cross-case analysis.

Appendix C – List of Publications

C.1 Conference papers

HENDERSON, J.R., RUIKAR, K. and DAINTY, A.R.J., (2010). The need for embedding learning in healthcare projects, 26th ARCOM International Conference, 22-24 September 2010.

Abstract:

The quality of service delivery in the healthcare sector is profoundly affected by the built infrastructure provided to support it. By capturing `lessons learnt' from healthcare projects in relation to the build quality of the final product and their effectiveness in terms of creating healing environments, the future design and operation of such facilities can be better informed. The aim of this paper is to present a critical synthesis of the OL literature, specifically concentrated within a healthcare infrastructure context. This paper reports on the potential benefits, challenges and strategies for embedding a learning culture in project-based environments and ultimately provides the business case for improving project-based organisational learning within healthcare infrastructure, as well as recommendations for further empirical investigation.

HENDERSON, J.R., RUIKAR, K. and DAINTY, A.R.J., (2010). Creating A Project-Based Learning-Loop within the Construction Phase of Healthcare Infrastructure Projects, PhD Workshop HaCIRIC International Conference 2010, 22-24 September 2010. pp12-20.

Abstract:

Service delivery in the healthcare sector is profoundly affected by the built infrastructure provided to support it. In order for a hospital environment to function optimally, there is a need to investigate how a learning culture can be nurtured within the design, construction and occupancy of healthcare facilities in order that its effect on the healing process of patients can be managed. A large focus of attention within the research conducted by the Health and Care Infrastructure Research and Innovation Centre (HaCIRIC) is centred on learning from buildings in use and post occupancy evaluation (POE). Interestingly, however, there has been little focus on capturing lessons learnt from the construction phase of projects. This could be particularly important to informing the future buildability of healthcare projects. The aim of this research is to examine how lessons learnt arising from the construction phase can be captured and fed back to designers and in some cases the client.

This is in order to create a learning culture and help improve the quality of future healthcare facilities/infrastructure. The paper reports on findings of an initial literature review that explores the potential benefits and challenges for embedding such a learning culture in project-based environments. Through this literature synthesis a significant case for improving project-based organisational learning within healthcare infrastructure is provided and recommendations for the need for further empirical investigation are made.

C.2 Journal Papers

Henderson, J. R., Ruikar, K. D., & Dainty, A. R. (2013). The need to improve double-loop learning and design-construction feedback loops: A survey of industry practice. *Engineering, Construction and Architectural Management*, *20*(3), 290-306.

Abstract:

Purpose – This paper reports the empirical findings of a survey aimed to investigate the need to improve cross-phase learning between design and construction. Through exploring the need to introduce a design-construction feedback loop, combined with the barriers against its development, an expansion of knowledge surrounding the deficiencies of current practice is provided.

Design/methodology/approach – The paper reports the results from an online survey conducted in spring 2011 targeted at experienced personnel in the planning, design, construction and facilities management phases of healthcare infrastructure projects.

Findings – The current approach of detecting and correcting errors is significantly hindering the extent to which learning from previous experiences is taking place. It is shown that improved integration between design and construction is required in the form of improved feedback if continuous improvement in the areas of efficiency, quality, value and general learning from previous experiences/ projects is to be achieved.

Research limitations/implications – The focused population of this study limits the extent to which the findings can be generalised. However, it is viewed that this context is potentially one of the most complex and unique project participant arrangements to overcome. Therefore if the need and ability to share learning outcomes across such a complex arrangement can be achieved, then it may be easier within traditional arrangements.

Practical implications – The practical implications of moving away from single-loop learning towards a double-loop learning approach are provided.

Originality/value – This paper identifies that there is a distinct need for further efforts to be applied in the area of improving feedback between the phases of design and construction.

Keywords: Feedback, Double-Loop Learning, Buildability, Learning, Construction, Design,

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HENDERSON, J.R., RUIKAR, K.D., DAINTY, A.R.J. Knowledge Management Processes: A Cycle of Disillusionment.

Abstract:

Purpose: This paper reports the findings of an investigation into how a knowledge management systems approach plays out within a construction industry context. Categorically highlighted are the intrinsic failings of this approach, which ultimately lead to its underutilisation, reduced worth and potential failure.

Design/methodology/approach: The KM processes and viewpoints of 103 highly experienced and influential employees involved in large complex construction projects were obtained through an electronic survey. Predominantly quantitative based questions were asked to enable statistical analysis to be conducted, thus identifying trends, with the responses being systematically explored and discussed according to the phases in the knowledge management lifecycle.

Findings: Significant deficiencies in knowledge capture, storage and reuse, especially in terms of their text-based nature and time delays in recording lessons learnt were discovered. Current practices are more suited to explicit rather than tacit knowledge, and are therefore significantly reducing the extent to which actionable knowledge is held and utilised. Ultimately these inadequacies lead to damaging subconscious beliefs towards KM, reducing the faith participants have in reusing organisational knowledge. This perpetuates an on-going cycle of disillusionment.

Originality/value: Within more stable production settings such deficiencies are viewed as equally applicable, yet perhaps less discernible. This paper utilises the construction setting to promote a widespread move away from a purely KMS approach towards one that sees knowledge as situated and socially constructed. This paper provides a novel illustration of the destined decline in value of a KMS over time if socialisation is ignored.
