A KNOWLEDGE CHAIN FRAMEWORK FOR CONSTRUCTION SUPPLY CHAINS

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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 acknowledgements or in footnotes, and that neither the thesis, nor the original work contained therein, has been submitted to this or any other institution for a higher degree.

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ABSTRACT

Construction is a project-based industry and construction supply chains generally work with a unique product in every project. Commonly, project organizations are reconfigured for each project. This means that construction supply chains are characterised by various practices and disjointed relationships, with the result that construction supply chain actors generally have transient relationships rather than long term risk sharing partnerships. A consequence of this is the lack of trust between construction clients, designers, main contractors and suppliers. Because the construction supply chain works as a disparate collection of separate organisations rather than as a unified team, the supply chain suffers from lack of integration. Knowledge flow in construction supply chains are hindered due to the reasons such as inadequate adaptation to collaborative procurement type projects, inadequate collaboration between the downstream and upstream supply chain, lack of interoperability of the design tools, lack of well structured SCM process and lack of well developed knowledge management applications. These characteristics of the construction supply chains are the main reasons for its low efficiency and productivity in project delivery. There is a need for the development of appropriate systems to ensure the effective diffusion of knowledge such that each actor of the supply chain adds value to the project delivery process. This is expected to result in the creation of 'knowledge chains' in construction. It is believed that construction supply chain management (SCM), when integrated with knowledge management (KM), can successfully address the major problems of the industry

The main aim of this research was to develop a framework to transform construction supply chains into 'knowledge chains'. To reach this aim, the research first provided an overview of practices and issues in SCM across a range of industry sectors including construction, aerospace, and automotive industries. It discusses research and developments in the field of SCM and KM in construction industry, the key SCM issues with a knowledge flow focus, and the best practices from other industries to improve the construction supply chains. Furthermore, the results of the company specific and project specific case studies conducted in aerospace and construction industry supply chains are presented. These results include the key SC problems, key issues related to knowledge flow and the presentation of knowledge requirements of each supply chain actor.

Following the data analysis process, a framework to transform the construction supply chain into a 'knowledge chain' taking full cognisance of both the technical and social aspects

of KM was presented. The main purpose of the ‘knowledge chain framework’ was to enable construction bid managers/project managers to plan and manage the project knowledge flow in the supply chain and organise activities, meetings and tasks to improve SCM and KM throughout the supply chain in an integrated procurement type (PFI) project life cycle. The ‘knowledge chain framework’ was intended to depict the knowledge flow in the construction supply chain specifically, and to offer guidance for specific business processes to transform the supply chains into knowledge chains. Finally, this research focused on the evaluation of the framework through industry practitioners and researchers.

An evaluation of the Framework was conducted via workshop followed by a questionnaire comprising industry experts. The findings indicated that adoption of the Framework in construction project lifecycle could contribute towards more efficient and effective management of knowledge flow, standardisation and integration of SCM and KM processes, better coordination and integration of the SC, improved consistency and visibility of the processes, and successful delivery of strategic projects.

The overall research process contributed the construction research in many perspectives such as introduction of knowledge chain concept for construction supply chains; comparative analysis of the SCM practices in different industry sectors, identification of best practices for construction supply chains, better demonstration of the maturity level and critical factors of the SCM within the construction industry, demonstration of the KC framework which integrates the supply chain process and knowledge sharing within a single framework which covers all the recent trends in the construction industry like collaborative procurement route projects, creation of better integrated SCs, applications like off site construction and BIM where all supply chain management and knowledge management should take place.

Keywords: Knowledge management, knowledge chain, supply chain management, construction, aerospace, automotive, framework.

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List Of Abbreviations

BIW	Business Information Warehouse
BKM	Building Knowledge Model
BOT	Build Operate Transfer
COP	Communities of Practies
DFD	Data Flow Diagram
FFBD	Function Flow Block Diagram
FM	Facilities Maangement
HRM	Human Resources Management
IDEF0	Integration Definition for Function Modelling
ICT	Information and Communication Technologies
IT	Information Technologies
ITN	Invitation to Negotiate
JIT	Just in Time
JIS	Just in Sequence
KC	Knowledge Chain
KM	Knowledge Management
KMS	Knowledge Management Systems
MIS	Management Information Systems
OEM	Original Equipment Manufacturer
PhD	Doctor of Philosophy
PFI	Private Finance Initative
RBT	Resource Based Theory
R&D	Research and Development

SC	Supply Chain
SCM	Supply Chain Management
SECI	Socialization, Externalization, Combination, and Internalization
SMEs	Small and Medium Size Enterprise(s)
TPS	Toyota Production System
TLM	Through Life Management
TQM	Total Quality Management
UK	United Kingdom
UML	Unified Modelling Language

CHAPTER 1

1 INTRODUCTION

This chapter introduces the research work presented in this thesis. It describes the background, aim, objectives and methodology of the research, and provides a guide to the contents of the thesis.

1.1 Background

Knowledge Management (KM) deals with the organizational optimization of knowledge to achieve improved performance, increased value, competitive advantage, and return on investment by integrating various tools, processes, and methods in the organizational workflow (Skyrme and Amidon 1997; Siemieniuch and Sinclair 1999). NASA briefly defines KM as "getting the right information to the right people at the right time, and helping people create knowledge and share and act upon information in ways that will measurably improve the performance of an organization and its partners" (Murphy and Holm 2008). This definition is particularly different from the other KM definitions with its emphasis on the "partners of NASA". The integration of knowledge, information and materials flow between the client, and supply chain (SC) actors defines the concept of supply chain management (SCM) (Samaranyake 2005). Today, knowledge is regarded as the most important resource in the SC. Failure to transfer knowledge within organizations or along the complexities of SCs leads to wasting time and money reinventing the wheel for each project and impairs project performance (Koh and Gunasekaran 2006). Moreover, transfer of knowledge does not always mean the diffusion and internalisation of knowledge in the SCs. The diffusion of knowledge through SCs depends on the KM abilities of the organizations in the SC.

Construction Supply Chain Management (SCM) deals with managing the process of knowledge flow, financial flows, materials, activities, tasks and processes involved within various networks and linkages (upstream and downstream) of organisations in order to develop high quality construction products and services to clients in an efficient manner (Akintoye et. al., 2000; Tucker et. al. 2001). In construction supply chains where there is huge knowledge and information flow between the contractors, subcontractors, suppliers and distributors, it is essential to create a collaborative environment during the projects from the bidding phase to the delivery to customer. Construction projects are generally unique and may need different supply chain configurations for each project. There are also important issues regarding the creation, and storage of the knowledge. Creating a collaborative working environment within this variable and complex supply chain context can be problematic. Thus, cross-discipline co-ordination and knowledge exchange are crucial for these multidisciplinary collaborative processes in the construction supply chain management (Aouad et. al., 2002). For effective supply chains, all elements of the supply chain must be connected to enable the flow of knowledge (Desauza et. al., 2003). This creates heavy reliance on information and knowledge management to co-ordinate the whole supply chain (Tucker et. al., 2001). As a result, the flow of knowledge within both the downstream and upstream of supply chains is considered a critical issue in construction supply chains.

An investigation of supply chain management (SCM) with a knowledge management perspective will support the main objectives of supply chain management and create an innovative environment for knowledge cultivation, transfer and diffusion during construction projects. The integration of KM practices by considering both the social and technical perspectives can be very helpful to produce high quality, lower costs, and just in time knowledge sharing within construction supply chains. This integration can benefit significantly from a systematic approach. Using this approach can be very helpful in anticipating a variety of viewpoints and requirements and planning for accommodating these viewpoints and requirements (Jewell, 1986). Therefore from the organisation of case studies to the establishment of the ‘knowledge chain’ framework, this research benefited from a ‘systematic approach’.

There is a need for improved understanding of the knowledge requirements of construction supply chains, and the development of appropriate systems to ensure the effective diffusion of knowledge so that each actor of the supply chain adds value to the project delivery process. This is expected to result in the creation of knowledge chains in construction. A Knowledge Chain (KC) can be defined as a chain network based on the knowledge flows between various organizations with the aim of reaching a more innovative state for each organization (Gu et. al. 2005). A firm’s KC shows the effectiveness of the management of its knowledge resources and the ability of the organization’s to cope with its business environment. It also represents a firm’s cognitive power for action: its capacity for recognizing, and acting on market changes and developments (Spinello, 1998). Therefore supply chain management activities should be revised in light of knowledge management practices from both organizational and technical perspectives.

1.2 The Research Problem

The literature review and case studies identified major research gaps and problems of managing knowledge within the construction supply chains. These are as follows.

- Single project focus and the prevalence of competitive tendering procedures used in the construction industry has been a barrier for collaborative knowledge sharing and supply chain integration.
- Construction organisations have an unwillingness to rationalise their supplier and client bases. The selection criteria for suppliers are heavily based on cost and there is no feedback mechanism which can include the design team in the selection of the downstream suppliers or performance evaluation of the suppliers. There are not standard SC development programmes available to suppliers. Construction organizations do not benefit effectively from the partnership agreements particularly in the downstream supply chain. There is a need for standardised SCM procedures within organizations to select, evaluate, develop good relationships and keep the best suppliers which can support collaborative knowledge sharing practices in the supply chain.
- Construction projects usually consist of temporarily designed teams from different organisations to produce a unique product. Supply chain actors are generally new to each other and have not necessarily worked together before. Thus, it is difficult to set up collaborative long term relationships based on common goals and benefits which can improve knowledge sharing.
- The interpersonal skills, customer focus, team building, understanding on the specialist consultant’s knowledge and IT skills are the deficiencies that should be developed in the construction industry to improve knowledge creation and sharing between SC actors.
- The effectiveness of knowledge sharing between supply chain actors are hindered by factors such as lack of trust between the parties, lack of frequent consultation and undefined roles and lack of clarity on the knowledge requirements. Apart from this, fragmented and multidisciplinary nature of construction industry, fast-track construction by overlapping the design and construction and further reliance on sub-contractors affect the knowledge sharing process in construction supply chain negatively.

- It is difficult to access accurate data, information, and knowledge in a timely manner in every phase of the construction project lifecycle due to lack of co-ordination and collaboration within the supply chain throughout the life-cycle of the project.
- Poor communication of design information, which results in design changes, inadequate design specifications, unnecessary liability claims, and increases in project time and cost.
- There is inadequacy in knowledge flow between supply chain actors. Inadequate capture, evaluation and implementation of client requirements by clients affect the knowledge flow negatively. Designers do not benefit effectively from the specialist consultants' knowledge. Design team cannot establish strong links with the suppliers and specialist consultant early in the project.
- The fragmentation of design, fabrication and construction data, with data generated at one specific location not being readily re-used within various business units and projects;
- There is lack of standardised processes and well defined procedures for arranging, coordination and controlling the information and knowledge sharing during the project lifecycle. A common methodology for managing construction projects' information assets does not exist. There is a lack of interoperability between systems, with several standards competing for managing data.
- Inefficient knowledge sharing and communication prevents the innovation required for value adding and competitive advantage. Although the innovation is an emerging topic in construction and many other industries, it is still in its development phase.

All these issues require an integrated and coordinated structures to support information and knowledge sharing in the construction supply chain. The transformation of the construction 'supply chain' into a 'knowledge chain' is thus a fundamental multi-organizational change which should be implemented by considering these issues in detail. In the next section, the research questions which can address the main issues, practices and further development areas are presented.

1.3 The Research Questions

The research questions addressed are:

- What are the key issues defined in SCM literature in construction and other industries including automotive and aerospace?
- What is a knowledge chain and how can it be created?

- What are the key SCM practices within construction industry and other industries?
- What are the key knowledge requirements of different disciplines in the construction supply chain and the interdependencies across the supply chain?
- What are the key knowledge flow problems throughout the project lifecycle from the perspective of different supply chain actors?
- Can the knowledge chain framework address the key SCM issues of construction and promote knowledge flow?

These research questions explore different aspects of the research problem. The following chapters discuss how these questions were identified and researched.

1.4 Aim And Objectives Of The Research

The main aim of this research is to develop a framework to transform construction supply chains to knowledge chains. To achieve this aim the objectives of the research project are to:

- Review state of the art of issues and practices in SCM and KM in construction and across a range of industry sectors to learn and establish opportunities for improvement in construction industry;
- Investigate SCM practices with a particular focus on KM within construction and other industries (automotive and aerospace), to establish best practices and opportunities for improvement in construction industry;
- Identify the knowledge requirements of different sectors of the construction supply chain, the interdependencies across the supply chain, and the key issues related to the knowledge flow leading to the development of a knowledge chain in the construction industry; and
- Develop and evaluate a framework for transforming the construction supply chain into a knowledge chain, taking full cognisance of both the technical and social aspects of KM.

1.5 Research Methodology

To achieve the aim and objectives mentioned in Section 1.3, the following actions were taken in the Research Process as depicted in Figure 1-1:

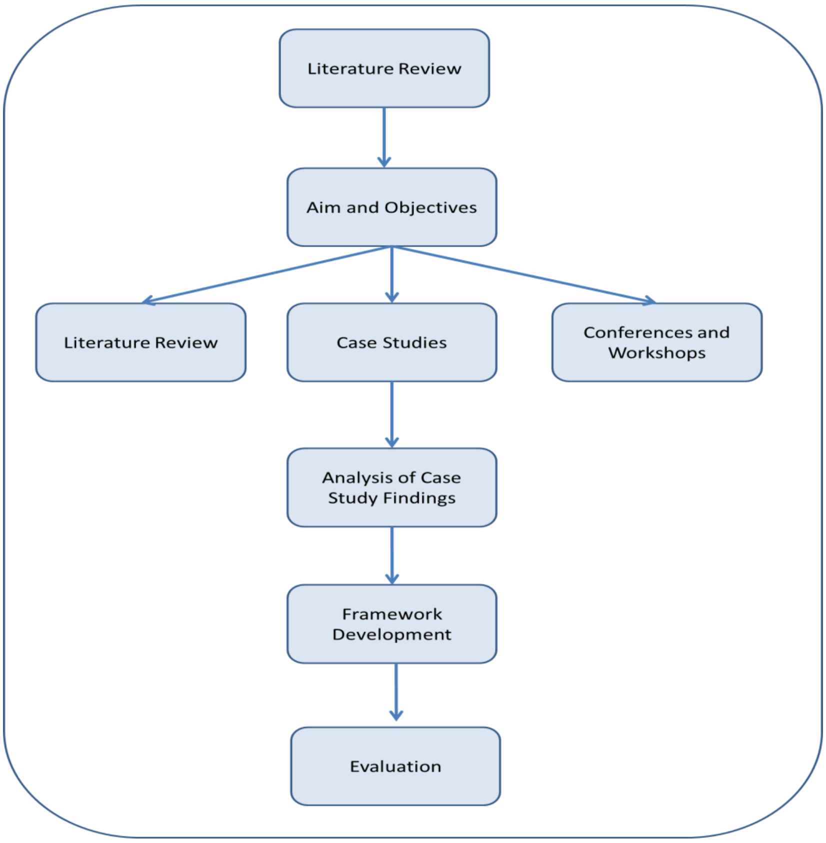

Figure 1-1 Research Process

1) The research started with literature review. This review was on understanding of the SCM field, practices and issues in construction SCM. Following this review, the aim and objectives of the PhD research are identified. This review revealed that construction supply chain management (SCM), when integrated with knowledge management (KM), can successfully address the major problems of the construction industry and its clients. There is a need for the development of appropriate systems to ensure the effective diffusion of knowledge such that each sector of the supply chain adds value to the project delivery process. As such, the theoretical implications of the literature review have served as a foundation for the case studies.
2) After identifying the aims and objectives, further research on literature was conducted. This involved investigating the other industry sectors SCM issues in detail to identify best practices for construction industry. To investigate the SCM issues industry-wide in detail, company and project specific case studies were organized and conducted within the construction and aerospace industries. It was decided that the most appropriate research approach was multiple-case studies incorporating interviews and other data describing the organization and processes of work since it

can provide deeper investigation of the particular issues within the research subject (Fellows and Liu, 2003; Yin, 2003). Structured and semi-structured interviews were adopted with large/mid-scale aerospace and large scale construction companies due to the need for rich data that could facilitate the investigation of the SC and generation of the basis for effective knowledge chain framework. These industries were selected for comparison on the basis that they are different and they can learn from each other. During this field work the research continued to benefit from literature review method to follow the new trends and keep the research updated.

3) The findings of the industry specific case studies were analysed. The key knowledge management issues and knowledge requirements of each supply chain actor were identified.
4) A Knowledge Chain Framework was developed to transform construction supply chains into knowledge chains. For the systematic representation of the framework IDEF0 diagrams were used.
5) An Evaluation of the framework was carried out through workshops and questionnaire surveys.

Details of the research methods adopted in undertaking the above tasks are presented in Chapter Four.

1.6 Key Findings

Key Findings of the research are identified as follows:

- Investigating the development of SCM as a field, one of the most important issue is found to be the lack of a unique definition. There is a remarkable gap in the theoretical work and the industry practice for SCM. Similar to SCM, KM has a lack of consensus on a unique KM definition and theoretical background; however this can be accepted as an evidence of the richness of these concepts. Both KM and SCM can be considered as multidisciplinary areas. The conventional demarcations in traditional subject areas are not comprehensive enough to establish the theoretical background of KM.
- Recent changes in procurement strategy, lack of SCM integration, lack of risk sharing partnering, inadequate trust, skill deficiencies, lack of innovative thinking, inadequate collaboration between the downstream and upstream supply chain, lack of interoperability of the design tools, lack of well structured SCM process and lack of well developed

knowledge management applications are considered as the main issues that needs detailed investigation for SCM in construction industry.

- Compared to construction industry, the automotive and aerospace industries have much more mature SCM applications. The automotive industry developed and implemented various innovative approaches such as JIT, JIS, lean, agile, flexibility, modularisation in their SCM processes. Although the aerospace supply chains are conservative and slow to adapt new challenges compared to automotive industry, aerospace supply chains also benefited from these improvements. Moreover, the aerospace industry significantly improved by the help of the nation-wide SC development programmes. These programmes helped the aerospace firms to develop common SCM priorities, supplier evaluation and selection criterion, and awareness on SC collaboration. Both aerospace and automotive industries have mature relationships and a high level of R&D investment. This makes these industries quicker to implement new technologies and processes than the construction industry.
- Construction industry can learn from automotive and aerospace supply chains in many aspects such as implementation of lean SC practices, improving collaboration between project actors to improve knowledge sharing, improving relationship development between the SC actors, standardisation of SCM processes.
- There is a need for a change of mind in the construction industry, the cost oriented approach of the industry hinders the improvement of it’s supply chain.
- Construction organizations need to implement standard set of SCM procedures in their organizations. These procedures should be identified in line with the overall company strategy. The procedures should cover application of consistent supplier selection and evaluation criteria, implementation of development programmes/trainings for the SC actors, usage of supplier performance records in new projects, standard and timely engagement of SC actors to the projects, and integration of design team and specialist consultants to the downstream suppliers.
- Construction organizations need to implement standard set of KM procedures and tools in their projects. These procedures should be identified in line with the overall company strategy. The procedures should cover identification of KM unit/people who is in charge of knowledge management, implementation of ICT tools with associated trainings available to the SC actors, maintaining the inter-operability of design tools, planning of trainings where the SC actors has skill deficiencies, getting the benefit of lessons learned

in future projects, and implementation of mechanisms to encourage collaborative knowledge sharing.

- Construction organizations should improve the collaboration with the Client from the early stages of the projects. There is a need for early collaboration between the Client, contractor, design team and specialist consultants. Early collaboration between the SC actors is identified as the main driver for innovation.
- There should be more focus on knowledge sharing between the upstream and downstream supply chain. The input from the design team and specialist consultants in the preparation of supplier and sub-contractor specifications is essential.
- The integration of KM practices by considering both the social and technical perspectives can be very helpful to produce high quality, lower costs, and just in time knowledge sharing within construction supply chains. KM can facilitate the transfer of knowledge across a variety of project interfaces, bring increased intellectual capital and innovation, improve performance and project delivery, help firms to avoid repeating past mistakes, retain tacit knowledge, become agile, and minimize risks. Therefore KM based Construction SCM will change the problematic nature of current construction SCM.
- A firm’s KC shows the effectiveness of the management of its knowledge resources, the ability of the organization to cope with its business environment, its cognitive power for action, its capacity for recognizing, and acting on market changes and developments. The creation of KCs not only enhances the final product but also can affect the whole business nature in a positive way. Because of this, transformation of the supply chains into knowledge chains is critical in terms of diminishing the issues of construction supply chain.
- The ‘knowledge chain’ framework is a potential management tool for the project/bid managers to plan and manage project knowledge flow and in the supply chain and organise activities, meetings and tasks to improve SCM and KM throughout the supply chain of an PFI type (integrated procurement) project life cycle. The framework brings consistency, visibility and standardisation to the project life cycle whilst considering all the recent trends in the construction industry like off-site construction and BIM coordination where all SCM and KM should take place. It has the potential to significantly improve the successful delivery of strategic projects in the industry.

1.7 Key Contributions To Knowledge

Contributions of the research are identified as follows:

- A comparative analysis of the SCM practices in different industry sectors, a better demonstration of the maturity level and critical factors of the SCM within the construction industry and identification of best practices for construction supply chains;
- Introduction of knowledge chain concept for construction supply chains taking full cognisance of both the technical and social aspects of KM which needs to be implemented in construction supply chains;
- Demonstration of knowledge requirements for different sectors of the construction supply chain and their interdependencies;
- Identification of key knowledge flow issues in the existing construction and aerospace supply chains, best practices and improvement approaches for construction supply chains;
- The development of a framework that enables construction supply chains to transform themselves into Knowledge Chains that add value to all stages of the project delivery process;
- Integration of supply chain process and knowledge sharing within a single framework which covers all the recent trends in the construction industry like collaborative procurement, applications like off site construction and BIM where all supply chain management and knowledge management should take place; and
- Creating awareness in construction organisations about ‘knowledge’ as a value in supply chain activities during the case studies and evaluation workshops;

1.8 Thesis Structure

This thesis is organised into ten Chapters and a set of Appendices (see Figure 1-2). Brief summaries of the various chapters are provided below.

Chapter One is an introduction to the research, it provides a statement of the problem, the aim and objectives of the research, and gives a preview of the research approach undertaken.

Chapter Two reviews state of the art theories and issues in SCM in construction indsutry. These include: Historical development of SCM, definition of supply chain management, current issues of construction supply chain management and current supply chain management issues of other industries as aerospace and automotive.

Chapter Three reviews state of the art theories and issues in SCM across a range of industry sectors including automotive and aerospace industries.

Chapter Four reviews definition, evolution, lifecycle and systems of knowledge management and its benefits in construction. Furthermore, it presents a systematic approach to knowledge management in construction supply chains.

Chapter Five discusses research methods available, and describes and justifies the methodologies used in the research.

Chapter Six presents the company-specific and project-specific case studies conducted in a large scale construction companies and their supply chains. The findings of the preliminary interviews, which presents the perspective of a construction company on the issues of its supply chain management, and the findings of the interviews conducted with the key supply chain actors of a sample project are presented.

Chapter Seven presents the company specific and project specific case studies conducted in a large scale construction company. The findings of the preliminary interviews, which presents the perspective of a construction company on the issues of its supply chain management, and the findings of the interviews conducted with the key supply chain actors of a sample project are presented.

Chapter Eight presents the case studies conducted in mid-scale and large scale aerospace companies. The findings of the preliminary interviews, which presents the perspective of aerospace companies on the issues of its supply chain management, and the findings of the interviews conducted with the key supply chain actors of a sample project are presented.

Chapter Nine presents a framework for transforming the construction supply chain into a knowledge chain taking full cognisance of both the technical and social aspects of KM.

Chapter Ten presents the evaluation of the framework.

Chapter Eleven presents conclusions from the work and discusses future research needed to bring about a greater awareness for the creation of knowledge chains within construction industry.

Appendices consist of additional information relevant to this research work. These comprise interview questions, supplier assessment procedures and tools, identified information and knowledge requirements of the suppliers for case study projects, and a list of papers that resulted from this work.

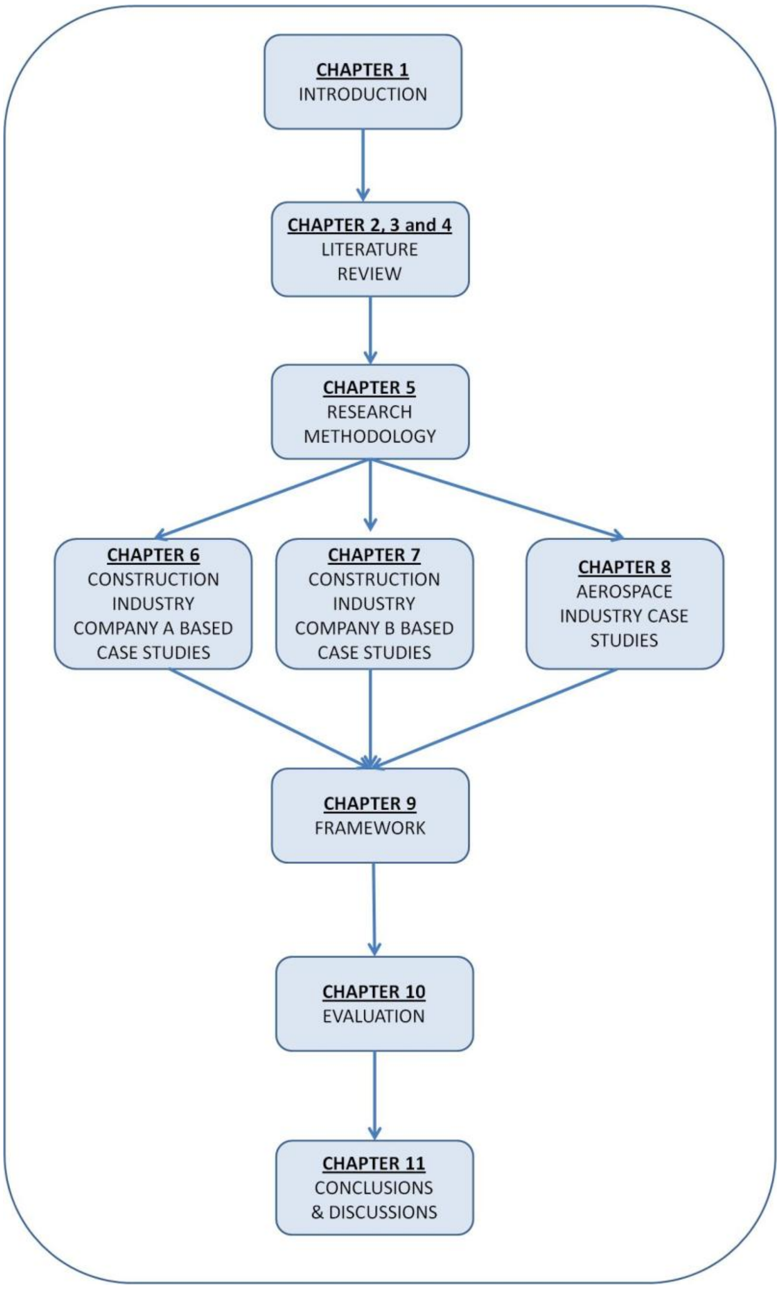

Figure 1-2 Layout of Thesis

CHAPTER 2

2 KEY ISSUES IN CONSTRUCTION SUPPLY CHAIN MANAGEMENT

2.1 Introduction

Supply Chain Management (SCM) is becoming widespread in all industries as global competition increases. Over the past 25 years, supply chain management (SCM) has been evolving as a concept and gradually managers have accepted that their firm is just one entity in the chain of firms whose purpose is to satisfy the customer (Soni and Kodali, 2011). SCM is playing a vital role in increasing the performance of many companies and restructuring their supply chain network to become more competitive. The Institute of Management Accountants (1999) describes the emergence of the SCM as follows:

"As we approach the 21st century one thing becomes clear: Supply Chain Management is not a wave of the future. It is a tsunami that will engulf everything in its path."

Based on this argument, it can be stated that improving SCM is becoming a major objective of the corporate world. Organisations have a great demand for better involvement of their supply chain network. Better understanding of SCM as a concept is the first step to learning the gaps and the needs of today's SCM field.

Construction SCM can generally be defined as managing the process of knowledge flow, financial flows, materials, activities, tasks and processes involved within various networks and linkages (upstream and downstream) of organisations in order to develop high quality construction products and services (Akintoye et al., 2000; Tucker et al., 2001). SCM in construction includes principal contractors, sub-contractors, suppliers, and distributors. The network of suppliers in the construction sector can be extremely complex, generally on a larger project the number of suppliers can be many hundreds (Dainty et al., 2001). As a consequence of this complexity, SCM becomes an emerging concept in the construction industry. This literature review starts with the general supply chain management research which includes its historical development, SCM definitions on the literature, and it's theoretical background. The second part of the literature review is the current management issues of construction supply chains where problems are discussed. The third part discusses knowledge management in construction and the need for a systematic approach to knowledge management applications in the construction industry.

2.2 Definition Of Supply Chain Management

Supply Chain Management is defined in different ways by various researchers and professional associations. There is no unique definition for SCM due to its multidisciplinary nature (Croom et al., 2000). Much confusion has occurred amongst supply chain researchers during the past two decades by the many supply chain management (SCM) definitions that have been proposed in the literature (Stock and Boyer, 2009). Whilst most researchers have agreed that SCM includes co-ordination and integration, co-operation among chain members, and the movement of materials to the final customer; there are still varying concepts of how SCM should be defined (Mentzer et al., 2001b). This confusion exists both amongst academics and industry practitioners (New, 1997; Tan, 2001). Without a detailed definition, it will be difficult for researchers to develop supply chain theory, define and test relationships between components of SCM, and develop a consistent research that "builds" on the past records (Stock and Boyer, 2009).

The definitions of some professional associations established to support SCM activities, include the following:

The Institute of Supply Chain Management describes SCM as:

> *"The design and management of seamless, value added processes across organisational boundaries to meet the real needs of the end customer. The development and integration of people and technological resources are critical to successful supply chain integration."* (Tan et. al. 2005)

The Supply Chain Council defines SCM as:

> *"Managing supply and demand, sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, and delivery to the customer."* (Tan et al., 2005)

The Council of Logistics Management defines SCM as:

> *"…the systematic strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across business*

within the supply chain for the purposes of improving the long term performance of the individual companies and the supply chain as a whole." (Tan et al., 2005)

The definition from the Council of Logistics Management seems the most comprehensive of the above. It suggests that the systematically planned SCM activities should improve the long term performance of the companies and create value in terms of cost, time, performance, (in other words competitiveness) of the organisations. Over the last 20 years the importance given to this field by scholars has increased (Cousins et al., 2006). However, the SCM definitions provided by the researchers do not provide a unique understanding either; they emphasize the different points of multidisciplinary SCM practices. It can be concluded that SCM has not been defined clearly enough and it has a high degree of variability in people's minds about what is meant exactly (Kathawala and Abdou, 2003). The points emphasized in each definition mainly depend on the background and the research area. Below are some examples of definitions made by the researchers in the SCM literature:

"SCM *covers the flow of goods from supplier through manufacturing and distribution channels to end user." (Oliver and Webber, 1982)*

"SCM is a single entity that aims at satisfying the needs and wants of the customer and eventually the ultimate customer" (Lambert, 1992)

"SCM *is an integrating philosophy to manage the total flow of a distribution channel from supplier to ultimate customers." (Ellram and Cooper, 1993)*

"SCM is the integration of business processes from end user through original suppliers that provides products, services and information that add value to customers." (Cooper et. al. 1997)

"SCM *is the network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the eyes of the ultimate customer." (Christopher, 1998)*

"SCM is the management of close inter-firm relationships and that understanding that partnering is important in developing successful retail supply chain relationships." (Mentzer et. al., 2000)

"SCM is a business philosophy that strives to integrate the different business activities of companies in a marketing channel." (Svensson, 2002)

"SCM is the management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction." (Stock and Boyer, 2009)

Although the definitions are all related, there is no consensus on one definition. There are different emphases in the definitions such as: flows of products, services, finances and information, customer satisfaction, distribution channels, organisation networks, inter-firm relationships, and marketing channels. Early SCM definitions only included materials flows, but over the past years the SCM definition expanded to cover services, financial and information flows, networks of relationships, maximizing profitability, adding value, and customer satisfaction. Similarly, early definitions typically only considered external networks however the latest definitions cover both internal and external networks (Stock and Boyer, 2009). Despite these changes, there are still differences in the definitions. According to the comprehensive literature review on the definitions of SCM conducted by Stock and Boyer (2009), some definitions concentrate on supply chain participants and activities whilst others place emphasis on material flows and inter-organizational collaboration. Some authors include end users in their definitions while others exclude them.

In early definitions, the term SCM was used synonymously with traditional definitions of logistics management. However, today SCM is defined to be more than logistics (Johnson and Wood, 1996; Lambert et al., 1998 a,b). From the early days of supply chain management activities, SCM has included certain effects from various disciplines such as operations management, purchasing, logistics and transportation, marketing/services, strategy, psychology/sociology, organizational behavior, finance/economics, information/communication (Burgess et al., 2006; Hobbs, 1996; Giunipero et al., 2008). The following activities are defined as the main interests of SCM:

- Arrangement of suppliers' products and services;
- Networks for efficient management of demand and flow of products and services;

- A philosophy for conducting the business; and
- A strategy to gain competitive advantage through the co-ordination and synchronization of actions of its members (Chandra and Kumar, 2000).

In the light of the presented activities and the supporting disciplines; the supply chain definition which best describes the whole phenomena is the one provided by the Council of Logistics Management and one of the latest definitions of SCM which is provided by Stock and Boyer, (2009). The SCM definition adopted in this thesis is defined as follows:

"SCM is the systematic strategic management and coordination of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, achieving customer satisfaction and improving the long term performance of the individual companies and the supply chain as a whole."

2.3 Evolution Of Supply Chain Management

The following developments in SCM have taken place starting from the 1960s up to the present (Chandra and Kumar, 2000; New and Westbrook, 2004; Blanchard, 2010).

- During 1960 to 1975, organisations were vertically aligned and the function was the main focus of optimization. Relationships with vendors were mainly winning-lose interactions.
- Starting from 1975, the benefit of interaction of functions as design and production was realized by many organisations. This awareness helped the quality theories such as TQM (Total Quality Management) to be developed.
- With the rapidly changing business environment, SCM was first used in its popular sense by Oliver and Weber in the early 1980s.
- In the early 1980s, the concepts of transportation, distribution, and materials management started to combine into a term called `supply chain management`. In 1985, Harvard University Professor Michael Porter`s book, Competitive Advantage, presented how to create a more profitable organization by analysing the five primary processes of supply chain as follows:

  - Inbound Logistics: These are the activities related with receiving, storing and disseminating inputs to the product (material handling, warehousing, inventory control)
  - Operations: Activities associated with transforming inputs into the final product form (machining, packaging, assembly, testing, and facility operations).
  - Outbound Logistics: These are the activities associated with collecting, storing, and distributing to customers.
  - Sales and Marketing: Activities which enable buyers to purchase products.
  - Service: Activities associated with providing service to keep the value of the end product.
- By 1990, the structures of the organisations needed to change due to harsh national and international competition. SCM has been of substantial importance in the business environment. The following changes can be regarded as the developments that created change within supply chain management.
  - To become more competitive, organisations have started to investigate their supply chains. Organisations started to align with processes therefore their structures were no longer vertical.
  - The most important impact was the invention of the Internet and other IT (Information Technologies) that are used within organisations. This was a great change for the nature of the business environment since it was a benefit in every process in an organisation from the design or manufacturing to the organisational communication.
  - Customer satisfaction has become an important focus for organisations.
  - The reliance on purchased materials has increased and the information sharing with the vendors and customers has increased with a simultaneous reduction in the number of suppliers.
  - Customized production has become an important solution for the customers rather than mass production.

There has also been a change within organisations as employee empowerment has become an important solution for more flexibility in processes and organisations. Despite the fact supply chain management entered the public awareness nearly 40 years ago, only a very small number of companies fully embraced the concept (Blanchard, 2010). The Latham

(1994) and Egan (1998) reports created awareness on strategic issues of SCM in construction. The Egan report recommended the adoption of the following features of SCM (Pryke, 2009):

- Acquisition of new suppliers through value based sourcing;
- Organisation and management of the supply chain to maximise innovation, learning and efficiency;
- Supplier development and measurement of suppliers` performance;
- Management of workload to match capacity of suppliers to improve performance; and
- Capture of suppliers` innovations in components and systems.

Effective implementation of SCM has helped various industries to improve their competitiveness in an increasingly global market place. Compared to construction industry, within aerospace, manufacturing and retail industries, there is a certain repeated process for manufacturing or purchasing. However, the construction industry lacks standardization and in very recent years there is an increasing trend for building construction projects with offsite manufactured and standardized products where SCM plays a key role for improving the product quality and process efficiency.

2.4 SCM Philosophy

According to Mentzer et al. (2001), the definitions of SCM can be classified into three main categories: a management philosophy, implementation of a management philosophy, and a set of management processes. SCM philosophy boundaries cover different functions in a firm within a supply chain to create customer value and satisfaction. Mentzer (2001a) proposed SCM as a management philosophy with the following characteristics:

- A systems approach to viewing the channel as a whole, and to managing the total flow of goods inventory from the supplier to the ultimate customer;
- A strategic orientation toward cooperative efforts to synchronize and converge intra-firm and inter-firm operational and strategic capabilities into a unified whole and;
- A customer focus to create unique and individualized sources of customer value, leading to customer satisfaction.

For the adoption of a supply chain management philosophy, firms must establish management practices which enable them to act consistently with the philosophy. Previous research suggested the following activities to implement an SCM philosophy successfully (Mentzer, 2001a):

- Integrated Behaviour;
- Mutually sharing information and knowledge;
- Mutually sharing channel risks and rewards;
- Cooperation and coordination;
- The same goal and the same focus of serving customers;
- Integration of processes; and
- Partners to build and maintain long-term relationships.

The conceptual and philosophical complexity of SCM urges the need to study the current management issues of SCM to clarify how and why different supply chain management arrangements emerge and for understanding the consequences of these arrangements for industry efficiency and competitiveness. In the following section, the current management issues that influence construction supply chains are presented.

2.5 Current Management Issues Of Construction Supply Chain Management

2.5.1 Overview of Construction Supply Chain Management

Construction Supply Chain Management (SCM) can be generally defined as managing the process of information flow, financial flows, materials, activities, tasks and processes involved within various networks and linkages (upstream and downstream) of organisations in order to develop high quality construction products and services to clients in an efficient manner (Akintoye et al., 2000; Tucker et al. 2001). SCM in construction includes principal contractors, sub-contractors, suppliers, and distributors. The network of suppliers in the construction sector can be extremely complex, generally on larger projects the number of supplier organisations can be many hundreds (Dainty et al., 2001). As a consequence of such a complex environment with thousands of actors, Supply Chain Management becomes an emerging concept in the construction industry.

The main roles of SCM are directing operations to link successive operating stages through product flow; and transforming these operating stages into a single cohesive unit by co-ordinating and controlling internal actions within these stages (Tucker et al., 2001). The upstream of construction SCM is in relation to the position of a main contractor consisting of the activities and tasks leading to preparation of the production on site involving construction clients and design team. The design team includes the architects, M&E Designers, structural engineers and specialist consultants. The downstream consists of activities and tasks in the delivery of construction product involving construction suppliers, subcontractors, and specialist contractors in relation to the main contractor. Downstream is believed to be the weaker link and needs to be improved if the full potential of SCM is to be realised (Akintoye et al., 2000). A case study in SMEs in the construction industry, carried out by Dainty et al. (2001) revealed that although there is a growing interest in supply chain integration in the upstream of construction, the downstream has important supply chain problems. Moreover, the flow of knowledge within both the downstream and upstream of supply chains is a critical issue in the construction supply chain. There is a heavy reliance on information and knowledge management to co-ordinate the supply chain (Tucker et al., 2001). As a result, information management becomes the heart of construction SCM.

A construction project includes various processes through the project lifecycle as procurement, planning, design, manufacture, construction, and facility management of buildings and other structures (Ireland, 2004). Therefore, cross-discipline co-ordination and information exchange are crucial for these multidisciplinary collaborative processes (Aouad et al., 2002). However, in reality, the construction industry has many short-comings such as: being fragmented; lacking co-ordination and communication between organisations; poor collaboration, adversarial contractual relationships, lacking client focus; poor information flows within construction supply chains; disjointed supply relationships; fragmented supply chain structure; and lack of trust between clients, main contractors and sub-contractors perceived low productivity; cost and time overruns; conflicts and disputes; and resulting claims and time-consuming litigation (Latham, 1994; Egan, 1998; Tucker et. al., 2001; Chan et al., 2003; Love et al., 2005; Fearne and Fowler, 2006). Evbuomwan and Anumba (1998) defined some of the consequences of the fragmentation problem as follows:

- inadequate capture, evaluation and implementation of client needs;
- the fragmentation of design, fabrication and construction data, with data generated at one specific location not being readily re-used within various business units and projects;

- development of sub-optimal design solutions;
- lack of integration, co-ordination and collaboration within the supply chain throughout the life-cycle of the project; and
- poor communication of design information, which results in design changes, inadequate design specifications, unnecessary liability claims, and increases in project time and cost.

Besides the fragmentation problems, the culture in construction supply chains is a serious issue. The culture is mainly based on price competition and organisational contractual arrangements depending on the complexity of projects (Saad et al., 2002). Clients and construction organisations are generally project-focused, with a short-term perspective, emphasising competitive bidding as the main tool in contractors, sub-contractors and supplier evaluation. Consequently, customer-supplier relationships in construction are generally of the arms-length type rather than being strategic partnerships due to use of competitive tendering to procure projects. This assures that sub-contracting is provided by the lowest-price supplier with limited guarantee to future work. (Tucker et al., 2001) Therefore, the industry is characterised by project-based contracts and fails to develop long-term constructive relationships between main contractors and key suppliers (Briscoe et al., 2001). All these shortcomings lead directly to inefficiencies in outcomes such as time and cost overruns, and low productivity, quality and customer satisfaction (Eriksson et al., 2008). However, in the UK, there are some improvements with the Partnerships Framework Agreements in these characteristics over the last few years. Partnering initiatives and multi-year construction contractor's framework agreements are indicators of strategies that aim to reduce the short-term strategies. Having a strategy that covers continuous FM service delivery, associated with better learning should increase the potential for having more loyal and long term clients for construction projects (Brochner, 2008). But these improvements are still in its developing stage and not enough to change these characteristics of the industry.

Apart from these, the construction supply chain is characterised by its generally unique product in every project, and repeated reconfiguration of project organisations for each project. This creates the instability, fragmentation and separation between the design and construction of the end product (Vrijhoef and Koskela, 2000). As a result of these, construction projects are treated as a series of sequential and fragmented operations where project members put very little effort for the long-term collaborative success of the resulting end-product (Briscoe and Dainty, 2005). Therefore, an application for this industry has to be flexible enough to accommodate project based supply chains efficiently (Titus and Brochner, 2005).

Construction supply chain is bombarded with initiatives trying to improve collaboration, integration, communication and coordination between customers and suppliers throughout the project supply chain (Akintoye et al., 2000; Vrijhoef and Koskela, 2000). To create awareness of these issues, the UK Government reports were generated. Egan (1998) and Latham (1994) reports identified the main bottlenecks of the construction industry and highlight the main barriers that are needed to be overcome for better integrated construction supply chains. These reports both suggest that the industry could achieve expected improvement through teamwork at the organizational level between the parties including clients, suppliers, designers. Recommendations within these reports facilitated the use of long-term/strategic arrangements, partnering, joint venture, public private partnerships, prime contracting and supply chain management in order to improve the construction project lifecycle (Akintoye and Main, 2007). However, the main barriers are still valid and there is an existing need for change in construction supply chains in order to be more efficient and effective (Fearne and Fowler, 2006). Construction does not have a systematic and strategic approach to change the effects of the cumulative and evolutionary aspect of SCM relationships (Saad et al., 2002). The culture in construction impedes innovation and increases complexity making the construction industry a slow adopter of supply chain information strategies (Titus and Brochner, 2005).

Based on a detailed literature review, recent trends in procurement strategy, SCM integration, collaboration and communication, partnering, trust, skill deficiencies, innovative thinking and KM are considered as the main issues that needs detailed investigation.

2.5.2 Recent Trends in Construction Procurement Strategy

In the UK, the private sector currently delivers public sector construction facilities and services with the use of the Private Finance Initiative (PFI) type contracts. In other countries, the use of project financing like Build Operate Transfer (BOT) is recognized as an important way of delivering public sector infrastructure projects like transportation and water resources. These innovative procurement methods demand higher level of collaboration between the clients (public sector), contractors and rest of the project team (Akintoye and Main, 2007).

Collaborative types of procurement methods such as Pubic Private Partnerships (PPP) and Framework Agreements tend to be achieved by larger contractors due to the complexity and size of the project. SMEs are not able to deliver these types of projects due to resources and procurement arrangements (Akintoye and Main, 2007)

In the traditional procurement method, the design phase is carried out by the architect, and design team who work directly for the client. Within the new procurement routes, the client only holds a contractual relationship with the main party (design and construct contractor) responsible for both design and construction (Joint Contracts Tribunal, 2007). An integrated procurement route ensures that design, construction, operation and maintenance are considered as a whole; it also ensures that the delivery team work together as an integrated project team (Procurement and Contract Strategies, 2007). Such configuration creates a collaborative working environment where architect, engineer and contractor influence each other in terms of their responsibilities, tasks and communication with the client, the users, the team and other stakeholders (Sebastian, 2010).

The transition from traditional to new integrated procurement methods requires a change in the mindset of the whole supply chain. Client and contractor`s collaboration and effectiveness of integrated collaboration is essential to organize innovative tendering procedures and deliver the overall project successfully (Sebastian et al., 2009).

A new dimension emerges when an architect works in a partnership with the contractor instead of the client. The most important benefit is realization of architectural concerns with an innovative engineering through an efficient construction process. In another way, an architect can be employed by the client with an advisory role instead of being the designer. In this case, the architect's only responsibility is translating client's requirements and aspirations into the architectural values to be included in the design specification, and evaluating the contractor's technical proposal against client requirements. In both cases, the architect holds the responsibilities as design team facilitator working collaboratively with contractor and client to achieve the requirements for both parties (Sebastian, 2010).

In certain countries, stronger relations between construction and facilities management (FM) have been raised through government policies similar to the UK Private Finance Initiative (PFI) contracts where design, construction, finance and operation of projects are integrated (Bennett and Iossa, 2006; Baldwin, 2003). An interesting study conducted by (Brochner, 2008) showed clearly that contractors engaged in facilities management were more innovative compared to traditional contractors without an FM business. They are more active in identifying and exploiting business opportunities and also tend to integrate upstream supply chain. Contractors who have FM services have more innovative and educated personnel compared to non-FM contractors (Brochner, 2008) due to experiences in completion of a project from the design or construction phases to operational phase.

2.5.2.1 Supply Chain Integration

SC integration has been key for supply chain management since the 1980s. SC integration is "attempting to elevate linkages within each component of the chain, to facilitate better decision making and to get all the pieces of the chain to interact in a more efficient way" (Putzger, 1998). The content of supply chain integration can be classified as follows: integration of flows (physical, information, financial), integration of processes and activities, integration of technologies and systems and integration of people (structures and organizations) (Fabbe-Costes and Jahre, 2007).

SC integration has been widely discussed and supported on an empirical basis in the literature which revealed out that the higher the level of integration the higher the operational and business performance of a firm (Cagliano et al., 2006). Although SC integration has direct links with the business performance of firms in the supply chain, the level of integration in construction supply stays as one of the major problems of the construction industry (Akintoye et al., 2000). The construction industry is defined as one of the least integrated of all major industrial sectors (Fearne and Fowler, 2006). The key barriers to integration originate from the historical fragmentation of project delivery systems, the adversarial culture of construction projects, and the disjointed relationships (Dainty et al., 2001; Fearne and Fowler, 2006). Fragmented and a largely sub-contracted workforce has increased the complexity of the construction supply chain and disabled the process integration (Briscoe and Dainty, 2005). Single project focus and the prevalence of competitive tendering procedures used in the sector has also been a barrier for supply chain integration (Dubois and Gadde, 2000). Moreover, the relationships between the contractors and sub-contractors are lack of trust and heavily based on price and competitive bidding (Dainty et al., 2001). In this context, the downstream of construction does not have longstanding, efficient supplier-contractor relationships (Akintoye et al., 2000). A case study in SMEs of construction industry, performed by Dainty et al. (2001) revealed that although there is a growing interest in the integration of the upstream of construction supply chain, there is a lack of interest and development in the integration of downstream suppliers to construction supply chains. Barriers to downstream SC integration are defined as; late and incorrect payments, unrealistic project planning; traditional contracts which do not endanger good working relationships; lack of encouragement on sub-contractor integration in the main contractor organisations, lack of knowledge and information sharing, lack of long term partnerships, lack of skills relating to design, legislation and costing and lack of fair treatment on sub-contractors by the main contractors (Dainty et al., 2001).

For successful integration of supply chain, timely information exchange and communication throughout the supply chain is defined as essential, specifically through early involvement of the actors, for example contractors, sub-contractors and engineers (Love et al., 2004). Regarding the design-construction integration, greater involvement of contractors in the specification stage is required (Akintoye et al., 2000). According to Akintoye et al. (2000), early engagement of contractors and suppliers early in the design phase decreases the risks of buildability issues and increases the integration of work and knowledge exchange. Bankvall et al, (2010) summarised the rest of the main improvements for successful integration as:

- the development of effective ICT systems for dissemination of information;
- the use of standards for alignment of systems, quality assurance and innovation as well as risk reduction;
- developing solutions based on more pre-assembly would increase efficiency;
- co-ordinated working and development of close relationships;
- trust and mutual understanding are emphasised as necessary preconditions when close relationships are built.

Although developing closer relationships and achieving SC integration are apparently difficult to realise in practice (Briscoe and Dainty, 2005), the construction literature seems to agree upon “supply chain integration” being the core task of SCM in construction (Bankvall et al., 2010) and the key to solve the problems caused by fragmentation (Dainty et al., 2001b). However, due to the multi-disciplinary nature of construction industry, supply chain integration needs a holistic and systematic view which can review and improve the integration of flows (physical, financial, information and knowledge), integration of processes and activities, integration of technologies and systems and integration of people.

2.5.2.2 Collaboration and Communication

Collaboration refers to the co-operative supply chain relationships forged, both formally and informally, directly and indirectly among organizations, supply chain partners, and customers to enhance business operations (Blanchard, 2007). Collaboration has a significant impact on project performance in terms of time, cost and quality objectives and also improves innovation with improved client satisfaction (Akintoye and Main, 2007). Improving construction supply chain collaboration and performance is central for achieving short-term business objectives and long-term competitive advantage (Eriksson, 2010).

Collaborative supply chain management involves a synergistic work environment wherein the supply chain actors work together toward the enhancement of supply chain practices and processes (Vanvactor, 2011). It can also create a common understanding of vision, values, and business purposes amongst supply chain actors (Atchison and Bujak, 2001). Therefore, collaboration can be defined as the main element which can enable and enhance integration of flows (physical, financial, information and knowledge), integration of processes and activities, integration of technologies and systems and integration of people.

The use of collaboration to deliver construction projects involves various parties in the construction industry. This can be achieved by effective communication supply chain actors. Communication is the most important aspect of multidisciplinary collaboration. Apart from enhancing collaboration, effective communication between supply chain actors brings benefits such as saving construction time, reducing cost (Anumba et al., 2008). In an integrated construction process, the project team not only needs to share project information and knowledge, but also needs to share the rationale of decision making so that everyone understands why certain decisions are made and their implications for others (Aouad et al., 2002). Thus, collaboration requires adequate information and knowledge flow and communication among the collaborating organizations and reliable access to the latest technological and management knowledge (Yashiro, 1996). Apart from this, mutual benefits, risk sharing agreements, reward for collaborating, trust, ICT technologies are defined as the other key elements of collaboration (Barrat, 2004; Mason, 2007; Shelbourn et al., 2007).

Akintoye and Main (2007) define the most important factors for unsuccessful collaboration in construction industry as collaborating parties' failure to contribute to the common needs, goals and objectives. This is followed by lack of trust between the parties, lack of frequent consultation and undefined roles and responsibilities. Apart from this, fragmented and multidisciplinary nature of construction industry, fast-track construction by overlapping the design and construction and further reliance on sub-contractors affect the collaboration process negatively (Baldwin et al., 1998). Much of the recent work undertaken on collaboration in construction literature has focused on the delivery of technological solutions with a focus on web, CAD, and knowledge management technologies. However, recently it is recognized that collaboration is a result of a holistic approach on the organizational people issues and information technology. In summary, the planning and implementing of "effective" collaboration is still in its early stages of widespread adoption within the construction industry (Shelbourn et al., 2007).

2.5.2.3 Partnering

Partnering has increased in recent years as an alternative approach to traditional procurement methods (Xie, 2010). Partnering aims to increase co-operation, communication, collaboration and integration between parties by building trust and commitment while decreasing conflicts and disputes (Eriksson, 2007; Xie, 2010). Egan (1998) defined partnering as; "the involvement of two or more organisations working together to improve performance through agreeing mutual objectives, deriving a way of resolving any disputes and committing themselves to continuous improvement, measuring progress and sharing the gains". In other words, partnering can be viewed as a relationship between organisations committed to common objectives and benefits to increase the overall performance of each organisation. A case study by Fernie and Thorpe (2007) revealed that SCM is considered to be synonymous with partnering by many practitioners within construction organisations. However, it can be concluded that partnering is an important subset of supply chain management.

One of the most important problems of the construction supply chain is the lack of partnering within the downstream relationships. In current construction supply chains, partnering is mainly focused on only developing collaboration in upstream relationships between regular and frequent clients, consultants and contractors (Edum-Fotwe et al., 2001). Moreover, the aspects of context as workload continuity, and legitimacy of short term thinking impedes the partnering opportunities (Fernie and Thorpe, 2007). The lack of trust in the industry is another barrier to create partnerships. Although it was stated that even in the absence of trust, partnerships can be initiated and integrated (Sahay, 2003), this kind of partnership will be open to conflicts and may easily end when the project is completed.

Because of this distrust culture, many sub-contractors who had not previously had partnering agreements were very sceptical that such an arrangement could succeed (Briscoe et al., 2001).

The construction industry is based on high degree of competitive bidding amongst its many different suppliers instead of having relationships based on common goals and benefits (Briscoe et al., 2001). However as stated in Egan's report (1998), partnering is more than selecting the lowest price. Instead, it implies the selection on the basis of attitude to team-working, ability to innovate, and to offer efficient solutions. Recent research studies show that partnering can improve the following areas: quality, safety performance, sustainability, dispute resolution, human resource management, innovation, as well as time and cost reductions (Barlow et al., 1997; Egan, 1998; Chan et al., 2003). The benefits of partnerships in supply chains can be explained as; full communication with partners; collaborative working rather than trying to take advantage; knowledge sharing; straight talking with no hidden agendas; rapid responses to queries; enabling partners to perform teamwork and interdependence; seeking continuous improvement through co-operation; willingness to change to accommodate partners; profit sharing on a ‘‘win–win’’ basis; risk sharing; and common interest in providing client satisfaction (Briscoe et al., 2001; Xie, 2010). This approach to partnerships clarifies that relationships should extend beyond the exchange of materials or services for a price and proves that partnering has a significant potential for better SCM.

2.5.2.4 Trust

Trust, being one of the most complex issues of construction supply chains, is a major requirement for successful SCM. However, in the construction industry, it is negatively affected by many factors such as lack of honest communications and reliability, and the problems in the delivery of the project (Khalfan et al., 2007). Especially the relationship of SMEs with their potential partners suffers from a basic lack of trust. The degree of distrust is significantly high on financial issues. Especially, in the situation that the main contractors systematically take advantage of the financially weaker SMEs in withholding monies that were due for payment, distrust is unavoidable (Briscoe et al., 2001).

To implement successful SCM in construction is only possible when a trust culture if flourished within the supply chain actors. Khalfan et al. (2007) explains the ways to build trust as: sharing goals; having experience of working together; solving problems together; rewarding culture on trusted behaviours; fair working and reasonable behaviours in work environment. It can be concluded that a strategy to create collaborative working environment and appropriate training and education at all levels of the industry will be helpful to change this distrust culture (Akintoye et al., 2000).

2.5.2.5 Skills Deficiency and Attitude Change

As defined earlier, construction projects consist of huge number of different organisations from different disciplines. These organisations have to work together to complete a project over a long period. For effective communication between these organisations, the skills of interacting organisations should be compatible. There is a clear need to find out more about what skills already exist in the construction supply chain and how these might be improved to facilitate successful partnering in the 21st century (Briscoe et. al., 2001).

The barriers of SCM in construction industry show that there is a demand to change for a better integrated construction industry. A cultural change within the industry may only be possible when the skills of the industry are assessed and a training strategy developed for the skill improvement. Especially the interpersonal skills, customer care, team building, business knowledge and IT skills are the deficiencies that should be developed in the construction industry (Dainty et al., 2001). As long as these skills are developed and the culture is changed, partnering, long term relationships and better integration of construction SCM will be more achievable.

2.5.2.6 Innovative Thinking

The Egan Report (1998) highlighted the importance of innovation within the industry, and proposed that continuous service, product improvement, and profitability can only be achieved through innovation. Ling (2003) defined innovation in construction as the implementation of a new idea to a construction project with the intention of deriving additional benefits, although there might be some associated risks and uncertainties. In the construction industry, innovation has been recognized in three domains: product, process, and organisation. However, innovation in construction is dominantly seen in terms of product, or design innovation. On the other hand, the strategic priority areas in construction as supply chain integration are not only the issues of design (Stewart and Fenn, 2006). For example, innovative procurement initiatives in supply chains can promote the collaborative culture, long term relationships, team work, transparency, visibility of the future work with the existing clients and have potential to overcome the problems of construction supply chains (Khalfan and McDermott, 2006). Despite the fact that there is a growing interest in innovation in construction supply chain process, it is still at the developing stage. The adversarial culture firstly created by the clients and transferred through the main contractors to sub-contractors is a strong barrier to innovation (Smyth, 2005). Knowledge can be regarded as a vital organisational resource and stays at the heart of innovation. However the lack of knowledge sharing culture impedes innovation in construction (Anumba et al. 2005).

2.5.2.7 Knowledge Management

A critical issue in SCM is the effective management of knowledge through the project lifecycle. This involves the flow of knowledge within and between different sectors of construction supply chain as well as the accumulation, coding, and storage of knowledge in the organizations. There is a heavy reliance on KM to manage the supply chain (Tucker et. al., 2001). As a result, KM becomes the heart of construction SCM.

A typical construction project involves various tasks which are divided between professional and trade disciplines (Love et al., 2005; Turner and Muller, 2003). There are numerous distinct organisations working in a collaborative environment over long periods. The documents shared between these organizations vary from technical drawings and legal contracts to purchase orders, project reports, and schedules (Titus and Brochner, 2005). Within such a complex environment, information and knowledge flow and sharing is the backbone of effective communication of supply chain actors.

The large number of organisations in construction and their complexity make it difficult to facilitate fluent knowledge flow and sharing (Titus and Brochner, 2005). Construction organisations have an unwillingness to rationalise their supplier and client bases and share knowledge and information within their supply chains (Saad et al., 2002). Besides the tendency to keep knowledge, the nature of the construction projects is also a disadvantage for the knowledge sharing. Construction projects usually consist of temporarily designed teams from different organisations to produce a unique product. These team members are generally new to each other and have not necessarily worked together before. Thus, it is difficult to set up channels to exchange information and knowledge. In addition, lack of common goals make project participants focus only in their part and ignore the knowledge needs of their partners (Titus and Brochner, 2005). The commitment of participants to contribute to both individual and common benefits is the first step of knowledge sharing

(Simatupang and Sridharan, 2004). Moreover, because the organisations in construction industry come from different disciplines, the shared information and knowledge may not have the same meaning for the supply chain partners (Love et al., 2005).

Because there are numerous documents in different formats that need to be shared between the organisations of different disciplines, the use of Information & Communication Technology (ICT), the tools for data and information creation and the collaboration technologies are important elements in knowledge management and supply chain integration. ICT and collaboration technologies create a platform to share information in order to improve supply chain performance among all of the players. However, in construction the effectiveness of these technologies in a construction project is hindered by inability to share data in an electronic form between partners (Mohamed, 2003). According to FIATECH, Fully Integrated and Automated Technology (2011), in construction industry:

- It is difficult to access accurate data, information, and knowledge in a timely manner in every phase of the construction project lifecycle.
- There is a lack of interoperability between systems, with several standards competing for managing data. A common methodology for managing construction projects' information assets does not exist.
- Program plans and designs are optimized for a limited set of parameters in a limited domain. The capability to support ‘‘total best value” decisions do not exist.
- Tools for project planning and enterprise management are maturing, but an integrated and scalable solution that delivers all needed functionalities for any kind of projects is not available.
- Lifecycle issues are not well understood and therefore modelling and planning do not effectively take all lifecycle aspects into account. Operation, maintenance, environmental impact, and end-of-life disposal issues are given limited consideration in the project planning equation.
- The ability to assess uncertainties, risks, and the impact of failures is not mature, partly due to the lack of knowledge to support these evaluations, and partly due to the limitations of available tools.
- The business foundation for addressing increased security concerns does not exist, and the ability to address these issues is limited by the lack of understanding of the risks and alternatives.

Despite these challenges Building Information Modelling (BIM) is increasingly used as an ICT support in complex building projects. Because BIM seeks to integrate processes throughout the entire lifecycle (Aouad and Arayici, 2010), it is a potential source for construction supply chain integration. An effective multidisciplinary collaboration supported by an optimal use of BIM requires changing roles of the clients, architects, and contractors; new contractual relationships; and re-organized collaborative processes. Unfortunately, there are still gaps in the practical knowledge on how to manage the building actors to collaborate effectively in their changing roles, and to develop and utilize BIM as an optimal ICT support of the collaboration (Sebastian, 2010). Although BIM has existed for over 20 years, it is only over the last few years that building owners are becoming aware that BIM promises to make the design, construction and operation of buildings much more streamlined and efficient (Coates et al., 2010). The main challenges for BIM in construction industry are defined as (Arayici et al., 2009 a,b; Eastman et al., 2008):

- overcoming the resistance to change, and getting people to understand the potential and the value of BIM over 2D drafting;
- adapting existing workflows to lean oriented processes;
- training people in BIM, or finding employees who understand BIM;
- the understanding of the required high-end hardware resources and networking facilities to run BIM applications and tools efficiently;
- the required collaboration, integration and interoperability between the
- structural and the MEP designers/ engineers; and
- clear understanding of the responsibilities of different stakeholders in the new
- process by construction lawyers and insurers

2.5.3 Chapter Summary

In this chapter, the supply chain management as a whole concept and the philosophical basis of SCM were discussed. Following this, the current management issues of construction supply chain are clarified. The main problems of construction supply chain mainly come from the characteristics of the industry. Lack of strategic risk sharing partnerships, distrust culture between partners, and fragmented supply chains create huge problems for the construction industry parties. Since a typical construction project is one-of-a-kind, temporary, and involves different kinds of tasks which are distributed between different organisations, knowledge flows between and within these organisations have a very critical impact in terms of projects success and delivery. However, there is insufficient knowledge transfer within and between organisations. The main reasons of these are, unwillingness to share knowledge, lack of commitment in common goals and objectives between actors of supply chain, and the adversarial culture of the construction industry. One of the consequences of insufficient information and knowledge sharing is the problems in communication and collaboration in construction projects. Inefficient knowledge sharing and communication prevents the innovation required for value adding and competitive advantage. Although the innovation is an emerging topic in construction and many other industries, it is still in its development phase.

As a consequence of the review of the construction literature, it can be concluded that improvement in knowledge flows within the supply chains and the change in adversarial culture will have a great impact in reducing waste and costs, increasing quality and performance of the construction supply chains. In the next Chapter, the automotive and aerospace industries are investigated to identify best practices for construction supply chains.

CHAPTER 3

3 SUPPLY CHAIN MANAGEMENT ISSUES OF OTHER INDUSTRIES

3.1 Introduction

This Chapter investigates the SCM issues in other industry sectors. The main purpose of selecting other industries are to learn about the current SCM trends, improvements and failures which can be useful to understand the issues of the construction industry, and to identify best practices for construction industry. For this purpose two capital and technology intensive industries, automotive and aerospace industries are investigated. These industries are selected in particular because both have engineering design, production (manufacturing) and maintenance phases similar to construction industry, however they are more mature in SCM applications. Latham (1994) and Egan (1998) highlighted the inefficiency of the construction industry and suggested that the construction industry needs to reflect the lessons learnt from the manufacturing industry to provide a satisfactory product and meet client requests. Furthermore, Fernie et al. (2001) discussed the structural differences between construction and aerospace sectors and its significant impact on supply chain management approaches.

3.2 Automotive Industry

The automobile industry is defined as one of the more active in developing supply chains and manufacturer-supplier networks (Pérez and Sánchez, 2001). In today's tough economy, the competition among large corporations has long been extended to the competition among players in automotive supply chains. This implied the supply chain management as a critical area in operations management and a decisive factor for the success or survival of the automobile manufacturers (Xia and Tang, 2011).

The infrastructure of the automotive industry is unique and complicated; both product quality and differentiation are the fundamental challenges for automotive companies (Wei and Chen, 2008). The automotive industry today is characterised by customer ordered production which means that production planning is based upon the wishes of the customer (“pull”, build-to-order) instead of the possibilities of the car maker (“push”, build-to-stock)

(Miemczyk and Howard, 2008). This made the automotive manufacturers very competitive in the past years. Many automotive companies are renewing their model lines to enlarge their customer base; however, the growth in demand remains very limited. Increasing customer requirements as a result of improved market transparency, availability of information and products aggravate the market. Due to enormous competition many automotive manufacturers and retailers in Europe need to develop strategies to stay competitive and continuously improve their market position (Godlevskaja et al., 2011). This competition brings the need for continuous product and process improvement and differentiation for the automotive manufacturers. These challenges implied low cost manufacturing, high quality products, technological complexity, short product life cycles, quick delivery times and small buffers of assets or time lags (Lambrechts, 2010).

In the current business situation, many traditional auto manufacturers struggle to survive the financial and economic crises while they have to meet explosive demand growth in new geographic regions and manage increasingly complex SCs, changing customer preferences, and evolving production changes. The pull of customer demand from developing regions has fuelled new competitive business strategies by many western automotive manufacturers who wish to enter new growing and profitable markets (Liao et al., 2011). Besides these, because product-based differentiation in the automotive industry is increasingly difficult, many automotive companies expanded their business to the service area to recover from the difficulties in product and process differentiation (Hovarth and Partners, 2007). Continuous expansion of market and the business brought the necessity of innovation for the automotive industry. This is why the automotive industry is leading innovation around the world. According to European Automobile Manufacturers Association (ACEA, 2010), the industry invests 26 billion in R&D; generates more than 500 billion and it is a large export industry (ACEA, 2010).

3.2.1 Challenges Of Automotive Industry

As a result of the evolution in industrial production, for the past several years, the automotive industry has undergone significant technical and organisational change challenges in the competitive world market that have affected supply chain design for many organizations. These changes include (Xia and Tang, 2011; Womack et al., 1990; Morris et al., 2004):

- globalization produced longer lead times in production;

- traditional methods of production have largely been replaced by various hybrids of Japanese lean production methods;
- reduction of costs for products and transportation that leads organizations to take the advantage of economics of scales by shipping large quantities of products from overseas that in turn, leads to increase in logistics costs and large inventory;
- long and geographically diverse supply chain that exposes to numerous threats of disruption and risks;
- due to interdependency between assemblers and suppliers, relationships embraced innovations in design and technology, creative research and development and quality improvement;
- significant increase of labour costs in developing countries (for example 20 percent increase in China vs 3 percent increase in the USA) that shrinks labour cost savings in these emerging entities overtime;
- change in regulations requires companies to consider the amount of carbon emission the supply chain produces that leads organizations to focus on green supply chain and long-term sustainability;
- volatility of commodity prices (for example coal, gold, oil, steel) that causes changes in procurement of commodity (long-term vs. short-term commitment) in the markets; and
- due to the rapid changes the market demand of automobile becomes much more uncertain, which increases the bullwhip effect in the auto supply chain and causes a tremendous amount of waste in purchasing and inventory.

For a better understating on these challenges, the developments such as lean production, just in time production, modularisation, outsourcing, supplier parks, SC relationships and collaboration issues, sustainability, globalization effects are discussed in the following section since these issues have been highly addressed in the relevant literature.

3.2.2 Lean Manufacturing/Production

Lean manufacturing/production was first used by Womack et al. (1990) and described as a way of thinking, and the whole system approach that creates a culture in an organization based on continuous improvement in operations. Lean can be considered as manufacturing without waste which can be classified as (Taj and Berro, 2006):

- Motion: movement of people that does not add value.
- Waiting: idle time created when material, information, people or equipment is not ready.
- Correction: work that contains defects, errors, rework, mistakes or lacks something necessary.
- Over-processing: effort that adds no value from the customer's viewpoint.
- Over-production: producing more than the customer needs right now.
- Transportation: movement of product that does not add value.
- Inventory: more materials, parts or products on hand than the customer needs.
- Knowledge: people doing the work are not confident about the best way to perform tasks.

Some authors base the lean approach on Henry Ford’s approach on Ford’s production (Ohno, 1988; Womack et al., 1990; Womack and Jones, 1996), and some even go earlier in history and considers the British automaker Morris Motors Ltd or the pioneering work of Frank G. Woollard as possible influences on Toyota Motor Corporation particularly in its formative years (1933-1950) (Emiliani and Seymour, 2011). According to Emiliani and Seymour (2011), Woollard's work significantly expands the understanding of progressive management practices in the British automotive industry in 1920s, and also informs new contributions that may have helped shape today's practice of lean management. Basically Woollard's work was on achieving flow in processes upstream of final automobile assembly, principally to reduce queue time and to produce a greater output from a fixed quantity of resources, to support the rapid sales growth and to reduce the costs associated with raw material and finished goods inventories. On the other hand, it is stated that lean thinking as a term inspired by practices at Toyota (Womack and Jones, 1996). Toyota’s Production System (TPS) is recognized with distinctive characteristics such as work cells, part families, standardized work, just in time production, zero inventory, supermarkets, automation, tact/cycle time, quick change-over, multi-skilled workers, arranging the equipment in the sequence in which value is added (Emiliani and Seymour, 2011). TPS has a big impact on the organization of the automotive supply chain and delivery of the processes in the supply chain. As a result of these developments, the decade of 1990s was witness to many transformation of traditional manufacturing into a lean approach (Taj and Berro, 2006). Although a lean approach in the automotive industry drastically improved efficiency in the automotive supply chain, recently, there are some criticisms on this approach. According to Doran (2005), the main criticism is on the inability of the lean approach to operate within non-stable demand conditions. Instead of lean approach, flexible/agile operations which can be quickly reconfigured to reflect non-stable demand conditions is suggested as a more efficient approach. The "agile" supply chain is defined as a chain capable of reading and responding to real market demand (Christopher, 2000). According to the author, the development of supply responsiveness that aims to match supply chain capabilities with global market demands is a dominant theme in automotive supply chains today. Based on these discussions, it can be concluded that to keep lean and be agile at the same time will be the next challenge for the automotive supply chains.

The lesson learnt for construction supply chain is to establish lean manufacturing philosophy and principles for production of construction materials and structural elements in order to improve the project delivery in terms of quality, speed and health and safety. The construction technology like offsite manufacturing and construction can be a good example for lean manufacturing and production in automotive industry.

3.2.3 Just in Sequence (JIS)-Just in Time (JIT)

Mass customisation and the reduction of inventory pose great challenges for automotive supply chain management (Wiengarten, 2010). A priority challenge for the industry is to develop demand-driven supply chains to quickly respond to changing consumer needs and expectations; however, the challenge of implementing such a strategy in the automotive industry is more involved due to the much larger quantity of parts involved, and the complexity of their supply chains (Wiengarten, 2010). All these challenges led the industry to move towards Just in Sequence (JIS) and Just in Time (JIT) supply. Just-in-time (JIT) supply chain produces and delivers goods just in time to be sold, sub-assemblies just in time to be assembled into finished goods, fabricated parts just in time to go into sub-assemblies, and purchased materials just in time to be transformed into fabricated parts (Schonberger and Gilbert, 1983) Similarly, JIS is the delivery of components in sequence to manufacturing as opposed to the traditional practice of delivering identical components in large batches (Wiengarten, 2010).

JIT and JIS are considered as a strategic part of the automotive industry, and JIT procurement and production systems continue to grow in number and importance (Matson, 2007; Waters-Fuller, 1995).

The lesson learnt for construction supply chain is how to make construction suppliers and subcontractors work closely with each other for just in time delivery of products and installation services. This requires the contractors to work collaboratively with the client in order to forecast the projects in the pipeline; to transfer the forecasted information to the suppliers on time; and to improve the suppliers' flexibility for on time delivery.

3.2.4 Modularisation

Since the 1990s, production methods have evolved to incorporate the concept of modularisation (Morris et al., 2004). Modularisation is the process of building a complex product or process from smaller subsystems that can be designed independently (Carliss et al., 1997). The move toward modules within the automotive sector has been influenced by a number of factors including declining profit per vehicle, shorter product life cycles and the increasingly sophisticated demands of consumers in global markets (Veloso and Kumar, 2002). As a result of these developments, design outsourcing and concurrent engineering became a critical component of competitive strategy. By allowing each member of the supply chain to focus on a key competency, the industry is reducing the cost and time required to develop new products. To compete in the competitive automotive market, manufacturers and their suppliers must design and produce modular products Christensen (2001). Modularisation often involves heavy outsourcing and requires the interchanging of modules such as platforms, engines, transmissions, cockpits and other key parts such as front and rear ends between models to reduce production costs and yet, at the same time, allow a diversity of models to be spun off from the same generic origins (Morris et al., 2004).

Increasing technological complexity has also led to recognition by the automotive assemblers that they do not necessarily have the knowledge and expertise to construct modern automotive entirely on their own and so modularisation and closer relationships with suppliers are required. A major feature of the modern car industry is that no one firm possesses all the substantive knowledge necessary to develop and produce the final product. The design of a new car can be characterised as a "knowledge immature" product whilst the major sub-assemblies are usually "knowledge mature" (Foss et al., 2000). The overall manufacture of a product in a situation where immature and mature elements are present requires a substantial degree of supply chain collaboration (Morris et al., 2004).

The lesson learnt for construction supply chain is to transform traditional construction methods into modularisation of structural elements, mechanical and electrical components and their installation.

3.2.5 Global Outsourcing

Global competition is evolving from enterprise-specific to supply chain-wide (Lambert and Cooper, 2002). Globalization led the automakers to secure a strategic wide global supply chain network (Liao and Hong, 2007). Most automakers react to the market by lowering purchase costs and outsourcing to low-cost countries. For example recently, Chrysler reduced 25% and Nissan reduced 5% of their purchasing department (Xia and Tang, 2011).

According to the industry survey conducted by Xia and Tang (2011), the application of the low-cost purchasing/outsourcing strategy is expected to go further and deeper, however, the authors think that it may cause more harm than good in the long run and may not even generate enough benefit in the short run as expected. This is mainly caused by:

- high transportation costs and transportation capacity along with events such as natural disasters and wars can severely hurt the stability of the supply chain (Hopkins, 2010).
- uncertainty of the demand and severe bullwhip effect in the supply chain channel, and therefore wasted a huge amount of financial resources in inventory management;
- more cost for storage and reduced flexibility. The loss of time, flexibility, and market is directly related to the loss of money;
- challenges in quality control, supplier communication, and technology development that are essential to the core competence of automakers;
- loss of jobs;
- to cut loose the business relationships with the local suppliers and partners. This can put many suppliers out of business, affecting the entire local economy and the people, distortation of the corporations' images.

Instead of focusing on outsourcing, automotive manufacturers need to implement a balanced outsourcing with a focus on innovation, so that they can create more “bang for the buck” from innovation spending (Stanko et al., 2009).

The lesson learnt for construction supply chain is to create diversity in products and outsource from global resources with the right innovation, price and quality. However, at the same time keeping balance with local procurement resources is essential for the continuity of supply chain relationships.

3.2.6 Supplier Parks

Supplier parks emerged when in 1992 when Seat officially labelled a co-located industrial estate adjacent to its assembly plant in Abrera (Spain) as a “supplier park”. Since, then the phenomenon has gained wide-spread popularity with supplier parks opening in Europe (for example Bratislava, VW; Cologne, Ford), in various newly industrialised countries, such as Brazil (Curitiba, Renault), and very recently also in North America (for example Chicago, Ford). (Reichhart and Holweg, 2008) “Supplier park” refers to the phenomena previously termed industrial parks, supplier campuses, modular consortia and condominiums (Sako, 2003). Supplier parks as a procurement concept are described by handling value-added manufacturing processes to some core suppliers next to the production of the customer (Arnold, 2000; Kotzab, 2001). The drivers for supplier parks were mentioned as high volume of just in time procurement, reduced transport costs; lower capital and working costs, low manufacturing depth, reduced inventories; transfer of tacit knowledge, willing to overtake tasks, readiness for co-operations between suppliers and service providers, potentials for co-operative relationship between suppliers and manufacturer, high requirements for logistics, low number of suppliers, high flexibility in production, great variety of components (Pfohl and Gareis, 2005; Morris et al., 2004; Reichhart and Holweg, 2008).

Pfohl and Gareis, (2005) considers the concept as balancing the advantages of outsourcing while still having control of the processes of the supplier. On the other hand, it is also noted that supplier parks can limit a firm's strategic flexibility due to higher degree of mutual commitment (Millington et al., 1998; Sako, 2003).

Supplier park idea highly decreases transportation costs and time spent during installation of different supplier packages for the end product. Since offsite construction applications are evolving in construction industry, the lesson learnt for construction supply chain is to make suppliers work together in a dedicated space for creating modular parts of the construction projects in order to eliminate transportation cost and time delays.

3.2.7 Relationships and Supply Chain Collaboration

In the automotive industry, there had been distinctive differences between the different geographical locations in the world in terms relationships and SC organization. For example, Japanese automotive company Toyota represented a distinctive improvement compared to its competitors by developing and managing mutually beneficial supplier relationships in a family like network form (Lambrechts, 2010; Dyer and Hatch, 2004). The Japanese system was said to support high dependency, tighter communication and co-operation together with compatible information systems, thus implying more technological diffusion (Lai, 1999). Although Toyota’s competitors all over the world have refocused their supply chain management activities towards establishing closer and longer-term relationships with fewer suppliers, they could not be as successful as Toyota in their collaboration with their suppliers (Cousins and Menguc, 2006; Dyer and Hatch, 2004; Wee and Wu, 2009). This is mainly because western automotive supply chain management systems involve heavy formalized shorter-term contractual relationships, a higher degree of vertical integration, larger in-house component operations, large numbers of suppliers competing fiercely, principally on the basis of price, detailed contracts to protect parties from any opportunistic behaviour, and a flat hierarchy, however this did not add value to the relationships due to lack of informal commitment and mutual trust. (Morris et al., 2004; Mudambi and Helper, 1998; Clark and Fujimoto,1991). The relationships were treated as win-lose situations by the parties, therefore, communication and interaction took place at arm's length and the parties behaved like adversaries (Wasti et al., 2006). However, some authors claims that western automakers also move towards Japanese systems and this clear distinction between western and Japanese supply chain systems no longer exists (Wasti et al., 2006; Liker et al., 1996). However, it is also noted collaboration and supply chain integration took Toyota decades to develop and implement these practices that western suppliers are trying to introduce in a few years (Bennet and O’Kane, 2006).

Despite the differences between the different geography based automakers, recent changes in the industry as outsourcing bring the need to move towards increasingly collaborative supplier relationships (Stuart and McCutcheon, 1996); and lean applications led the automakers move towards much greater interdependency between assemblers and suppliers (Morris et al., 2004). The importance of collaboration by integrating suppliers earlier in design process is addressed in the automotive literature (Binder et al., 2008; Clifton, 2001; Primo and Amundson, 2002). An interesting study conducted by Binder et al. (2008) revealed out that the following changes will add significant value to automotive supply changes:

- an early and intense involvement of key suppliers;
- an open and intense sharing of know how between the project partners;
- a long-term orientation towards inter-firm R&D relationships;
- an involvement of multiple cross-functional interfaces and clearly defined responsibilities; and
- an existence of a competent leader within the supply network who manages the interfaces between the project partners.

Despite the availability of these studies, existing automotive literature mostly focuses either on intra-firm collaboration such as the issues related to integration of various functions within an organization or on inter-firm collaboration such as the issues related to the manufacturer-supplier interface and/or manufacturer-customer interface instead of a collaboration between upstream and downstream collaboration (Luo et al., 2010; Binder et al., 2008). Widespread use of these collaborative supplier relationships is new and relatively little is known about the attribute that may promote success or failure in automotive industry (Bennet and O'Kane, 2007). Therefore, collaboration with suppliers and facilitating supplier input in design and development is still seen as a key challenge for relations between automotive manufacturers and their suppliers (Clifton, 2001). A holistic approach to supply chain collaboration starting from design stage through to the production and maintenance is a demanding area in the automotive literature.

The lessons learnt for construction supply chain are early engagement of suppliers, subcontractors, contractors, clients and designers; and sharing know how and R&D in order to work collaboratively from the first phase of construction projects.

3.2.8 Sustainability

Much of global warming, reductions in air quality, pollution of waterways and widespread loss of biodiversity arises from manufacturing organizations that continue to produce large amounts of unnecessary waste or emissions (Klassen, 2000; Simpson, 2007).

The use of environmental issues in a supply chain and operations management are significantly growing to be able to meet the challenges of sustainability (Frankel, 1998). All big automotive companies such as Ford, Toyota, BMW or Mitsubishi require environmental standards from their suppliers or involve supplier activities in statements of environmental responsibilities (Young and Kielkiewicz-Young, 2001). Due to global warming, the energy for the auto industry (in terms of type, form, source as well as storage and supply of green and renewable energy) becomes the centre stage and a dominant challenge in the near future (Tang, 2010). However, green energy is in the immature stage of the life cycle. At a time when global manufacturing industries face significant constraints on the availability of natural resources and multiple threats to survival, the imposition of environmental performance requirements represents a new and complex pressure for the organization to manage (Simpson, 2007). The construction industry has similar challenges, as reducing carbon emissions, sustainable procurement, protecting environment, waste recycling, low energy consumption, renewable energy usage (Building a Greener Future, 2007).

3.2.9 Quality Standards

In today's automotive industry, a first tier supplier will struggle to win business unless their system is certified to certain quality standards (Bramorski et al., 2000). Quality Standard provides a quality management system that focuses on continuous improvement, defect prevention, reduction of variation and reduction of waste in the supply chain thus increasing customer satisfaction and reducing quality cost (Bennet and O’Kane, 2006). This situation has now cascaded itself down to the second tier supplier, in as much as the major first tier suppliers would expect the second tier to have fully approved quality standards in place. Failure of the second tier supplier to agree to do this could mean de-selection (Bennet and O’Kane, 2006). Japanese automotive giants such as Toyota have controlled the quality of automotive components by buying mainly from their own suppliers (Liu and Brookfield, 2006). According to Liu and Brookfield (2006), by providing standardized training to employees, the skills became more mature and each procedure became as if it is a part of a dance. Making workers as a part of the factory's quality control system has reduced boredom and increased both the productivity of the employees and the quality of the finished product. This situation helped the automotive supply chain to provide high quality standardized processes and products.

The lesson learnt for construction firms is to cascade the implementation and use of quality management systems and standards to the second tier suppliers and using the suppliers with these systems in place to have a continuous control on quality.

3.2.10 Future Trends

The automotive industry faces a number of global challenges including satisfying the needs of different customers and markets under varying market conditions and demand growth, the creation of agile and flexible supply chains, balancing the outsourcing and local procurement, balancing lean and agile applications in the supply chain as discussed. Apart from these, Xia and Tang, (2011) considered the four elements which lie in the future of auto industry which are:

- sustainable development;
- less dependence on gas;
- green energy reform; and
- high moral standard.

It can be considered that the future automotive supply chains are not only being more sustainable, fast and cost effective but also becoming agile and flexible enough to respond in time to the varying market demand and changing customer requirements.

3.2.11 Aerospace Industry

The aerospace industry is characterised by relatively a stable demand, long lead times, complex and inflexible operations, small production series, severe competition and increasing outsourcing of high-technology elements (Gustavsson, 2008; Bales et al., 2004). Companies in the industry compete on flexibility, product performance, delivery, availability and price (O'Neill and Sackett, 1994).

Aerospace SCs deals with a variety of systems and parts that make up a high technology end product. The design of aerospace systems deals with complexity, traceability, maturity of knowledge, awareness of the status of information, trust in knowledge and interaction between experts (Boy and Barnard, 2005). Aerospace systems are increasingly challenging to manage, and system interactions are growing more complex (Jafari et al., 2007). However, technological integration in the aerospace industry is high overall and the supply chain integration is characterised by risk and revenue sharing among the supply chain actors (O'Neill and Sackett, 1994; Gallo et al., 1997). Firms are integrated into a few large groups each trying to deal with the increasingly higher technological, financial and market barriers (Rose-Anderssen et al., 2009). Globalisation hugely affected the industry and harsh competition increased the need to provide more innovation, and to minimize costs in aerospace supply chains (Rose-Anderssen et al., 2009).

Another character of the aerospace industry is the strict regulations and standardization in the industry. Aerospace firms have to comply with strict rules and regulations established by the certification authorities and the certification process might consume more time than inventing a new product (Brusoni and Prencipe, 2001; Voordijk and Meijboom, 2005).

The comparison and relevance between construction and aerospace supply chains are summarized in the following Table 3-1 (Fernie et al.,2001; Green et al., 2004). These differences highly affects the organization of supply chains in each industry.

Table 3-1 Supply Chain Management approaches- Construction vs. Aerospace

Construction	Aerospace
No single player which can influence parties for SCM (fragmented structure)	Dominated by one large organisation
Absence of unified approach for information exchange	Certain standards for information exchange
Short term relations between project parties	Long term relations between organizations
Various clients	Close relations with government
Low levels of R&D investment	High levels of R&D investment
Lean construction is at the early stages of development	Lean concept is integrated from automotive industry
Low trust economy	High trust economy
SCM discussed extensively as a good initiative but appears to have had little impact on practice.	SCM practice exists and is used extensively
No argument regarding the industry wide adoption of new working practices	The changes due to new working practices are accepted to be reason for industry wide crisis.
Limited understanding of SCM, restricted to certain individuals.	Widespread and in-depth understanding of SCM
SCM is frequently discussed in the project level and rarely in the organizational level.	SCM thinking and practice is beyond the organizational boundaries.

Fragmented structure of industry provides little imperative to change.	SCM provides basis for standard integrated systems across the whole supply chain.

At present, the aerospace industry, particularly the aircraft sector, is going through its second crisis since the 1990s. This is approached by a process of globalisation leading to the integration of firms into just a few large groups each trying to deal with the increasingly higher technological, financial and market barriers (Rose-Anderssen et al. 2009). High level of outsourcing in design and manufacture has changed the structure of the industry (Fine, 1998). The local western suppliers are challenged by the risk of being replaced by low-cost country suppliers in the global market place. Consequently, firms have concentred more on the core competencies of design, assembling and marketing (Rose-Anderssen et al., 2009; Jafari et al., 2007). Also, various risk sharing partnerships are established between aerospace firms. These risk-sharing partnerships are open to high-technology aerospace suppliers that are financially strong enough to invest into new practices, technologies and products. At the same time, particularly the first tier suppliers have moved from being suppliers towards being system suppliers (Walls et al., 2006; Smith and Tranfield, 2005). The future evolution of aerospace supply chains in the global environment is likely to grow from the Joint venture SC branch (Rose-Anderssen et. al., 2009).

Increased competition in the global marketplace lead to the production of innovative solutions in terms of technologies, practices and end- products while reducing lead-time for delivery and costs (Rose-Anderssen et al., 2005; Goffin et al., 2006).

In the aerospace literature, the key issues and concepts are identified as increasing globalization and outsourcing, partnering and collaborative relationships, information exchange, co-ordination, integration of suppliers in design, competitiveness, risk and uncertainty within the business environment, total quality management, lean and agile supply chains, manufacturing responsiveness, and learning and communication (Bales et al. 2004; Rose-Anderssen et al., 2008, 2010; Stiles, 1995; Michaels, 1999; Saad and Gindy, 2007). In the next section, these key issues and challenges which took place in the aerospace industry are discussed.

3.2.12 Lean Approach and Manufacturing Responsiveness

A reactive response to the evolution of the aerospace industry can be seen as adapting to the practices of lean thinking from the automotive industry (Womack et al., 1990; Hines et al., 2004). Despite the fact that aerospace is a conservative industry and very slow to adapt to changes, applying lean practices of automotive industry throughout the supply chain has been a necessary step for being competitive (Rose-Anderssen et al., 2010).

In the literature on aerospace supply chains, lean and agile supply chains are the only identified supply chain forms (Rose-Anderssen et al., 2009). Lean system introductions have been associated with time, space, quality, people, and cost savings. A recent Lean Aerospace Initiative study (MIT Lean Aerospace Initiative, 2005) found the following improvements as a result of lean application in aerospace supply chains (Mathaisel, 2005):

- labour hours: 10-71 percent improvement;
- costs: 11-50 percent improvement;
- productivity: 27-100 percent improvement;
- cycle time: 20-97 percent improvement;
- factory floor space: 25-81 percent improvement;
- travel distances (people or product): 42-95 percent improvement;
- inventory or work in progress: 31-98 percent improvement;
- scrap, rework, defects or inspection: 20-80 percent improvement;
- set up time: 17-85 percent improvement; and
- lead time: 16-50 percent improvement.

According to Michaels, (1999) lean production is not a “quick win” initiative because the major changes in mind-set and skills take time. The author specified the timing for the implementation of a lean approach as; at least one to two years for basic understanding, another three to four years for training and implementation, and two to four more years to achieve sustaining skills and behaviours. To have a full lean approach in aerospace supply chains, the supply chain management executives should join together and co-author letter of joint expectations for lean production to their supply chains. This means that leadership and awareness creation is a major step to be taken to transform to lean as a supply chain.

The majority of the practices in aerospace supply chains are intended to remove waste from the manufacturing system and strive for maximising resource utilisation that are associated with lean manufacture (Saad and Gindy, 2007). The authors also criticize that over emphasis on applying “lean practices” can lead to difficulties in the manufacture of technologically advanced, assembled products, made in low volumes with high variety and product mixes, which characterise the manufacturing environment in the aerospace sector. This can also lead to a loss of ability to meet the conditions of an upsurge in production (Saad and Gindy, 2007). At this point, the necessities of becoming agile and achieving high manufacturing responsiveness are highlighted as a balanced approach between lean and agile supply chains. Manufacturing responsiveness relates to the ability of manufacturing systems to make a rapid and balanced response to the predictable and unpredictable changes that characterize today's manufacturing environments (Gindy and Saad, 1997). An interesting study conducted by Saad and Gindy (2007) revealed out that the most significant elements in achieving manufacturing responsiveness are: customer driven product development, supply chain design, intelligent and flexible technology, integrated product and process development, concurrency of the extended manufacturing enterprise, cost effectiveness, ability to implement new technology and systems and supply chain management and logistics. For a balanced approach between lean and agile supply chains the firms need to strategically review and organize according to these elements.

The lesson learnt for construction supply chain is to establish lean manufacturing philosophy and principles for production of construction materials and structural elements in order to improve the project delivery in terms of quality, speed and health and safety. The construction applications like offsite manufacturing and construction can be a good example for lean manufacturing and production in automotive industry.

3.2.13 Outsourcing

Severe competition to win fewer new orders and an increased need to get new products to the market quickly have a powerful impact on the way supply chains in the aerospace industry are structured and managed (Fine, 1998). Many companies in the aerospace industry have gone through a painful process of redefining their core competencies and re-evaluation of “make or buy” decisions leading to significant out-sourcing and down-sizing (Saad and Gindy, 2007). As a result of this process, the aerospace manufacturing industry is characterised by severe competition and more and more outsourcing of high-technology elements in the global market place (Rose-Anderssen et al., 2009). The global aerospace market is increasingly influenced by offset and technology transfer issues. The Far East is becoming an important marketplace and a potential source of low-cost manufacturing. Outsourcing activities has altered the shape of the supply chain. The overall number of supply chain actors has decreased but the sub-contract base now carries out a greater volume of manufacturing work and of an increasingly complex nature (Bales et al., 2004).

The lesson learnt for construction supply chain is to create diversity in products and outsource from global resources with the right innovation, price and quality. However, at the same time keeping balance with local procurement resources is essential for the continuity of supply chain relationships.

3.2.14 Collaborative Relationships and SC Integration

Collaborative relationships are an important element for the creation of well integrated supply chains. The main idea of integration is to bring together companies that have both the technological expertise to develop innovative solutions and have the financial capacity to invest in change and development (Rose-Anderssen et al., 2008).

Aerospace supply chains have changed significantly in terms of relationships between suppliers and aircraft manufacturers, and the potential for integrating expertise on engineering and technology management (Rose-Anderssen et al., 2011). Transforming into lean led the aerospace firms to focus on understanding the suppliers cost and quality systems through open interdependencies between manufacturers and suppliers (Rose-Anderssen et al., 2009). As a result of this openness suppliers and customers became closely integrated into long-term relationships for reducing costs and ensuring high quality (Cagliano et al., 2004). To ensure openness at the same time to protect sensitive information from competitors, airframe producers invested high-level single supplier relationships (Rose-Anderssen et al., 2009).

In the current situation of the aerospace industry, supplier and manufacturer relationships are being based on the situational context somewhere on a continuum from discrete transactions, to repeated transactions, to long-term relationships and to more formal partnerships (Goffin et al., 2006). According to Bales et al. (2004), there is a move away from adversarial trading relationships towards a partnering approach which will create integrated aerospace supply chain in future (Bales et al., 2004). The current situation and trends in aerospace supply chain relationships are explained by Rose-Anderssen et al. (2010) based on their research in Europe, Japan and the USA aerospace industry as follows:

- There is an increasing trend for improving a high level of collaborative relationship to satisfy a common interest, and successful production.

- Risk-sharing partnerships are being developed at the top of the supply chain to bring the investment in technology and expertise together. Although it has been evaluated as a threat at national levels, it can also be seen as an opportunity for Western suppliers who have the willingness and resources to contribute in the innovation of technology and products.
- There is awareness in improving dialogue with suppliers adapting the successful standards of the automotive industry.

Another recent study conducted by Johnsen et al. (2009) on the major changes currently taking place that have major impacts on defence supply relationships presented the following results:

- There is a shift towards through-life management (TLM), where major equipment platforms are kept in service for long term.
- TLM requires much closer partnerships in the defense supply chain where suppliers will take more responsibility in areas such as in-service support and maintenance.
- Product-service specific capabilities need to be developed especially in areas such as accurate lifecycle costing collaboratively in the supply chain.
- The development of integrated supply partnerships requires greater emphasis on openness, risk and reward sharing, trust and long-term commitment in supplier relationships.
- There is also a need for early supplier involvement to ensure not only design for manufacture, but design for maintainability and logistics.

These two important studies describe that there is a developed awareness on open, long term collaborative relationships and risk sharing closer partnerships to develop expertise and technology collaboratively in both civil and defence aerospace supply chains. The use of collaborative relationships to deliver products and service has also become an important issue for research projects in the manufacturing and aerospace industries (Rose-Anderssen et al., 2009).

As Rose-Anderssen et al. (2010) presented in Figure 3-1, for an integrated supply chain, firms in the SC need to pursue a common purpose and establish mutual benefits. Coordination and communication are the two main activities which support and feed the integration. Coordination may enhance integration through the common object formation process. This overcomes boundary differences. The fact is that the new practices as supporting risk-sharing partnerships are gradually emerging. Communicative interaction is the instrument to create common object and to enhance collaboration.

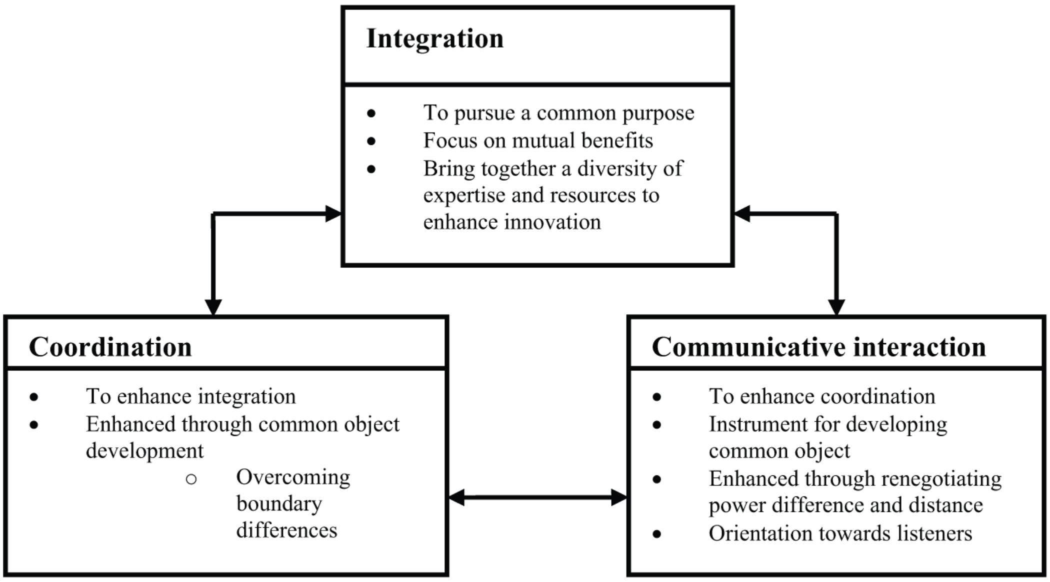

Figure 3-1 Elements of SC Integration (Rose-Anderssen et al., 2010).

All these supply chain integration activities and early collaboration of supply chain actors will motivate and help the firms to:

- invest in their people, facilities, equipment and infrastructure;
- establish mutual benefits knowing that their own success and the success of their customer are linked together;
- reduce development cost and lead time;
- access to innovative technology collaboratively and easily (Binder et al., 2008; Primo and Amundson, 2002).

In the next stage, information and knowledge exchange process which needs to be coordinated effectively for well integrated supply chain is reviewed and discussed.

3.2.15 Information and Knowledge Exchange

A typical aerospace project is long in duration and includes project phases such as specification and requirements definition, conceptual and detailed design, manufacture, assemble, test and certificate (Fan et al., 2000). The creation of knowledge during the project lifecycle is incremental. Owing to large amount of knowledge and intellectual capital inside the aerospace industry, firms now face considerable pressure to improve co-ordination and flow of knowledge in their SCs (Tabibzadeh and Wireman, 2003; Jafari et al., 2007). Particularly, with the high level of outsourcing, the aerospace industry is in a position to manage knowledge dispersed across several organisational units and geographically dispersed organizations around the globe (Meijboom and Vos, 1997; Fan et al., 2000). In such an environment, the successful collaboration of the supply chain in terms of information and knowledge exchange between customers, manufacturers and suppliers is a significant issue for the successful delivery of the aerospace projects (Samanranayake, 2005). Therefore, knowledge exchange in aerospace SCs is considered as highly critical.

Knowledge exchange process covers all of the product life cycle issues form capture of customer requirements and concept definition to product disassembly and disposal (Saad and Grindy, 2008). For a clear understanding on the nature of information and knowledge shared through the aerospace project, the phases that took place during the project lifecycle should be reviewed. The first phase is “define specification and obtain instruction to proceed” where the customer expectation of the product is defined. In this stage strategic and risk sharing partners are secured, information on supplier capability can be gathered. The previous experience of supplier development with the partnership set would be beneficial groundwork.

The next phase is the design activities which involves initial design where the schemes and interface specifications are defined and the “detail design” where creation of data for manufacture is created. A variety of methods are used to facilitate the incorporation of suppliers input in the design such as; subcontracting the complete design and build package to the supplier, thus passing the responsibility of manufacturability to the supplier or the involvement of suppliers’ guest engineers in design built teams is a common practice. The integration of supplier and manufacturing expertise in design has been and is still being developed in various initiatives in aerospace industry. The recent adoption of knowledge based systems requires the collection of manufacturing rules from the suppliers through questionnaires, interviews, study of existing manufacturing plans or intranet guidebooks.

The third phase, “manufacture and assembly” involves the selection of all suppliers, the manufacturing engineering activities to prepare the product for production and all the management and logistics operations to build the product. The focus of supplier information moves from the manufacturing knowledge to the suppliers’ capability to deliver the components.

The last phase, “test and certificate” makes ready the product for the customer. The suppliers’ information in this phase follows that of the “manufacture and assembly”.

During the whole project life cycle, information and knowledge exchange and processing capacity of the supply chain can be increased by developing coordination strategies and investing in collaborative relationships and information systems (long-term planning and ICT) in companies involved in the same supply chain (Voordijk and Meijboom, 2005). However, the exchange of supplier knowledge in the design activities is still a difficult challenge for aerospace supply chains (Fan et al., 2000). Studies on supply chain design issues to ensure concurrency of the supply chain are limited in the aerospace industry literature (Saad and Gindy, 2007). In the context of design and build teams, the main difficulty is defined as the time and efforts needed to coordinate and integrate the group of individuals from different companies and functions working together (Voordijk and Meijboom, 2005). Also, due to outsourcing of components, design stages can be separated from manufacturing process. The broken relationship of design from manufacture creates difficulties when design team do not know the details about the manufacturing supplier (Fan et al., 2000). Moreover, in the civil aerospace industry where many design and manufacture concepts are mature, there are many instances where the “know how” has been maintained and the “know why” is lost (Fan et al., 2000). During manufacturing, although there are agreed standards of manufacture which provide the guidelines needed for specifying the product for manufacture, the amount of time and effort needed to get production right whenever any components are transferred between suppliers cast doubts on the effectiveness of these guidelines (Fan et al., 2000). As a result, more effective use of the supplier knowledge and effective knowledge transfer will be the differentiator for aerospace product development projects (Fan et al., 2000).

Besides these issues, outsourcing disseminates supply and demand information throughout the supply chain and blurs the customer-supplier boundaries (Bales et. al, 2004). Because customer demand is rarely perfectly stable, businesses must forecast demand to properly position inventory and other resources (Chen, 1998). Forecasts are based on statistics, and they are rarely perfectly accurate. Because forecast errors are a given, companies often carry an inventory buffer called "safety stock". As each manufacturer has different ways of interpreting customer information, distortion of the information increases while causing the ‘bullwhip effect’ (Simchi-Levi et al., 2002). The infrastructure within the supply chain needs to support the necessary exchange of supply, demand and payment information. The inter-connectivity of the systems and their associated processes affect supply chain visibility. Using open-book contracts and sharing information via web-enabled databases increase visibility. Creating a transparent supply chain system encourages supply chain actors to plan accurately. Matching supply and demand means developing technological, inter-organisational supply chain solutions that allow the necessary level of information transfer (Bales et al., 2004).

The lesson learnt for construction supply chain is to improve information and knowledge exchange between parties throughout the project lifecycle by integrating the right parties at the right time and utilising technology and process with the right people skills.

3.3 Lessons from Automotive and Aerospace SCM

The automotive industry has very mature SCM applications and is subjected to continuous improvement in SCM with various applications as JIT, JIS, lean SCs, agile SCs, flexibility, and innovative production and procurement methods as modularisation, supplier parks. The industry faces a number of global challenges including satisfying the needs of different customers and markets under varying market conditions and demand growth, balancing the outsourcing and local procurement, balancing lean and agile applications in the supply chain. The industry is very competitive and many traditional auto manufacturers struggle to meet explosive demand growth in new geographic regions and manage increasingly complex SCs, changing customer preferences, and evolving production changes. Sustainability and green energy is in the agenda for the future of automotive SC.

The aerospace supply chains are conservative and slow to adapt new challenges compared to automotive industry. However, because aerospace and automotive industries involve heavy manufacturing, the aerospace industry benefits from the improvements in the automotive industry such as JIT and JIS production, lean applications, trend to move to agile SCs. The effective use of knowledge across the supply chain is accepted to be essential for the success of any project in defence and aerospace industry. Due to outsourcing of components, aerospace supply chain has the difficulty of managing design stages and keeping the design in line with the manufacturing process. The industry struggles to manage the broken relationship of design from manufacturing stage. However, due to a high level of standardization, the industry has defined procedures to create and share design knowledge. Both aerospace and automotive industries have mature relationships and high level of R&D investment. This makes these industries to implement new technologies and processes quicker than construction industry. Aerospace industry led by a couple of organizations worldwide, has limited clients and closer relationships with government whereas automotive industry works in a more competitive global environment.

After a detailed review on automotive and aerospace supply chains, the following practices can be captured for the use of construction supply chains.

- To establish lean supply chain and lean principles for production of construction materials and structural elements in order to develop long term collaborative relationships with suppliers;
- To search for opportunities to transformation of traditional construction methods into modularisation of structural elements, mechanical and electrical components and their installation early in the projects;
- To search for opportunities to create diversity in products and outsource from global resources for better price and quality;
- To search for opportunities for collaborative work environment and to improve the communication between supply chain actors, an example can be creation of some parts of supply chain in a dedicated space for creating modular parts of the construction projects in order to eliminate transportation cost and time delays;
- Early engagement of suppliers, subcontractors, contractors, clients and designers; and sharing know how and R&D in order to work collaboratively from the first phase of construction projects.
- To cascade the implementation and use of standard SCM procedures and quality management systems to the second tier suppliers and using the suppliers with these systems in place to have a continuous control on supplier performance and quality.

3.4 Chapter Summary

In this Chapter, the SCM issues in aerospace and automotive industries are presented. The literature review revealed that the automotive industry has very mature SCM applications and are subjected to continuous improvement in SCM with various applications as JIT, JIS, lean, agile, flexibility, modularisation. The industry faces a number of global challenges including satisfying the needs of different customers and markets under varying market conditions and demand growth, balancing the outsourcing and local procurement, balancing lean and agile applications in the supply chain. The industry is very competitive and many traditional automotive manufacturers struggle to meet explosive demand growth in new geographic regions and manage increasingly complex SCs, changing customer preferences, and evolving production changes.

The Aerospace industry, led by a couple of large firms worldwide, has limited clients and closer relationships with government whereas the automotive industry works in a more competitive global environment. The aerospace supply chains are conservative and slow to adapt new challenges compared to automotive industry. However, aerospace supply chains benefited from the improvements in the automotive industry such as JIT and JIS production, lean applications, and trend to move to agile SCs. Due to outsourcing of components, aerospace supply chain has the difficulty of managing design stages and keeping the design in line with manufacturing process. The industry struggles to manage the broken relationship of design from manufacturing stage. However, due to a high level of standardization, the industry has defined procedures to create and share design knowledge. Both aerospace and automotive industries have mature relationships and a high level of R&D investment. This makes these industries quicker to implement new technologies and processes than the construction industry.

CHAPTER 4

4 KNOWLEDGE MANAGEMENT

4.1 Introduction

Knowledge Management has become an emerging discipline in business management which was popularised around 1995 by scholars and practitioners (Jashapara, 2004; Stankosky, 2005). There is a growing recognition in the business community about the importance of managing knowledge (Holsapple and Joshi, 1999). In the knowledge economy, it is mainly accepted that knowledge is a key ingredient of what is bought and sold, which rises the value of knowledge as input and output, the value of knowledge resources and new technologies and techniques for managing knowledge resources (Stewart, 1998).

In the SCM literature, close attentions have been paid to physical distribution, capital flow and information flow without due care to the knowledge flow and knowledge management (Liang andYuanyuan, 2010). As discussed in Section 2.2, construction supply chains have several KM issues due to having fragmented operations, inefficient communication channels, the inability to share information, lack of knowledge sharing culture and common goals between SC actors, insufficient use of ICT and collaboration technologies, lack of understanding in project lifecycle issues, and lack of ability to assess uncertainties and risks. These KM issues significantly affect the performance and delivery of the projects. Therefore the premise in this research is improvement of knowledge flow between the construction supply chain actors and the integration of supply chain will have a great impact on increasing quality, performance and delivery of the construction projects. KM based Construction SCM will change the problematic nature of current construction SCM in terms of:

- providing sufficient and valuable knowledge flow throughout the supply chain;
- increasing collaboration in the SC and improving the relationships between SC actors;
- improving relationships and partnerships by supporting collaborative knowledge sharing and trust culture;
- diminishing the skill and knowledge deficiencies of different disciplines of supply chains;
- supporting the innovation by increasing the quality and amount of knowledge shared;

- providing better integration of supply chain actors.

4.2 Definition Of Knowledge Management

Despite the fact that KM is beginning to be realized across a variety of industry sectors, there is still no consensus on what KM means (Joseph and McEllroy, 2003; Anumba, 2009). There are several KM definitions which emphasize different aspects of KM which are:

- “KM draws from existing resources that your organization may already have in place- good information systems management, organizational change management and human resources management practices” (Davenport and Prusak, 1998).
- “KM is the explicit and systematic management of vital knowledge and its associated processes of creating, gathering, organizing, diffusion, use and exploitation, in pursuit of organizational objectives”(Skyrme, 1999).
- “KM is any process or practice of creating, acquiring, capturing, sharing and using knowledge, wherever it resides to enhance learning and performance in organizations” (Scarborough et al., 1999).
- “KM is a management discipline that seeks to enhance organizational knowledge processing (Joseph and McEllroy, 2003)
- “KM is the effective learning process associated with exploration, exploitation and sharing of human knowledge (tacit and explicit), that use appropriate technology and cultural environments to enhance an organization’s intellectual capital and performance.” (Jashapara, 2004).
- NASA briefly defines KM as "getting the right information to the right people at the right time, and helping people create knowledge and share and act upon information in ways that will measurably improve the performance of an organization and its partners" (Murphy and Holm 2008).
- “KM is the discipline of creating a thriving work and learning environment that fosters the continuous creation, aggregation, use and re-use of both organizational and personal knowledge in the pursuit of new business value” (Anumba,2009).

All these definitions emphasize different aspects of KM such as creating, acquiring, capturing, sharing of tacit and explicit knowledge, organizational learning, usage of technology, strategy, cultural and social aspects. The research in the field of KM has also sought to look into different aspects of organization and management of knowledge in different conditions and in different contexts (for example organisational, individual) (Liyange et al., 2009). Anumba (2009) considers this variety and the lack of consensus on a unique KM definition as an evidence of the richness of the concept rather than a problem, as it reinforces its potential as a transformational agent within and across business organizations (Anumba, 2009).

As a result, Knowledge Management can be considered as a multidisciplinary area, and the conventional demarcations in traditional subject areas are not comprehensive enough to establish the theoretical background of KM (Jashapara, 2004; Stankosky, 2005). KM has an impact on other areas such as systems engineering, communication, organizational management, organizational behaviour, strategic planning, human resource management, sociology, philosophy, visualisation, virtual networks, decision support systems, management information systems, database design, risk management, competitive intelligence, resource planning, business process engineering. All these areas also support the theoretical development of KM and add value to the KM lifecycle. KM has benefited from many theories of literature:

- Information Theory to explain the creation, transfer and storage of information process;
- Communication Theory to explain knowledge sharing which is a form of information exchange between individuals in organizations
- Organizational Learning Theory to explain the continuous learning process of organizations which occurs through interaction among employees.
- Dynamic Theory of Knowledge Creation which provides a comprehensive theoretical view on how to conceptualize the entire knowledge creation process.

4.3 Information, Data, Knowledge And Wisdom

For a better understanding of KM, the difference between data, information, knowledge and wisdom, and the types of knowledge should be clarified Jashapara, 2004):

- Data can be considered as known facts or things used as basis of inference;
- Information can be considered as systematically processed data which can allow users to predict or make inferences from data assuming it is based on a system;
- Knowledge can be considered as ‘actionable information’ which can allow the user to make better decisions and provide effective input to dialogue and creativity in

organizations. Davenport and Prusak's (1998) defined Knowledge as a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. This knowledge allows us to act more effectively than information and data and equips us with a greater ability to predict future outcomes;

- Wisdom is the ability to act critically or practically in a given situation.

Knowledge can be classified in two distinct forms as tacit and explicit knowledge which are expressed as follows:

- "Tacit knowledge is non-verbalized, intuitive and unarticulated knowledge'' (Polanyi, 1962). Because this type of knowledge is imbedded in the minds of human, it is difficult to capture, codify and diffuse this type of knowledge (Nonaka and Takeuchi, 1991). Polanyi (1983) characterized some tacit knowledge as inexpressible and stated that "we can know more than we can tell".
- Explicit knowledge can be articulated in formal language and easily be transmitted amongst individuals (Koulopoulos and Frappaolo, 1999). Unlike tacit knowledge, explicit knowledge can be expressed and codified easily (Liyange et al., 2009).

Briefly, as Polanyi (1975) stated, tacit knowledge forms the background necessary for assigning the structure to develop and interpret explicit knowledge. According to (Johannessen and Olsen, 2011), the main difference between explicit and tacit knowledge can be drawn between 'to know' and 'to have the ability'.

Development of tacit knowledge depends on three elements: the one who knows, the one who wants to know, and the practical context. The transfer and integration of tacit knowledge presuppose action, reflection and emotional involvement. The transfer and integration of tacit knowledge is based on the development of relations between actors, being based on trust and a basically helpful attitude (Johannessen and Olsen, 2011).

An understanding of the differences between information, data, knowledge and wisdom, and the tacit and explicit knowledge are important because these are the main elements of all developments in the knowledge management area.

4.4 KM Lifecycle

The Knowledge Management Lifecycle is a continuous management process of information and knowledge in an organization. Figure 4-1 presents each phase of this cycle which is associated with issues, input data, support mechanisms, and output data. The difference between the input and output data depends on the processes involved in the particular phase of the KM life cycle.

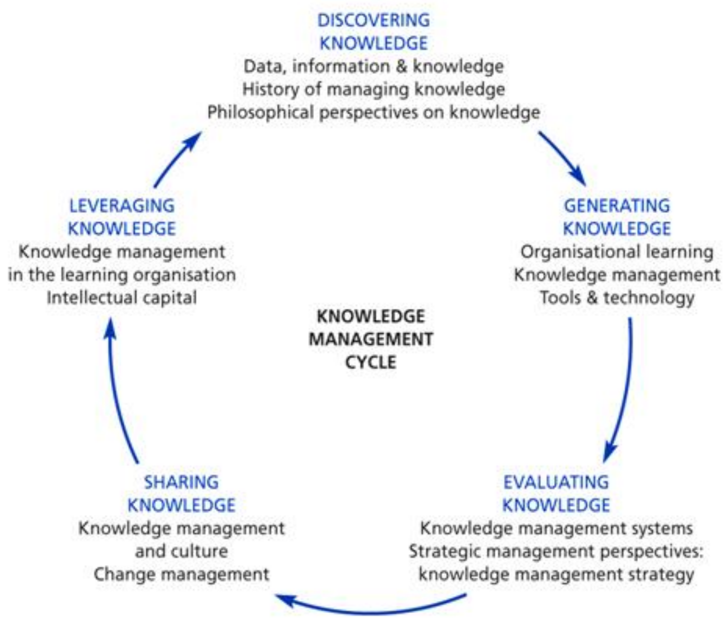

Figure 4-1 KM Life Cycle (Jashapara, 2004)

- **Discovering knowledge:** This phase deals with identifying knowledge that a firm or individual possess and discovering knowledge including what knowledge they have and what they want to achieve.
- **Generating knowledge:** This phase deals organizational learning which aims that producing new knowledge through people in the form of organizational learning and through the multitude of knowledge management tools and technology.
- **Evaluating knowledge:** It deals with the process of evaluating the effectiveness of knowledge through different knowledge management systems and strategic management perspectives from different point of view to achieve competitive advantage.
- **Sharing knowledge:** This phase deals with the human resource aspect of sharing knowledge and implementing knowledge management initiatives and change management's influence to organizational culture, leadership and employee.

- **Leveraging Knowledge:** This phase applies the knowledge obtained above in the organization generating and gain competitive advantages over the other and mainly focuses on organizational learning and the intellectual capital concepts in a firm.

This lifecycle is a comprehensive representation of the KM process, therefore each step of the lifecycle needs to be considered to transform the construction supply chains in to knowledge chains.

4.5 Knowledge Management Systems

Knowledge Management Systems (KMS) are defined as the information systems adopted and designed, which efficiently and effectively leverage the collective experience and knowledge of employees to support information processing needs, as well as enabling and facilitating sense-making activities of knowledge workers; i.e. systems that actualize the knowledge architecture (Wickramasinghe, 2003). Knowledge management systems (KMSs) involving the application of IT systems and other organizational resources are strategic tools to manage knowledge in a more effective and systematic way (Quaddus and Xu, 2005a). KMS in practice are touted as being able to support and enable the knowledge management process within the respective organizations (Wickramasinghe, 2003). KMSs provided the opportunity to extend the operating scope of Information Systems (ISs) through facilitating the organization's effort in managing both tacit and explicit knowledge (Alavi and Leidner, 2001). To add value to the KM lifecycle, KMSs, which facilitate the generation, preservation, and sharing of both tacit and explicit knowledge is essential (Duke et al., 1999; Bonner, 2000).

The effective usage of KMSs in the construction supply chains are essential to foster collaborative knowledge creation and sharing in the supply chain. The interoperability between the systems, the availability of the skill set for the usage of KMSs, the trainings on KMSs in place for supply chain actors are important factors to improve the usage and effectiveness of KMSs. A comprehensive research conducted by (Quaddus and Xu, 2005b) revealed that the top ten most widely used KMS technologies were (in order): e-mail and communication systems, internet, databases, intranet, document management systems, customer management systems, video conference, online discussion forum, workflow systems, data warehousing/mining, and search and retrieval tools. Apart from those, construction organizations also use the following technologies and applications to manage their knowledge (in order): executive information systems, electronic bulletin board, electronic meeting systems, learning tools, people information archives, decision support systems, groupware, best-practice databases, corporate yellow pages, online analytical processing system, knowledge repositories, knowledge portals, lesson-learnt databases, extranet, issues management systems, knowledge directories, expert systems, and artificial intelligence. As can be seen from this list, KMS initiatives highly rely on IT as an important enabler. However, according to some practitioners, the application of KMSs has a tendency to overlook the socio-cultural aspects that underpin KM (Malhotra, 2000). It is believed that KMS that embed social awareness can play an important role in promoting social capital in the fragmented and distributed networks of the construction industry (Rezgui, 2007). The overall strategy behind the KMS must reflect on the key business drivers, cultural implications, and knowledge creators and users and their role (Holm et. al., 2006). Therefore implementation of KMSs which will be used in the supply chain needs to be strategically identified according to the knowledge requirements and ICT capabilities of the SC actors. This effective usage of these systems should be encouraged considering the cultural and organizational implications of SC actors.

The current generations of KM systems are proving reasonably effective in helping organizations to manage their intellectual assets, however, at project level, next-generation KMSs will better facilitate the “live” capture and reuse of knowledge, and collaborative learning during the course of the project (Anumba, 2009). Next-generation KM systems are expected to make seamless the linkage between KM and business processes by (Anumba, 2009):

- Having demonstrable or self-evident performance benefits such that knowledge managers no longer have to justify investments in KM.
- Having an intelligent agent-based component which will be able to act on behalf of their owners in interacting with any existing knowledge repositories or tools, and can build user profiles automatically.
- Incorporating more sophisticated tools and techniques for knowledge capture and reuse, which will enable automatic capture of knowledge as it is generated and facilitate knowledge sharing across organizational boundaries.

- Enabling more ubiquitous, context-specific and, location-based delivery of knowledge and associated services which will allow an unprecedented degree of personalization, while enhancing the utility and relevance of these systems.
- Supporting effective integration of personal KM systems with corporate KM systems in such a way that organizations can better leverage the knowledge held by their employees without privacy violations.
- Having sophisticated mechanisms for supporting Communities of Practices (COPs) and capturing storytelling and anecdotes which are rich in knowledge content.
- Supporting the development and management of “knowledge chains” (See Section 3.8), which facilitate the flow of knowledge within and across construction supply chains.
- Contributing to the market value of construction sector organizations as the value they provide becomes more of a distinguishing factor in the evaluation of organizations.
- Being supported by an increased number of people whose roles involve the management of knowledge assets in organizations.

4.6 Benefits Of Knowledge Management In Construction Supply Chains

The complexity associated with the delivery of construction projects by a transient project team made up of individuals/teams from a variety of suppliers make the implementation of KM challenging. However, it is also for the same reasons that construction supply chain cannot afford to ignore KM. Some of the key benefits of KM to construction organizations identified by Anumba et al., (2005) are presented with a supply chain approach as follows:

- Innovation is more likely to thrive in an environment where there is a clear strategy for managing knowledge in the supply chain;
- improved performance will result from organizing the knowledge flow more effectively (adopting the most appropriate solutions) and more efficient (using less time and other resources) in the supply chain;
- KM is vital for improved construction project delivery, as lessons learned from one project can be carried on to future projects through collaborative knowledge sharing in the supply chain;

- KM can facilitate the transfer of knowledge across a variety of supply chain actors effectively, firms and project teams can avoid repeating past mistakes and/or re-inventing the wheel.
- Firms that adequately manage their knowledge are better placed to respond quickly to clients' needs and other external factors.
- KM results in improved support for supply chain actors; dissemination of best practice is one of the results of collaborative knowledge sharing in the construction supply chain;
- Increased value can be provided to construction clients through better management of knowledge in the supply chain.
- With effective KM, construction supply chain actors can be more agile and better able to respond to organizational changes.
- Risk minimization is one of the key benefits of KM, as the enhanced knowledge base means that organizations have fewer uncertainties to deal with.

Apart from these, knowledge sharing across the SC can enhance greatly the value of the collaborative relationships. In long term, this will be a solution to the current arm length relationships in construction SC, and this will improve the trust between SC actors. The premise in this research is to transform the supply chains into knowledge chains with high level of knowledge sharing and integration between SC actors. In the next section knowledge chains and the key activities to create knowledge chains in construction are presented.

4.7 Knowledge Chains

Knowledge chains (KCs) were addressed in academic literature in a few studies conducted by Spinello (1998), Hollsaple and Jisheng (2001), Jinxi and Jisheng (2001), Hollsaple and Jones (2004a and 2004b), Gu et al. (2005), Konukcu et al. (2008). Construction supply chain consists of various organisations which come together with different specialties and knowledge to complete a construction project. Each organisation contributes its knowledge in a form of people, processes and technologies to the construction process (Maqsood and Walker 2007). Therefore a successful supply chain is only possible when all of the knowledge contributed by each organization is linked to each other.

A KC can be defined as a chain network based on the knowledge flows between various organizations with the aim of reaching a more innovative state for each organization

(Gu et. al. 2005). A firm's KC shows the effectiveness of the management of its knowledge resources and the ability of the organization's to cope with its business environment. It also represents a firm's cognitive power for action: its capacity for recognizing, and acting on market changes and developments (Spinello, 1998). It is clear that the creation of strong KCs not only enhances the final product but also can affect the whole business nature in a positive way. Because of this, transformation of the supply chains to knowledge chains is critical in terms of diminishing the issues of construction supply chain.

KC within a firm has four interrelated stages as given in Figure 4-2. (Spinello, 1998).

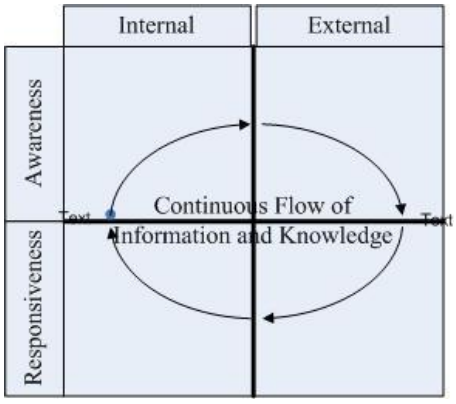

Figure 4-2 Four stages of Knowledge Chain (KC) (Adapted from Spinello, 1998)

The brief definition of each quadrant of Figure 4-2 is explained as follows:

- External awareness is defined as the ability of a firm to absorb information and transform it into usable knowledge.
- Internal awareness is defined as a firm's understanding of its resources and a firm's ability to preserve and disseminate the knowledge.
- Internal responsiveness is defined as the ability to organize and marshal the resources to meet the needs of the market, take advantage of an economic opportunity, develop a new project/ product or cope with an apparent threat.
- External responsiveness is defined as taking the necessary steps to bring the product into the external marketplace and market it properly (Spinello, 1998).

Knowledge flow presents a continuous process and lies in the heart of knowledge chains. When the complex construction supply chain composed of various organizations is considered, the only way for the transformation of supply chain to knowledge chain is to reexamine each organization's knowledge chain activities in terms of their awareness and responsiveness both internally and externally.

The most important part of this approach for organizations is the continuous flow of knowledge while dealing with business processes and competing in the evolving business environment. Knowledge flow in the supply chain is the synthesis and promotion of the three flows (physical distribution, capital flow and information flow), which includes the whole process from knowledge search to absorption and use (Xu and Sun, 2010). Attention have been paid to the research on the knowledge flow in supply chain however the research is very limited and the subject is still in abstract form. In summary, these work are conducted by:

- Ameneh et. al. (2007) developed the conceptual model for knowledge flow in supply chain which divided the knowledge in supply chain into three levels as personal knowledge, group knowledge and organizational or inter-organizational knowledge, then he put forward the corresponding control measures.
- Garacia-Flores (2001) proposed the conceptual model for the knowledge flow in the supply chain by the relevant theories of agent and probed the effective factors through the process of knowledge communication among firms in supply chain.
- Zhang et. al. (2007) investigated the knowledge exchange process in and out of the firms in supply chain, and applied sensitive analysis to the effective factors.
- Wang et. al (2008) introduced a conceptual model facilitating a knowledge-sharing process as a supplement and a tool in this field. The authors applied the CBR (Case-based reasoning) technique supporting the formation of their conceptual supply chain knowledge-sharing model which has a focus on new knowledge creation based on previous knowledge in the supply chain at both strategic and operational levels.

Although the studies presented in this section are helpful to create better understanding on the knowledge flow in supply chain, there is no comprehensive work which discusses the knowledge chains in construction industry. Therefore, the activities to create knowledge chain are investigated in detail to provide a strong basis for the transformation of construction supply chains in to knowledge chains.

4.7.1 Knowledge Chain Activities

There are some KC activities that should be done to increase the awareness and responsiveness levels in organizations. These activities are firstly defined by Hollsaple and

Jisheng (2001) and then advanced by Jinxi and Jisheng (2001). According to Hollsaple and Jisheng (2001), there are primary activities called Knowledge Conversion Process and four secondary activities called Function Management of Knowledge Activities as shown in Fig 4-3 (Jinxi and Jisheng, 2001). Hollsaple and Jisheng (2001) categorized the primary activities as knowledge acquisition, knowledge selection, knowledge generation, knowledge internalization (assimilation) and knowledge externalization (emission), and the secondary activities as measurement, control, co-ordination and leadership. Jinxi and Jisheng (2001) categorized the primary activities as knowledge acquisition, knowledge application, knowledge creation, and the secondary activities as leadership and culture management; structure and human resource management; technology development. For a solid categorization, the KM life cycle was reviewed to establish the categorization in compliant with the KM processes that needs to be performed to transform supply chains into knowledge chains. Based on the work of Hollsaple and Jisheng (2001) and (Jinxi and Jisheng, 2001), this research categorised the knowledge model into 5 primary activities and 4 secondary activities as presented in Figure 4-3. These activities are described as follows:

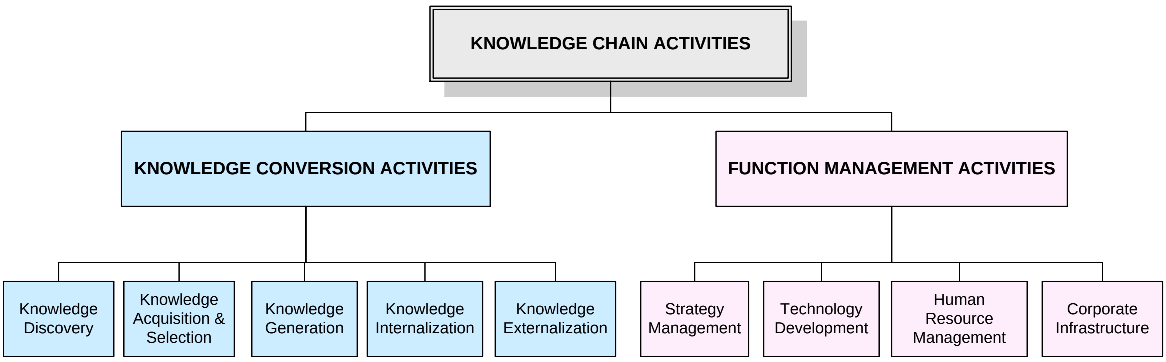

Figure 4-3 Activities of Knowledge Chain Process

Primary Activities (Knowledge Conversion Activities)

- **Knowledge Discovery:** This phase is about discovering and identifying who knows which kind of knowledge both internally and externally in the supply chain and which kind of knowledge is needed with associated internal and external sources. The activities of this phase involves focusing on knowledge of customer needs, including suppliers and customers in meetings to gather knowledge for defining a vision and strategy of a project, identifying knowledge dependencies in supply chain, utilizing relationships with supply chain actors, participating in Communities of Practices (CoPs), gathering advice from professional literature and consultants, appointing the supply chain actors with necessary expertise or hiring an employee.

- **Knowledge Acquisition & Selection:** This phase is about acquiring and capturing the identified knowledge from internal or external sources in the supply chain, transferring organized knowledge for immediate use or assimilating it within the organization for subsequent use and evaluating knowledge acquired in terms of its use for the generation task. The activities of this phase involves bringing the right information to the right people in an understandable context, capturing tacit and explicit knowledge, organising and participating project meetings or inter-organizational CoPs to gather knowledge, using relationships through the knowledge acquisition process, improving processes through the use of necessary technology.
- **Knowledge Generation:** This phase is about generating knowledge either from existing or external sources in the supply chain in a collaborative way where needed. The activities of this phase involves providing the right information in a context that aids collaborative decision-making in an organization or supply chain, fostering and providing access to rich pools of ideas so supply chain actors can capitalize on them, benefiting from lessons learned, using appropriate technology for the creation of new knowledge, including suppliers and customers in meetings to help make necessary alterations for the new product or create a future version of an existing product.
- **Knowledge Internalization:** This phase is about altering the state of an organization's knowledge resources by distributing and storing acquired, selected, or generated knowledge in a standardized way. A processor performing knowledge internalization receives knowledge flows and produces knowledge flows that impact the organization's state of knowledge. The activities of this phase involves developing a formal knowledge transfer process, using knowledge repositories to store knowledge for later use, using less structured repositories such as discussion databases or lessons-learned systems to store insights and observations, using technology or human means to transfer knowledge, informally sharing best-known practices across the enterprise, leveraging what people know, know-how and know-what, practicing organizational learning, participating in communities of practice, making experts' knowledge available by developing expert systems, using mentoring and storytelling as a transfer mechanism for knowledge.
- **Knowledge Externalization:** This phase is about embedding knowledge into organizational outputs for release into the supply chain or any other environmental use.

The activities of this phase involves integrating new knowledge into decision processes by sharing and collaborating with players and stakeholders in decision processes, establishing processes and tools to enable capture and sharing knowledge in order to support collaboration, participating in inter-organizational knowledge networks communities of practices, forming joint ventures with other organizations, providing technical support to the supply chain actors, creating products, and services, organising lessons learned and posting ideas.

Secondary Activities (Function Management Activities)

- **Strategy Management:** Establishing conditions that enable and facilitate fruitful conduct of KM such as providing a KM vision, leadership and fostering collaborative knowledge sharing culture in the organization and the supply chain supply chain.
- **Technology Development:** Developing technologies and tools which enable the effective transfer of knowledge within the organization and the supply chain actors.
- **Structure and Human Resource Management:** Organizing the structure of the organization and the supply chain in a way that enables effective knowledge transfer and diminishes skill deficiencies in the organization and the supply chain.
- **Corporate Infrastructure** which comprises measurement, control, corporation, protection and other support for the entire knowledge chain. *Knowledge measurement* is defined as assessing values of knowledge resources, knowledge processors, and their deployment. This includes quantitative methods, qualitative assessment, performance review, and benchmarking. From the supply chain perspective this should be an input of the supplier selection or assessment process of an organization. *Knowledge control* is defined as ensuring that needed knowledge processors and resources are available in sufficient quality and quantity, subject to security requirements. *Knowledge co-ordination* is defined as managing dependencies among KM activities to ensure that proper processes and resources are brought to bear adequately at appropriate times. It involves managing dependencies among knowledge resources, among knowledge manipulation activities, between knowledge resources and other resources (i.e., financial, human, and material), and between knowledge resources and KM activities.

All these activities need to be investigated in practice to propose the knowledge chain framework for the construction supply chain.

4.8 Transformation of Construction Supply Chains to Knowledge Chains

The idea of this research is mainly based on the positive outcomes of these KC activities. The flow and the effective flow and transfer of knowledge within the construction organizations will be investigated in detail under the light of Knowledge Conversion Process. It is believed that this will help to increase the quantity and the quality of shared knowledge between and within organizations in the construction supply chains. The creation of an effective KC can overcome the defined issues in the construction industry. Function Management activities which provide a collaborative environment for fluent flow of knowledge are considered to be very helpful in the creation of common goals, vision and strategy between the supply chain actors. This is an important step for the creation of long term collaborative relationships and partnering opportunities. Improvements in skill deficiencies in organizations by HRM activities and ICT or collaboration technology applications can also enable the flow of knowledge in construction supply chains. All these activities will increase the awareness of employees on KM, and willingness to share knowledge. Systematic application of these activities will also help to change the adversarial culture in construction, and improve trust within and between the organizations. Finally the premise in this research is the creation of knowledge chains in construction that will have a significant impact on supply chain integration.

In Figure 4-4, the SC actors adopting SCM and KM through the knowledge chains are presented. In this ideal context, the steps of the knowledge conversion processes should be visible to the SC actors. The actors should be well informed about the knowledge creation, sharing and storage process and the tools that enable the creation and transfer of knowledge. They need to be aware of the knowledge dependencies amongst SC actors. There must be well developed procedures and tools in place for the continuous flow of knowledge in both upstream and downstream SC. The possible outcomes of the adaptation of Function Management of Knowledge Activities are considered as follows: to support common goals and strategy between organizations, provide partnering opportunities, create knowledge sharing culture, increase trust, improve the organization skills and create compatibility for better communication. The premise in this research is the function management of knowledge activities when combined with the knowledge conversion activities will improve the information and knowledge flow, integrate the SC and bring innovation in long term. Thus, the construction SCs will transform to KCs.

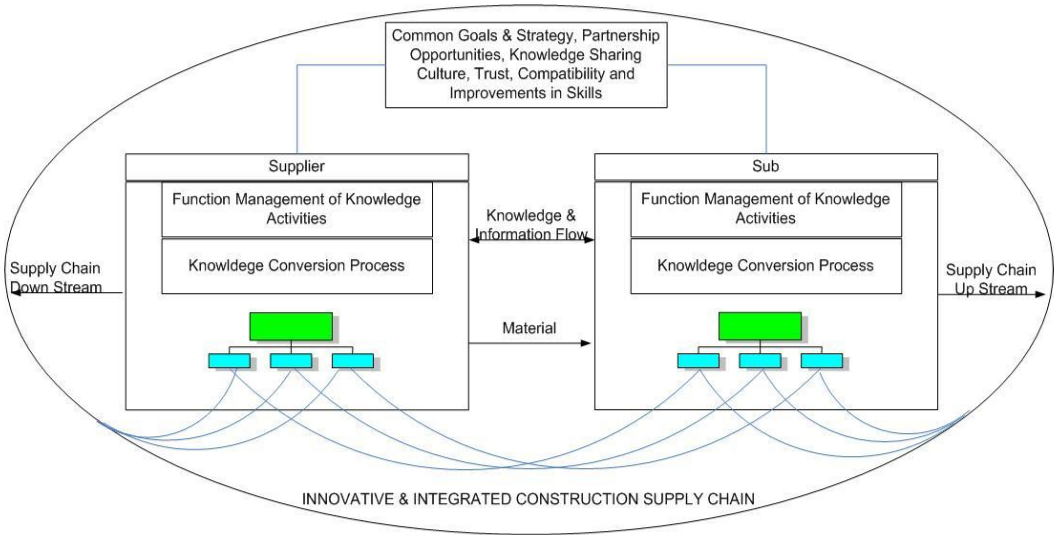

Figure 4-4 Supply Chain Actors Adopting SCM and KM, through KC Adapted from (Holsapple and Singh, 2001)

4.8.1 A Systematic Approach to KM in Construction Supply Chains

The integration of KM practices, by considering both the social and technical perspectives, can be very helpful to produce high quality, lower costs, and just in time knowledge sharing within construction supply chains. This integration can benefit significantly from a systematic approach. The application of a systematic approach facilitates determining that problems exist, refining the problems, generating possible solutions within a defined set of limiting conditions (constraints) and determining which solutions are best according to the stated criteria (Jewell, 1986). This approach recognizes that a problem and its solution have many elements or components and there are many different relations among them (Sage and Armstrong 2000). Therefore, this will help to define components, decide which components should be included in the system, and define how the components are related to each other (Holmberg, 2000). Parnaby (1995) states that organisations which use a systematic approach in their operations deliver better engineering solutions throughout all their activities. Using this approach can be very helpful in anticipating a variety of viewpoints and requirements and planning for accommodating these viewpoints and requirements (Jewell, 1986). The structurist character of the systems approach can be very helpful in building the structure, processes or operations of the construction supply chain in a systematic manner assuring its effective functioning (Vrijhoef and Ridder, 2007).

4.9 Chapter Summary

This chapter has reviewed the knowledge management concepts, benefits of knowledge management in construction, knowledge chains and need for a systematic approach to knowledge management in construction supply chains. In light of the literature review the following issues were revealed:

- The research in the field of KM has also sought to look into different aspects of organization and management of knowledge in different conditions and in different contexts. Similar to SCM, KM has a lack of consensus on a unique KM definition and theoretical background; however this can be accepted as an evidence of the richness of the concept. Knowledge Management can be considered as a multidisciplinary area, and the conventional demarcations in traditional subject areas are not comprehensive enough to establish the theoretical background of KM.
- The integration of KM practices by considering both the social and technical perspectives can be very helpful to produce high quality, lower costs, and just in time knowledge sharing within construction supply chains. KM can facilitate the transfer of knowledge across a variety of project interfaces, bring increased intellectual capital and innovation, improve performance and project delivery, help firms to avoid repeating past mistakes, retain tacit knowledge, become agile, minimize risks. Therefore KM based Construction SCM will change the problematic nature of current construction SCM. Thus the premise of this research, the transformation of supply chains into knowledge chains is a significant change for construction supply chains.
- The creation of knowledge chains involves fundamental knowledge conversion activities such as knowledge discovery, acquisition, generation, and supporting activities such as HRM, strategy management, technology implementation. To enable the transfer of construction supply chains to knowledge chains, these activities and practices should be investigated further in practice and appropriate solutions should be proposed for the use of construction industry.

In the next Chapter, the research methodologies are reviewed to find the best effective research method to develop the 'knowledge chain' framework.

CHAPTER 5

5 RESEARCH METHODOLOGY

This chapter discusses the various methodologies available in the field of supply chain and knowledge management and justifies the choices that have been made in the selection of an appropriate strategy.

5.1 Definition Of Research

Research has several definitions in the scientific literature. Some of these definitions are:

"A systematic inquiry to provide a better understanding of a phenomenon and/or change a social circumstance (Marshal and Rossman, 2006).

"A procedure by which we attempt to find systematically, and with the support of demonstrable fact, the answer to a question or the resolution of a problem (Leedy, 1989)

"A `voyage of discovery`, whether anything is discovered or not. The depth of discovery depends on search techniques, the knowledge and abilities of researchers, the location and the subject of the material" (Fellows and Liu, 2003).

These definitions highlights the key elements of research such as the research problem, systematic approach, research techniques, depth of researcher's knowledge, empirical and critical investigation, and presentation of demonstrable facts. This reveals that the practice of research is much more than philosophical assumptions. Therefore, philosophical ideas should be combined to form research strategies and achieved using specific methods (Creswell, 2003). In other words, in order to conduct a research, suitable methodologies defining how the research shall be conducted and specific research approach and methods fitting the methodology should be employed (Silverman, 2001).

The philosophical research orientation may stem from one of the several characteristics, paradigms and approaches in research which will be introduced in the following sections.

5.2 Research Process

Figure 5-1 presents how the research process should work in the ideal world. The following part explains the details of research process.

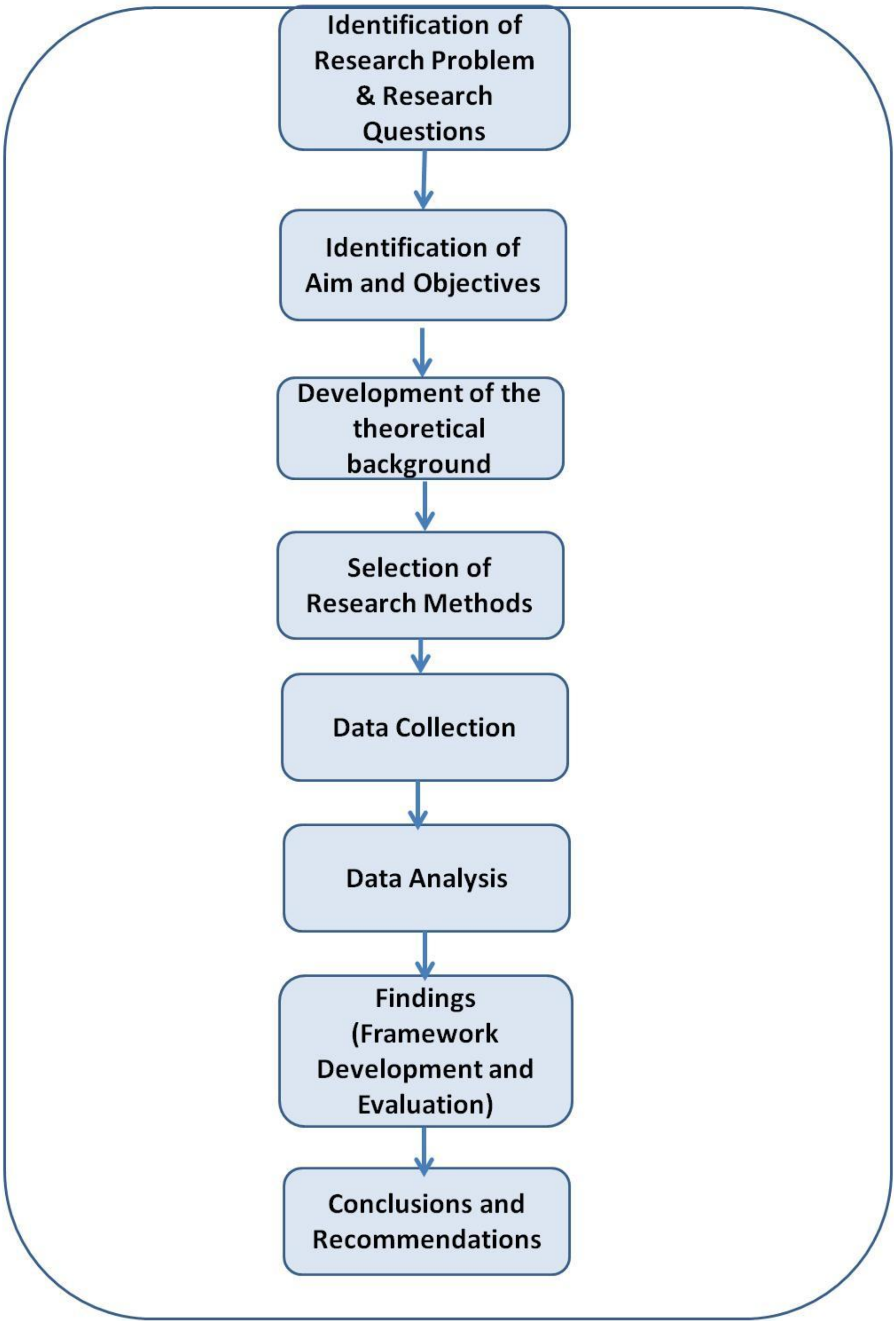

Figure 5-1 Research Process (adopted from Fellows and Liu, 2003)

- *Identification of research problem and research questions:* In all research projects, there is a need to define the research problem clearly. Depending on the nature of research problem, methods for investigation can be defined (Walliman, 2006). In this research, the research problem is identified based on a detailed literature review. The gaps and issues in the industry are investigated and the main questions which can address these issues are identified.

- *Identification of aim and objectives:* The aim of a research project is a strategic level statement of what the research project and researcher will attempt to do. The objectives are statements within the strategic statement of aim and they are designed to be at operational level. Objectives are statements which are related to each other logically but also individually they describe what the research hopes to discover throughout the study (Fellows and Liu, 2003). The key aim and objectives of this research are identified to address the research problem and questions.

- *Development of theoretical background:* During this stage the theory of the research should be identified. While working on the theoretical development, the ontological, epistemological and methodological approach should be identified. This identification establishes the fundamentals of the research.

- *Selection of Research Methods:* Once the research questions, aims and objectives and theoretical background of the research project are interrelated to each other, appropriate research methods should be identified.

- *Data Collection:* Data can be defined as the essential raw material of any kind of research project (Walliman, 2006). There are two main types of data which are:
  - Primary Data: This type of data are present around people so that their senses deal with them all through sounds, visual, stimuli, tastes. Primary data can be collected through observation, interviews, or questionnaires.
  - Secondary Data: The type of data which has been interpreted and recorded. News, broadcasts, magazines, newspapers, documentaries, books, published journals can be classified as secondary data. Therefore, it is always important to make an assessment of the quality of the information or opinions provided through secondary data sources.

According to the research method applied, primary and/or secondary data should be collected.

- *Data Analysis:* Data analysis can be grouped into quantitative and qualitative analysis and explained as follows (Walliman, 2006) :
    - Quantitative analysis works with numbers and utilizes mathematical operations to investigate the properties of data. Statistics is one of the important type of analysis and statistical methods are valuable tools to enable researchers to disseminate the data and to discover and quantify relationships. These techniques are user friendly computer programs (such as Excel and SPSS – Statistical Package for the Social Sciences) and will carry out all the presentation and calculations for the analysis of the various results (Walliman, 2006).
    - Qualitative data cannot be analysed by mathematical means such as statistics. Unlike the well-established statistical methods of analysing quantitative data, qualitative data analysis is still in its early stages of development. The certainties of mathematical formulas and probability calculations are not applicable to the 'soft' nature of qualitative data, which depends on human feelings, attitudes and judgements. Unlike quantitative analysis, there are no such standard procedures for codifying and analysing qualitative data. However, there are some certain activities that are necessary in all qualitative data analysis. Miles and Huberman (1994) suggest that there are three concurrent flows of action:
        - data reduction
        - data display (for example networks, charts, tables)
        - conclusion drawing/verification.
- *Findings, Conclusions and Recommendations: After the research project has been restructured, the theory and literature studied, the data collected and analysed, the following stages are (Fellows and Liu, 2003) :*
        - to generate results;
        - to examine and discuss the results of research work in the context of theory and literature;
        - to draw conclusions and make recommendations while describing the limitations of the study.

The findings should be related to analysis of data while the conclusions use those results together with theory and literature in order to determine what has been found out throughout the research. One of the important criteria is the evaluation and validation of the work in the findings. Evaluation is the process by which the researcher provides an account of the findings and the recommendations to participants and checks the agreement or disagreement of the account by these participants. (Bryman and Bell, 2003). The evaluation or application of the research lead recommendations for further research areas and inform the development of following research projects (Fellows and Liu, 2003). In this research, the analysed data provided insight to develop the knowledge chain framework. The framework was also evaluated by the industry practitioners to identify the strength, limitations and potential development areas of the framework.

5.2.1 Characteristics of Research Process

The research process must have certain characteristics (for example controlled, rigorous) as identified below (Kumar, 2005):

- *Controlled:* In real life, there are many factors that affect an outcome. In a study of cause and effect relationships, it is important to be able to link the effects with the causes and vice versa. However, in practice and even in the social sciences, it is quite difficult to create the link. The concept of control means exploring causality in relation to two variables where the effects of other factors affecting the relationship are minimised. However, in social sciences it is extremely difficult as research is carried out on issues relating to human beings and society where such controls are impossible. In this research, the factors which can affect effective knowledge flow and knowledge sharing in construction supply chain were investigated in detailed case studies and literature review. To be able to link the effects with the causes, the amount and the detail level of the data were organised in a way which can provide different perspectives of industry practitioners.
- *Rigorous:* The procedures followed to find answers to questions are relevant, appropriate, and justified. The degree of rigour varies between the physical and the social sciences. The research methods were investigated and the most appropriate ones are identified and justified.
- *Systematic:* This means that the procedures adopted to undertake an investigation follow a certain logical sequence.
- *Valid and Verifiable:* This implies that whatever concluded on the basis of findings is correct and can be verified by the researcher and others.

- *Empirical:* This means that any conclusions drawn are based upon hard evidence gathered from information collected from real-life experiences and observations. To explore real-life experiences case studies in construction and aerospace firms were organised.
- *Critical:* Critical scrutiny of the procedures used and the methods employed is crucial to a research inquiry. The process of investigation must be free from any drawbacks and the process adopted must be able to withstand critical scrutiny.

Throughout the research process the above characteristics were followed and implemented. Prior to discussing the research methods adopted for this research, the theoretical background of research, and the methods used in construction research are reviewed.

5.3 Fundamentals Of The Research Process

Remenyi et al (1998) state that the epistemological, ethical and ontological assumptions of the research should be considered at the beginning of a research process. It is essential to present ontology and the epistemology before the research method section because ontology logically precedes epistemology which logically precedes methodology (Hay, 2002).

5.3.1 Research Ontology

Ontology is the starting point of all research, after which one's epistemological and methodological positions logically follow (Grix, 2002). Ontology is concerned with the theory of social entities and the key issues there exists to be investigated (Walliman, 2006). Reich, (1994) defines the central ontological question as: *"Do we know things about the real world, or is our knowledge a reflection of our manipulation of the world*?"

The main theoretical positions of ontology are those contained within the perspectives 'objectivism' and 'constructivism (Grix, 2002, Walliman, 2006; Bryman, 2008).

- Objectivism is 'the belief that social phenomena and their meanings have an existence that is not dependent on social actors' as they are 'facts that have an independent existence'. A characteristic of an objectivistic worldview is the existence of objective, absolute and unconditional truths (Lakoff and Johnson, 1980).
- Constructivism is 'the belief that social phenomena are in a constant state of change because they are totally reliant on social interactions as they take place' (Walliman, 2006). Constructivist researchers mostly address the processes of interaction among

individuals and also focus on the specific contexts in which people live and work in order to understand the historical and cultural background of the participants (Blaxter, 2001; Creswell, 2003).

Objectivism deals with absolute facts which are independent of the social factors whereas constructivism is more about investigating the dependencies between actors. In this research, constructivist approach was followed since the effectiveness of knowledge flow process depends on the relationships and the availability of systematic and coordinated interactions between the supply chain actors. Therefore, all these interactions are considered with a focus on knowledge flow context.

5.3.2 Epistemology

Epistemology is concerned with the theory of knowledge, especially in regard to its methods, validation, the possible ways of gaining knowledge of social reality, and relation between humans and their knowledge (Grix, 2002, Coghlan and Brannick, 2005; Fellows and Liu, 2008). The central epistemological questions are defined as: *"What can we know? How do we know? What is truth? Is there a priori knowledge, and if so, of what?* (Bryman, 2008; Walliman, 2006).

The two theoretical positions of epistemology are those contained within the perspectives 'positivism' and 'interpretivism' (Grix, 2002, Walliman, 2006; Bryman, 2008).

- <u>Positivism:</u> Positivism derives from scientific thinking. This is the view that social science procedures should reflect, as similar as possible, those of the natural sciences. It is possible to capture `reality` through the use of research instruments such as experiments and questionnaires (Blaxter, 2001).
- <u>Interpretivism</u> is defined as the 'recognition that subjective meanings play a crucial role in social actions', which aims to reveal interpretations and meaning (Walliman, 2006). The interpretivist approach is also sometimes referred to as the hermeneutic, phenomenology, constructivist, postmodern interpretivism relativist approach (Coghlan and Brannick, 2005).

Interpretivisim is more about understanding the meaning of actions from actors' perspectives whereas positivism is more about developing facts or laws based on quantitative methods. In this research, the supply chain actors are the social actors that contribute to the supply chain relationships and knowledge flow process. The main aim of the data collection and analysis process is to reveal the key supply chain and knowledge flow issues, and the meaning behind these issues. Therefore, this research has an interpretivist approach which considers the meaning of supply chain issues from the different actors' perspectives.

5.3.3 Research Methodology

Research methodology is the framework associated with a particular set of assumptions that is used to conduct research (O'Leary, 2004). Research methodology is informed by what we know philosophically and its applications affect what we come to know (Smyth and Morris, 2007).

Research methodology is concerned with the logic of scientific inquiry; in particular with investigating the potentialities and limitations of particular techniques or procedures. The term pertains to the science and study of methods and the assumptions about the ways in which knowledge is produced (Grix, 2002). Grix highlights the differences between research methodology and research methods and states that methodology is concerned with the logic, potentialities and limitations of research methods and that the term is often confused and used interchangeably with the research methods themselves. The method(s) chosen for a research project are inextricably linked to the research questions posed and to the sources of data collected (Grix, 2002).

5.3.4 Relationship between Epistemology, Ontology and Research Methodology

To conclude, ontology can be defined as what we may know, then epistemology is about how we come to know what we know. The clear identification of the interrelationship between what a researcher thinks can be researched (their ontological position), linking it to what we can know about it (their epistemological position) and how to go about acquiring it (their methodological approach), the researcher can begin to comprehend the impact one's ontological position can have on what and how they decide to study (Grix, 2002).

Figure 5-2 presents the main steps that a researcher should take to establish a systematic approach to find solutions to a research question. At the beginning of a research project, the researcher should establish the ontological and epistemological background of the research. In this research, the research question deals with the understanding of collaboration, communication and KM practices between various organizations from different backgrounds.

It is dependent on the actors within the whole supply chain. Following establishing the ontological and epistemological basis of the research, potentialities and limitations of particular techniques or procedures are investigated to establish the research methodology of the research.

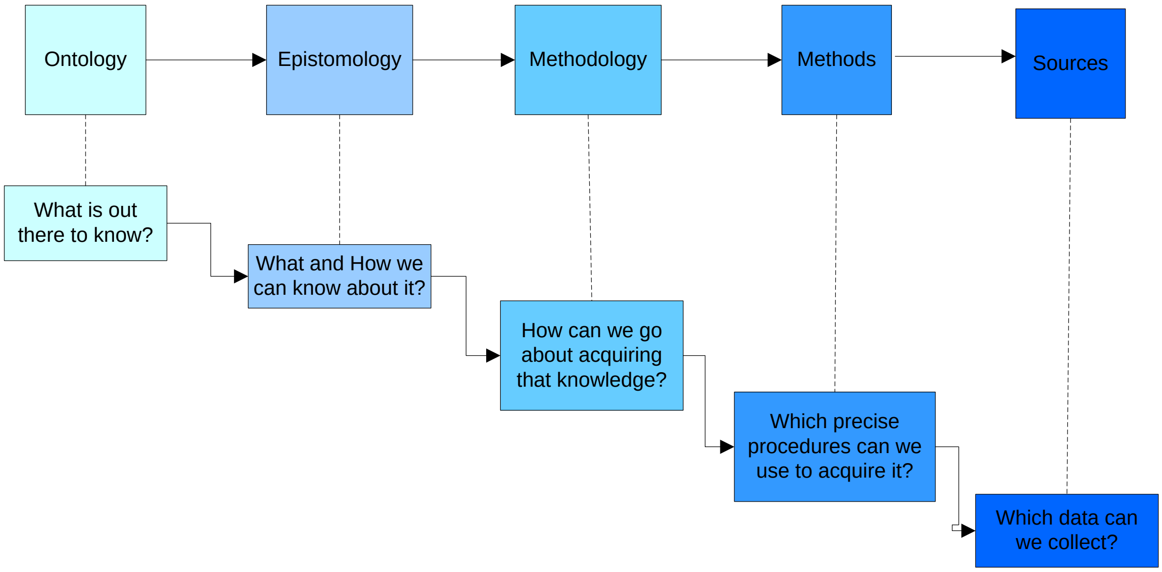

Figure 5-2 Systematic Approach to Research Process

5.4 Research Methods

A research method is a technique for collecting data and it can involve a specific instrument (Bryman, 2004). Methods themselves should be seen as free from ontological and epistemological assumptions, and the choice of which to use should be guided by the research questions (Grix, 2002). According to Fellows and Liu (2003), the research methods most involves different methods such as action research, ethnographic research, survey research, case studies and experimental research. These methods are described in the following section.

5.4.1 Action Research

The researcher actively participates in the process in order to identify and evaluate problems and potential solutions. Action research suggests and tests solutions to particular problems. Change/innovation is the main focus of the research and coordination is essential between researcher and participants (Fellows and Liu, 2003; Coombes, 2001). According to Gittins (2007), researchers should try out their theories with industry practitioners and organizations. Blaxter et al. (2001) defined the aim of action research as the continuous improvement of real practice. Coombes (2001) defined action research as an investigation focused on a particular issue of current concern with the aim of implementing a change in a specific situation. Therefore the disadvantage of this method is its high level of dependency on a single organisation. The advantage in this method is being based on practice and using the validity criteria and validation processes based on involvement in the practices (Wisker, 2001). Wisker (2001) defined the steps in action research as follows: focus on the problem, produce a general plan of action, action step, monitoring step, collect the data, evaluate the results, and then reformulate the plans.

5.4.2 Ethnographic Research

McNeill (1990) defined `ethnography` as `writing about a way of life`. Ethnographic research has replaced studies using participant observation since the early 1980s (Flick, 2006). It is concerned with the study of people and cultures and has its foundation in anthropology. In this type of research, a group of researchers observe subjects in detail in order to gain insights into how, what and why people's behaviours occur. McNeill (1990) defined the purpose of ethnographic research as being *"to describe the culture and life style of the group of people being studied in a way that is as faithful as possible to the way they see it themselves."* The essential elements of ethnography are interviews, observations and examination to gain understanding of the respondents` perspective (Fellows and Liu, 2003). The strengths of ethnographic research methodology come from creating new ideas and insights and its weakness comes from the subjective nature of the process (Ganah, 2003). The disadvantages of this style of research include being very laborious and time-consuming due to the involvement of the researcher full-time for extended periods without doing any other work (McNeill, 1990).

5.4.3 Survey Research

Blaxter et al. (2001) defined survey research as the method of collecting information by asking a number of predefined questions in sequence in a structured questionnaire to a sample of respondents selected to be representative of a specific population. The aim of surveys are to collect information from sampling frames, which include a number of respondents, to identify more specific characteristics among groups. Surveys are based on probabilistic or non-probabilistic sampling and vary from the use of questionnaires to structured interviews. In probability sampling, each element has an equal probability of being included in the sample and the inclusion of each element is an independent decision, on the other hand, non-probabilistic sampling uses best judgement to decide which elements are the best representative of the population (Judd et al., 1991).

- Questionnaire Surveys: The questionnaire survey is the most commonly used research method and can be used to gather information on any topic from large or small numbers of people. It is a written list of questions and the answers are recorded by respondents. Questionnaires must translate the research objectives into questions and the answers will provide data for further research (Frankfort-Nachmias and Nachimas, 1992). The main advantages of questionnaires are the ease of completion and analysis, access to dispersed respondents and accuracy (Kumar, 1999; Moore, 1983; Rothwell, 1993). In questionnaires, questions have to be clear and easy to understand because there is no one to explain the meanings of questions. Questionnaires are an inexpensive way to obtain information from the respondents and sometimes increase the likelihood of obtaining accurate information for sensitive questions. On the other hand, the main disadvantages of questionnaires are low response rate and some delay in getting results (Kumar, 1999; Rothwell, 1993; Bernard, 2000). Response rate is the main index of data quality in a questionnaire survey since it defines the extent of possible bias from non-response (Judd et al., 1991). Furthermore, besides the response rate, data quality is affected by the accuracy and completeness of the questionnaire (Judd et al., 1991).

- Interviews: Interviewing is a commonly used method of collecting information from people. Chadwick et al. (1984) defined the research interview as a two-person conversation, manipulated by the researcher for the specific purpose of gaining related information on research by the use of specified research objectives. Interviews are classified according to the degree of flexibility as structured, semi-structured and unstructured. A structured interview is prepared before the meeting with the respondent and it provides uniform information (Kumar, 1999; Lang and Heiss, 1985). Structured interviews are built around a questionnaire and use an interview schedule which is a clear set of instructions to interviewers who asks questionnaires orally (Bernard, 2000). Structured interviews are a helpful research tool when straightforward data is needed and questions are prepared (Coombes, 2001). Semi-structured interviews provide much more scope for the discussion and recording of respondents` opinions and views (Moore, 1983; Coombes, 2001). Using a semi structured interviewing technique is suitable in projects where the researcher is dealing with managers, bureaucrats, and elite members of a community (Bernard, 2000). Unstructured interviews are based on a clear plan that the interviewer keeps in mind and is characterized by the respondent's responses. The aim in unstructured interviewing is to get people to `open up` and let them express their ideas, beliefs, experiences in their own terms (Bernard, 2000). Unstructured interviews are suitable for researchers who have enough experience to obtain the required data (Coombes, 2001). Interview surveys have a great deal in common with questionnaire surveys (Moore, 1983). Interview techniques are more appropriate to collect in-depth information and can cover a wider area of application than questionnaires (Kumar, 1999). The main advantage of interviews is that they provide more opportunity to obtain qualified answers and to clarify or restate questions that the respondent cannot understand (Moore, 1983; Singleton, 1988). Interviews can be used to gather information in order to supplement information provided in a questionnaire and to help pilot a questionnaire and interview with a few people to test out the questions (Wisker, 2001). The strengths of interviewing are: face-to-face meeting with respondents, obtaining large amounts of data, and facilitating cooperation and collaboration (Greenfield, 1996). The disadvantages of interviews include being time-consuming, expensive and providing information that can be difficult to analyse. Moreover, interviews may be more subjective than questionnaires (Kumar, 1999; Moore, 1983). Other weaknesses of interviewing are that they can be open to misinterpretation due to cultural differences; are dependent on the honesty of interviewees and on the ability of researchers to be resourceful, honest and systematic. They can also be difficult to replicate (Greenfield, 1996).

A brief comparison of the advantages and disadvantages of using questionnaires and interviews are presented in the following Tables 5-1 and 5-2 below (Bernard, 2000):

Table 5-1 Advantages vs. Disadvantages of using Questionnaires

Advantages of Questionnaires	**Disadvantages of Questionnaires**
Low cost	Having no control over how people react questions
Same questions to respondents (standard)	Low reliability
Having chance to ask long questions	Not suitable for illiterate or non-literate populations
Easy to conduct and quick response	Low response rates

Table 5-2 Advantages vs. Disadvantages of using Interviews

Advantages of Interviews	**Disadvantages of Interviews**
Can be used with people who are illiterate, blind, or very old	Costly in both time and money
Having chance to explain questions	Limited number of respondents
Use different data-collection techniques	Needs experience
Long enough to capture valuable information	Subjective

5.4.4 Case Studies

This type of research facilitates deeper investigation of particular areas within the research subject and employs various data collection methods (Fellows and Liu, 2003). Blaxter et al. (2001) define a case study as the method of choice when the subject under research is not readily distinguishable from its context. Heath (1998) defines a case study as *"an account or description of a situation, or sequence of events, which raises issues or problems for analysis and solution."* Gillham (2000) defines a case study as *"an investigation of specific research questions and a range of different kinds of evidence, evidence which is there in the case setting, and which has to be abstracted and collated to get the possible answers to the research questions"*. Case studies are the preferred strategy when "how" or "why" questions are being asked, when the researcher has less control over events and when the focus is on a real-life context (Yin, 2003). Case study development can be divided into the following steps (Heath, 1998):

- Data Collection- interviews, observation;
- Restructuring data - deciding the structure, writing and editing.
- Case enhancement- supplementary word, audio, and video material.

Case studies employ various methods including interviews, participant observation, and field studies (Hamel et al., 1993). Case study data comes from different sources such as interviews, observations, company reports, and the writer's own experience (Heath, 1998; Yin, 2003). Interviews and observations are undertaken when the researcher wishes to record what is actually happening within the organization and the views about the organization's present and past situation (Heath, 1998). In case studies, it is important that researchers should know what they want to do and how to do (Heath, 1998). The most important form of interviewing in case study research is the semi-structured interview, which is the richest single source of data due to being very flexible and natural (Gillham, 2000). Observation can be a rich source of information for case study research and enables the researcher to capture what people actually do (Wisker, 2001). Observation is the most basic method for obtaining information and a selective way of watching and listening to an interaction (Kumar, 1999; Chadwick et al., 1984). The idea of observation underlies all the methods used by researchers in their data collection (Chadwick et al., 1984). When the researcher participates in the activities of the group as a member, it is called *participant observation*. When the researcher is not involved in the activities of the group and just observes the situations, this is called *non-participant observation* (Kumar, 1999). Case study research does not only include qualitative methods and data; quantitative data and its analysis can add to the overall picture (Gillham, 2000). The data are to be collected from people and organizations; therefore, in a case study the researcher should understand how to integrate real-world events with the needs of the data collection plan (Yin, 2003). Having all these in mind, the major tasks to collect data for the research are as follows (Yin, 2003):

- Gaining access to key organizations or interviewees;
- Having sufficient resources in the field (for example computer, recorder, etc.);
- Making a clear schedule of the data collection activities which are planned to be completed within a specific period of time;
- Being ready for the changes in the availability of interviewees.

The reporting phase of the case study is one of the most difficult parts to carry out and the best way is to combine the portions of the case study early rather than waiting until the end of the data analysis process (Yin, 2003). The last step for the research is the evaluation of the work done within the case studies and general research context. Weiss (1998) defined evaluation as "*systematic assessment of the operation and/or the outcomes of a program or policy, compared to a set of explicit or implicit standards, as a means of contributing to the improvement of the program or policy."* Weiss (1972) defined the purpose of evaluation research as "*to measure the effects of a program against the goals it set out to accomplish as a means of contributing to subsequent decision making about the program and improving future programming."* The five key elements for evaluation in these definitions are systematic assessment, the operation and outcomes of the program, standards for comparison and contribution to improvement. The evaluator's responsibility is to create an evaluation format that fits the questions to be asked and evaluation design should indicate which people or units will be selected, what kind of comparisons will be drawn and the timing of the investigation (Weiss, 1998). An easy way of collecting data for the evaluation stage is to develop a survey form that asks structured and unstructured questions about the research study (Weiss, 1998).

Bryman (2008) highlights that advantage of the case study research due to usage of both quantitative and qualitative methods in the analysis. This is advantageous as it enables a researcher to evaluate different sources of data to test a particular theory or concept on the basis that a consensus of the findings will yield more robust results (Proverbs and Gameson, 2008). One of the biggest disadvantages to using the case study method has to do with external vs. internal validity. Using the case study method, the PhD researcher often does not have control over certain variables and events and, therefore, cannot control them as the researcher could in a lab experiment. Consequently, the researcher using the case study method must be content that his/her findings may only be applicable to similar cases (Guba and Lincoln, 1993). Beyond the disadvantages, the case study can achieve many of the same goals as other methods. For example, the case study can be exploratory (create new knowledge), constructive (solve some problem), or confirmatory (test a hypothesis with empirical evidence).

5.4.5 Experimental Research

This type of research is best suited to `bounded` problems or issues in which the variables involved are known or hypothesized. Generally, experiments are carried out in laboratories and aim to test relationships between the defined variables (Fellows and Liu, 2003). However, randomized experiments can also be conducted in real-life environments (Judd et al., 1991). Experimental designs and procedures maximize the internal validity of research and, unlike field experiments, laboratory experiments are poor representations of natural processes (Judd et al., 1991). Moreover, there is no way to control all the possible independent variables in field experiments (McNeill, 1990). An important criticism about experimental research is that experiments do not provide useful descriptive data like survey research. Although surveys provide descriptive data about the population, experiments provide information about causes and effects and do not provide descriptive data about percentages of people in the population (Judd et al., 1991).

5.5 Research Approaches

Research approaches are commonly classified as: *qualitative, quantitative and mixed* (triangulation) approaches (Creswell, 2003). The quantitative and qualitative paradigms offer a basic framework for dividing into two areas.

5.5.1 Quantitative research

Quantitative research is a type of research where the data is in the form of numbers (Blaxter et al., 2001). The quantitative approach basically uses post-positivist claims for developing knowledge (i.e. cause and effect thinking, reduction to specific variables and hypotheses, use of measurement and observation and testing of theories), selects strategies of inquiry such as experiments and surveys and accesses numerical data (Creswell, 2003; Fellows and Liu, 2003).

5.5.2 Qualitative Research

Qualitative research is a type of research where the data are not in the form of numbers (Blaxter et al., 2001). Chadwick et al. (1984) defined qualitative research as: "*several different modes of data collection, including field research, participant observation, in-depth interviews, ethno-methodology, and ethnographic research.*" In qualitative research, the exploration of the research subject is undertaken without past formulations and the aim is to collect information and data for future emerging theories. Therefore, qualitative research is a precursor to quantitative research and the data gathered may be unstructured (Fellows and Liu, 2003). The qualitative approach is based on constructivist perspectives (i.e. multiple meanings of individual experiences, meanings socially and historically constructed.) or advocacy/participatory perspective (i.e. political, issue-oriented, collaborative or change oriented) (Creswell, 2003). The limitations of the quantitative approach is a starting point to use qualitative research since the main ideas surrounding qualitative research are different from those in quantitative research (Flick, 2006).

5.5.3 Comparison of Quantitative and Qualitative Research

To make a decision on the research approach appropriate for this thesis, the similarities and the differences of these two approaches are investigated. These are presented in Table 5-3 (Adapted from Blaxter et al., 2001; Bryman, 2004).

Table 5-3 The differences between qualitative and quantitative research

Qualitative	**Quantitative**
Natural and uncontrolled observation	Controlled measurement
Subjective	Objective
Process-oriented	Outcome oriented (static)
Close to the data: more inside perspective	Concluded from the data: outside perspective
Dynamic reality and ungeneralizable	Stable reality and generalizable
Micro	Macro
Rich, deep data	Hard, reliable data
Theory emergent	Theory testing

Blaxter et al. (2001) and Bryman (2004) explained the similarities and differences as follows:

- Quantitative research is mostly used for testing theory; on the other hand, it can also be used for exploring an area and generating hypotheses and theory.
- Qualitative research can be used for testing hypotheses and theories. However, it is mostly used for theory generation.
- Qualitative data often include quantification (for example statements like `more than`, `less than`, `most`).
- Quantitative research methods, such as large-scale surveys, can collect qualitative data through open-ended questions.
- Quantitative data are often called `hard` in the sense of being robust and having the precision offered by measurement. On the other hand, deep involvement of qualitative researchers results in rich and deep data.
- In quantitative research, researchers are not involved in their subjects due to their subjectivity concerns. However, the qualitative researcher seeks close involvement with the respondents being investigated.
- Quantitative researchers are often involved in large-scale connections between variables whereas qualitative researchers are concerned with small-scale aspects of social reality.

Quantitative research is a static image of social reality with its emphasis on relationships between variables whereas qualitative research is interconnected with the actions of the participants of social settings.

5.5.4 Triangulation Research Approach

The mixed approach (triangulation) uses the strategy of collecting data either simultaneously or sequentially to best understand research questions. Triangulation means combining qualitative and quantitative methods (Flick, 2006). This approach uses both numeric (for example instruments, surveys) and textual (interviews) data collection techniques. Triangulation is very helpful for gaining results and to assist in making inferences and drawing conclusions (Fellows and Liu, 2003).

5.6 Adopted Research Methods And Justification

The decision was taken to use a combination of qualitative and quantitative methods as the most appropriate research approach for this study. Furthermore, it was considered that a combined research strategy would enable the findings from each stage of the project to inform and refine the following stages and also support the reliability and validity of the research. Table 5-4 summarizes the overall research objectives, research questions and applied methodologies as follows:

Table 5-4 Summary of research objectives, research questions and applied methodologies

Objectives	Research Questions	Research Methods
1. Review state of the art of issues and practices in SCM and KM in construction and across a range of industry sectors to learn and establish opportunities for improvement in the construction industry;	• What are the key issues defined in SCM literature in construction and other industries including automotive and aerospace? • What is a knowledge chain and how can it be created?	• Literature review
2. Investigate SCM practices with a particular focus on KM within construction and other industries (automotive and aerospace), to establish best practices and opportunities for improvement in construction industry.	• What are the key SCM practices within construction and other industries (including automotive and aerospace)?	• Literature review • Case studies which involves structured and semi structured interviews
3.Identify the knowledge requirements of different sectors of the construction supply chain, the interdependencies across the supply chain, and the key issues related to knowledge flow leading to the development of a knowledge chain in construction industry.	• What are the key knowledge requirements of different disciplines of the construction supply chain and the interdependencies across the supply chain? • What are the key knowledge flow issues throughout the project lifecycle from the perspective of different supply chain actors?	• Literature review • Case studies which involves structured and semi structured interviews
4. Develop and evaluate a framework for transforming the construction supply chain into a knowledge chain taking full cognisance of both the technical and social aspects of KM.	• Can the knowledge chain framework address the key SCM issues of construction and promote knowledge flow?	• Workshops and Questionnaire for evaluation

As presented in Table 5-4, the research objectives, and the research questions which need to be addressed in the data collection process are presented. The data collection method which can provide the necessary information to reach each objective of this research is also presented. The adopted methodologies for this research are identified as literature review and case studies for data collection process and workshop and questionnaire for the evaluation of the framework. All these methods adopted in this research were based on the constructivist ontological approach and interpretivist epistemological approach due to the nature of SCM research. For example, in this research, the literature review and the content of the case studies investigated the factors which affects the supply chain relationships, the supply chain integration issues and the interactions between supply chain actors while sharing project knowledge. The key knowledge flow issues, the meaning behind these issues were also discussed. The following sections will address these methods and their justifications for each research objective.

5.6.1 Literature Review

A literature review is 'the study on the selection of available documents, which contain information, ideas, data and evidence from a particular standpoint to achieve predefined aims and objectives' (Hart, 1998). According to Saunders (2009), the critical literature review is a basis on which research is built. The main starting point of the research is the literature review which is often called 'desk research' and its aim is to identify what has been done before and to justify the research. A literature review is a continuous process. It begins before the finalisation of the research problem and continues until the research is completed. The literature review brings clarity and supports the methodology. A literature review for a proposal or a research study means finding and summarising the previous or existing studies about the research topic (Creswell, 2003). The research process is concerned with collecting data and processing it into information (Moore, 2000). The main sources for the literature review are published books, journal articles, and recent conference papers and published theses (Kumar, 1999; Creswell, 2003). Nowadays, Internet and databases are essential repositories for accessing various magazines, e-journals.

As Kumar (1999) and Creswell (2003) defined the possible sources, the recently published electronic and print journal articles, books and the Internet sources were mainly used in this review. Journal articles were mainly accessed from the databases such as Scirus, Science Direct. The relevance and usefulness of such articles were searched by defined terms or key words. Also, web search engines such as Google and Google Scholar were used for retrieving some relevant information for the other information needs of this thesis.

The literature review in this research was undertaken to review, investigate and identify the SCM practices within construction and other industries (automotive and aerospace industries), various issues related to SCM with a focus on knowledge flow, the knowledge chain concept and KM principles in the literature. Therefore, this method helps to reach the first three objectives of this research. The reason of selecting other industry sectors was to identify best SCM practices to create knowledge chains in construction industry. For this purpose automotive and aerospace industries are selected for two reasons. Firstly, both industries have engineering design, production (manufacturing) and maintenance phases similar to construction industry. This makes the comparison between industries easier. They are all capital and technology intensive industries. Secondly, despite the similarities, there are significant differences between construction and the other two industries in terms of SCM approaches and applications. In particular, automotive is the leading one in terms of SCM applications and improvements. Aerospace industry also has learnt significantly from automotive and developed its supply chain practices in recent years. Therefore, these industries are identified to learn best practices for construction SCM improvement.

5.6.2 Case Studies

Case study method based on interviews was adopted for this research because it is the most suitable method which can provide in-depth information in different aspects of supply chain management and knowledge management to this research. The interview method is selected in particular because it covers a wider area of application than questionnaires. Forty two professionals from different companies were interviewed to have robust results which can be generalised for construction industry. Also, in order to improve the external vs. internal validity of the results of the case study, number of different companies were selected. Similar to the approach in literature review method, case studies in aerospace industry were also conducted to identify best practices for construction industry.

Case study method of this research aimed to achieve the following objectives:

- Investigate SCM practices within construction and other industries with a view to establishing current practices and opportunities for improvement.

- Identify the knowledge requirements of different sectors of the construction supply chain and the interdependencies across the supply chain, leading to the development of a knowledge chain.

To achieve these objectives, the case studies focused on:

- understanding the problems and issues in SCM in construction and aerospace industries;
- understanding best practices for construction industry and;
- to discover ways to develop the knowledge chain framework.

Case studies were organised at two different levels, company-specific and project-specific case studies, in three different stages. The main reason for planning the case study at two different levels comes from the need to access different types of knowledge in each stage of the case study. Company-specific case studies (first stage) were conducted to collect data on the actual SC practices, issues, recent developments and future expectations from the supply chains. Project-specific case studies (second and third stages) were conducted to collect data on the actual SC issues with a focus on knowledge flow in a recently completed project. The main criteria for the selection of case studies was the company's scale in the construction and aerospace market. This was essential to understand industry wide issues and problems. (See Section 6.2. Section 7.2 and Section 8.2 for further details on the firms) After acceptance from the companies, the three main stages which involved a set of interviews in each company and its supply chain for a particular project was started (Figure 5-3).

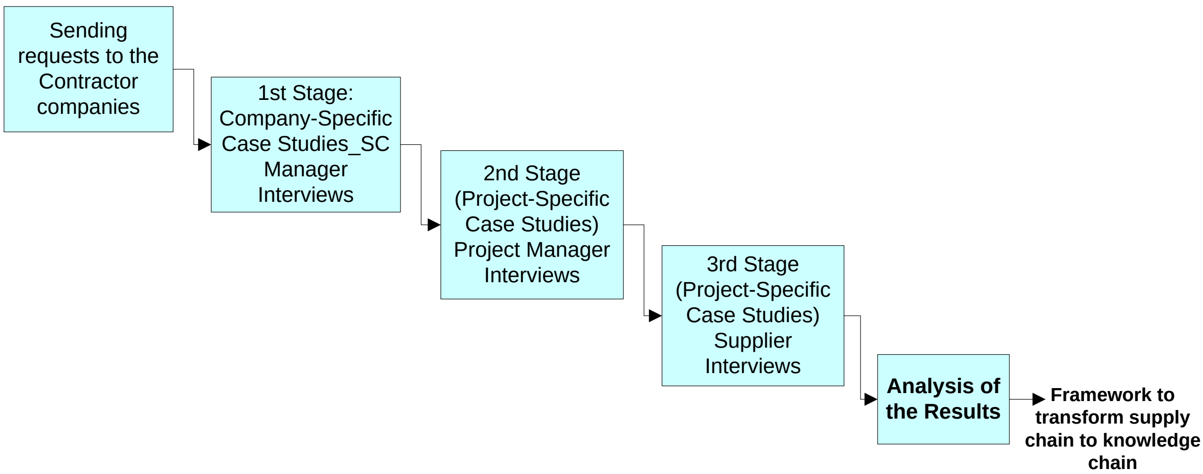

Figure 5-3 Workflow of the Case Study

The first stage is the company-specific case studies where the general SC issues of the companies selected to be identified. For company-specific case studies, structured interviews were conducted with the supply chain managers to obtain background information about supply chain management issues in the selected companies. The main reason to select structured interview method for this stage is the need to collect systematic data from the interviewees. The interviewees were presented a set of key questions in relation to certain issues identified from the secondary data collected from the literature review. Each interview lasted approximately 1-2 hours. Every interview session was recorded on tape for later transcription. The interview questions are presented in Appendix A. The information on the interviewees is presented in Table 5-5. During these interviews information was collected on the following areas:

- Number of Suppliers and Supply Chain Assessments;
- Supplier Selection Criteria and Supply Chain Relationships;
- Knowledge Exchange and Collaboration Issues; and
- Other Issues and Future Plans of the Supply Chain.

Table 5-5 Summary of Interviewees of the First Stage (Company-specific) Case Studies

Industry	Company/ Field of the Interviewee	Role of the Interviewee	Experience in Industry	Experience in the Company
1 (Construction)	Company A	SC Director	40	25
2 (Construction)	Company A	Bid Manager	20	7
3 (Construction)	Company B	SC Manager	25	25
4 (Construction)	Company B	Collaboration Manager	20	12
5 (Aerospace)	Company C	SC Manager	25	3
6 (Aerospace)	Company D	SC Director	22	6
7 (Aerospace)	Company E	SC Manager	17	5
8 (Aerospace)	Company F	SC Manager	20	6

The main output of the first stage (company-specific case study) was the understanding of the general supply chain management problems of the contractor organisation. Following these interviews, recently completed projects (project specific case study) were selected in the companies. This is where the project-specific case studies were started. (See Section 6.5, Section 7.5 for the details of construction projects and Section 8.5 and Section 8.6 for the details of aerospace projects). As a part of project-specific case studies, another set of interviews with project managers (Stage 2) and SC actors (Stage 3) were conducted in order to investigate the chronological descriptions of the project knowledge shared through the SC and general KM issues in the SC.

The Second Stage was planned as a semi-structured interview set with the project manager/related project team member of a recently finished project. A semi-structured interview method was selected to provide more scope for the discussion with the project manager/ related project team member about general the project. These interviews provided an insight into the general project management approach, and access to the supply chain actors of a real project. The project managers briefly explained the phases of the project in chronological order and provided information (selection, relationship, etc.) on the main suppliers in each phase. The information on the interviewees are presented in Table 5-6.

Table 5-6 Summary of Interviewees of the Second Stage (Project-specific) Case Studies

Industry	Company of the Interviewee	Role of the Interviewee	Experience in Construction Industry	Experience in the Company
9 (Construction)	Company A	Bid Manager	20	7
10 (Construction)	Company A	Project Manager	16	16
11 (Construction)	Company B	Project Manager	12	10
12 (Construction)	Company B	Procurement Manager	8	4
13 (Construction)	Company B	ASITE Manager	10	7
14 (Aerospace)	Company C	Project Manager	15	7
15 (Aerospace)	Company D	Project Manager	26	15

The Third Stage was intended to review how the knowledge was created, transferred and stored throughout the whole project lifecycle in the supply chain. This involved the investigation of the knowledge flow and associated issues in detail. Structured interviews were conducted with supply chain actors in order to collect systematic data from the supply chain actors. In these interviews information was collected on the following areas:

- Project knowledge created/disseminated/shared/stored in each phase of the project;
- Methods and tools used for knowledge creation and sharing;
- Knowledge management (KM) issues and problems in the project supply chain; and
- Future Expectations for Construction Supply Chains.

The details of the interview questions are presented in Appendix B. The information on the supplier interviewees are presented in Table 5-7.

Table 5-7 Summary of Supplier Interviewees of the Third Stage (Project-specific) Case Studies

Industry	Company/ Field of the Interviewee	Role of the Interviewee	Experience in Construction Industry	Experience in the Company
16 (Construction)	Company A- Architect	Director	26	5
17 (Construction)	Company A- Landscape Architect	Architect	15	7
18 (Construction)	Company A- Education Specialist	Consultant	10	4
19 (Construction)	Company A-M&E Services Subcontractor	Director	30	23
20 (Construction)	Company A- Fire Eng. Consultant	Consultant	10	4
21 (Construction)	Company A- Furniture Supplier	Consultant	10	7
22 (Construction)	Company A- ICT Provider	Consultant	5	5
23 (Construction)	Company A- Facility Management Services (FMS)	Director	8	3.5
24 (Construction)	Company A-Building Control Services (BCS)	Building Controller	21	5
26 (Construction)	Company B	ASITE Manager	15	7
27 (Construction)	Company B- Architect	Director Architect	26	5
28 (Construction)	Company B- Landscape Architect	Landscape Architect	15	3
29 (Construction)	Company B- Structural Designer	Structural Designer	7	2
30 (Construction)	Company B- M&E Consultant	Mechanica l Systems Consultant	10	3
31 (Construction)	Company B- M&E Consultant	Electrical Systems Consultant	30	23
32 (Construction)	Company B- M&E Consultant	Sustainabi lity Consultant	10	5
33 (Construction)	Company B-FireEng. Consultant	Consultant	40	17

34 (Construction)	Company B- Furniture Supplier	Consultant	10	7
35 (Construction)	Company B- Acoustic Engineer	Consultant	5	5
36 (Construction)	Company B- M&E services Contractor	Director	8	3.5
37 (Aerospace)	Company B- Joinery and Glazed Partitioning Cladding	Manager	10	6
38 (Aerospace)	Company B-Metalwork Sub-contractor	Manager	8	7
39 (Aerospace)	Company C	Production Manager	25	15
40 (Aerospace)	Company C-Foundry 1	Project Manager	15	3
41 (Aerospace)	Company C-Foundry 2	Production Manager	8	5
42 (Aerospace)	Company C-Shot-peening Sub-Contractor	Business Manager	10	3

Through this work, an in-depth case history of project knowledge flow and KM practices in the SC were obtained.

5.6.3 Analysis of Case Studies

The findings of the construction industry specific case studies were analysed in Chapters Six, Chapter Seven and Chapter Eight. Chapter Six presents the construction company-specific case study (Company A) and its corresponding project-specific case study. Chapter Seven presents another construction company-specific case study (Company B) and its project specific case study. Chapter Eight presents four company specific case studies in the aerospace industry (Company C-Company D-Company E-Company F) and the project-specific case studies (Company C-Company D). Due to collecting very detailed level of data in 42 interviews through all these case studies, no more case studies are organised in Company E and Company F.

The main elements of the knowledge flow between each supply chain actor through each project are presented in Tables within Appendices D, E and F. The Tables present:

- the information and knowledge requirements of the supply chain actors;
- the actors (in brackets) who provided the required knowledge;

- the information and knowledge created by each supply chain actor; and
- the supply chain actors (in brackets) who received the created knowledge.

5.6.4 Framework Development

The data/information flow models and diagrams can depict the knowledge flow in SC specifically and offer a guidance to KM and the 'transformation of supply chain to knowledge chains'. Most systems engineers and researchers use graphical representations for modelling a system/developing a framework while communicating its function and data requirements (Long, 2002). The most commonly used methods are Function Flow Block Diagram (FFBD), Data Flow Diagram (DFD), N2 Charts, IDEF0 Diagram, Use Case, Sequence Diagram (Long, 2002). These techniques are explained in the following sections.

5.6.4.1 Function Flow Block Diagram

The FFBD notation was developed in the 1950s, and is widely used in classical systems engineering. FFBDs are one of the classic business process modelling methodologies, along with flow charts, data flow diagrams, control flow diagrams, Gantt charts (Dufresne and Martin, 2003). These diagrams are used to develop requirements of a system and incorporate alternate and contingency operations, which improve the probability of mission success, and example is shown in Figure 5-4. The flow diagram provides an understanding of overall operation of a system (NASA, 1995). The main purpose of the diagram is to show the sequential relationship of all functions that must be accomplished by a system. Each function (represented by a block) is identified and described in terms of inputs, outputs, and interfaces from top down so that sub-functions are recognized as part of larger functional areas. Each diagram contains a reference to other functional diagrams to facilitate movement between pages of the diagrams. Gates are used: "AND", "OR", "AND" is used to indicate parallel functions and all conditions must be satisfied to proceed. "OR" is used to indicate that alternative paths can be satisfied to proceed (i.e., selection). These symbols are placed adjacent to lines leaving a particular function to indicate alternative paths (Dufresne and Martin, 2003).

Although the FFBD network shows the logical sequence of "what" must happen, the disadvantage of this method is it does not describe a time duration to functions or between functions (Dufresne and Martin, 2003).

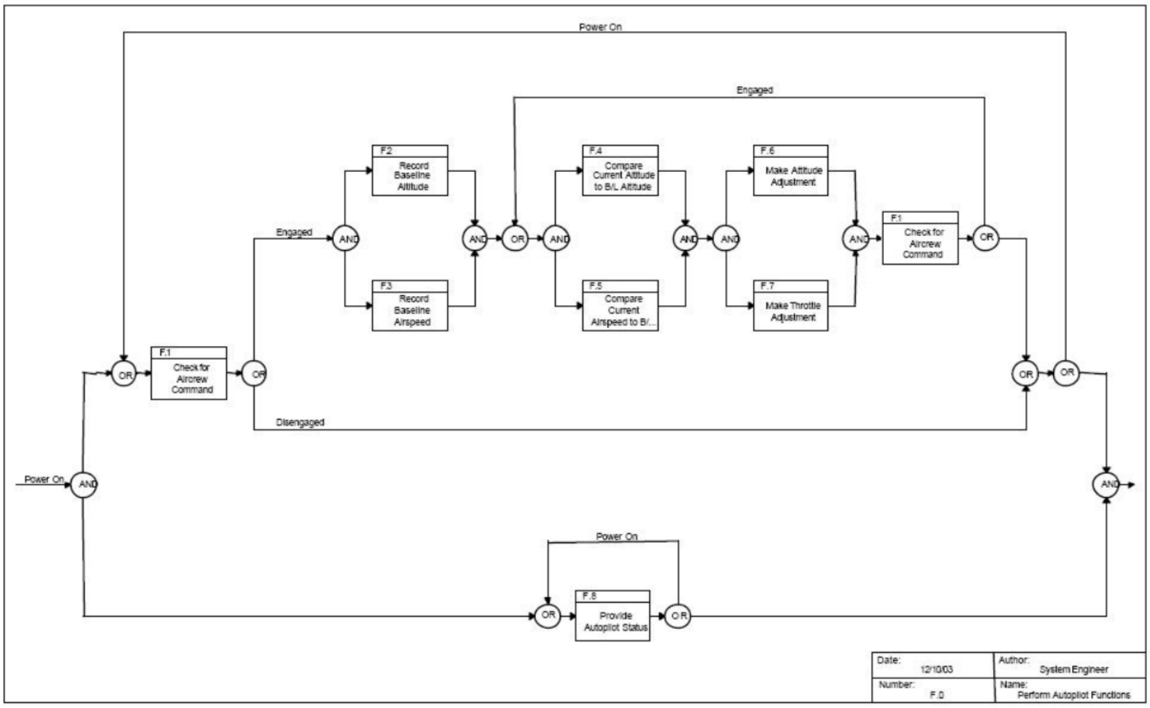

Figure 5-4 Example FFBD (Long, 2002)

5.6.4.2 Data Flow Diagram (DFD)

A data flow diagram (DFD) has been widely used by software engineers and serves as the basis of many software engineering methodologies and automated tools (Long, 2002). DFD is a graphical representation of the "flow" of data through an information system and modelling the process aspects (Bruza and Van der Weide, 1993). A data flow shows the flow of data from a source to a destination. The flow is shown as an arrowed line with the arrowhead showing the direction of flow. Each data flow should be uniquely identified by a meaningful descriptive name (caption). A DFD shows the following (Figure 5-5, Figure 5-6):

- Data input and output from the system;
- Processes are transformations, changing incoming data flows into outgoing data flows;
- Source and destination of data (data and customer in the example): The external entity represents a person or a part of an organisation which sends or receives data from the system but considered to be outside the system boundary (scope of the project);
- Storage of data: A store is a repository of data; it may be a card index, a database file, or a folder in a filing cabinet.

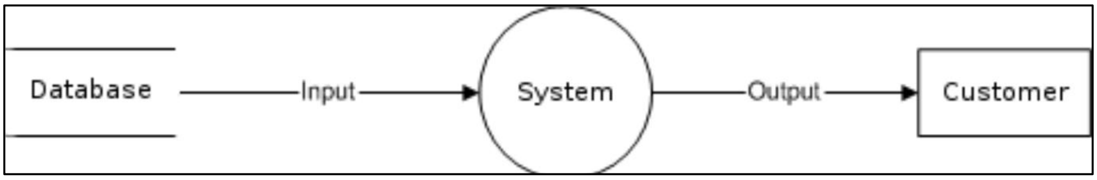

Figure 5-5 Data Flow Diagram Example (Long, 2002)

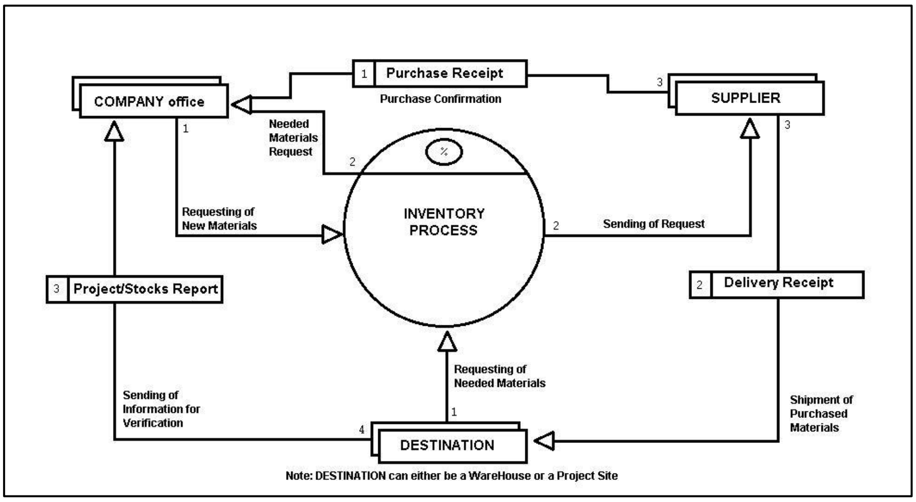

Figure 5-6 DFD example of an inventory/purchase system (Long, 2002)

The key advantages of DFDs are its simplicity, inputs and outputs to which people can readily relate, the ability to represent the system at different levels of details, the ability to define the boundaries of the system. The disadvantage of this method is it does not describe a time duration (Dufresne and Martin, 2003).

5.6.4.3 N2 Chart

Figure 5-7 presents an N2 chart which is a type of diagram in the shape of a matrix and presenting functional or physical interfaces between system elements. It is used to systematically identify, define, tabulate, design, and analyse functional and physical interfaces. The N2 Chart usually applies to system interfaces and hardware and/or software interfaces. The N2 Chart has the same capability as the DFD with a more formal format. (NASA, 2006).

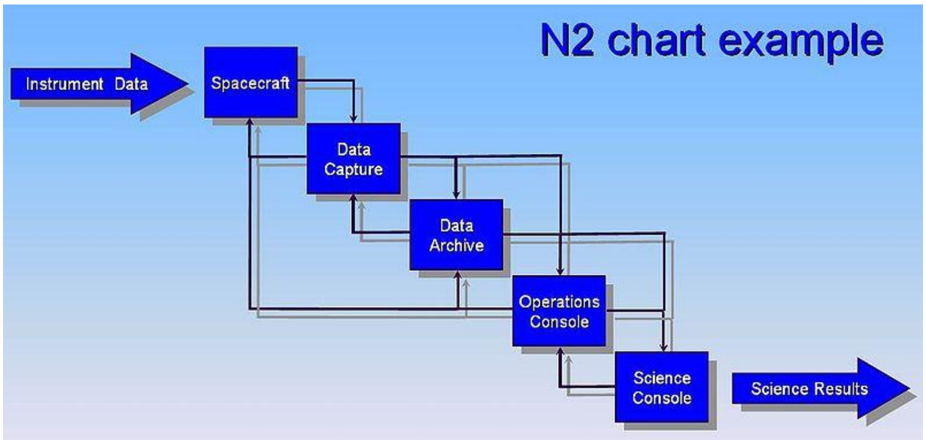

Figure 5-7 N2 Chart Example (adopted from Azzolini, 2000)

5.6.4.4 IDEF0

IDEF (Integrated Definition for Function Modelling) is a function modelling technique for describing the decisions, actions, and activities of an organization or system (Grover and Kettinger, 2000; DAU, 2001). IDEF family of models include different types as presented in Table 5-8 (ISA, 2009).

Table 5-8 IDEF Family of Models

IDEF0	Function Modeling
IDEF1	Information Modeling
IDEF1X	Data Modeling (particularly relational databases)
IDEF2	Simulation Model Design
IDEF3	Process Description Capture
IDEF4	Object-Oriented Design
IDEF5	Ontology Description Capture
IDEF6	Design Rationale Capture
IDEF8	User Interface Modeling
IDEF9	Scenario-Driven IS Design
IDEF10	Implementation Architecture Modeling
IDEF11	Information Artifact Modeling
IDEF12	Organization Modeling
IDEF13	Three Schema Mapping Design
IDEF14	Network Design

Since IDEF0 is the mostly used to model the business processes, the most useful in establishing a scope of an analysis and simplest of all IDEF models, IDEF0 is discussed mostly in this section (ISA, 2009). IDEF0 assists the modeller in identifying what business processes are performed, and what is needed to perform those functions, A functional flow block diagram is used to show the functional flow of a product, however, IDEF0 is used to show data flow, system control, and the functional flow of lifecycle processes (Figure 5-8, Figure 5-9). IDEF0 is capable of graphically representing a wide variety of business and other types of operations in detail. It has been used in many government and private industry projects and is generated by various computer graphics tools (DAU, 2001).

The basic element of an IDEF0 model is called function block, as shown in Figure 5-8. The individual function blocks are linked together through the inputs, the outputs, the mechanism, and the controls. When an input is utilised to create and output, a function will be actuated. The performance of the function is carried through a mechanism under the guidance of the control. The inputs of a function entering the function block from the left are usually the consumed by the function to produce outputs. The mechanism represented by an arrow entering the flow block diagram indicates the resources which are required to carry out the transform process. The control which enter from the top of the block influence the transformation process. IDEF0 can be expanded any level of detail (Wu, 1994).

The primary content of the IDEF0 Diagram is the specification of data flow between system functions (Long, 2002). The result of applying IDEF0 to a system is a model that consists of a hierarchical series of diagrams, text, and glossary cross-referenced to each other as presented in an Figure 5-9.

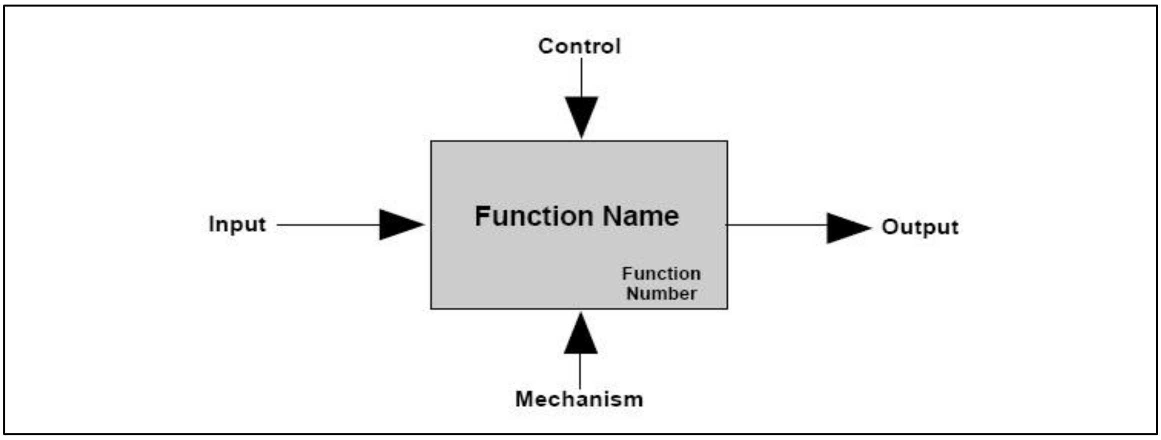

Figure 5-8 IDEF0 Box Format (Long, 2002)

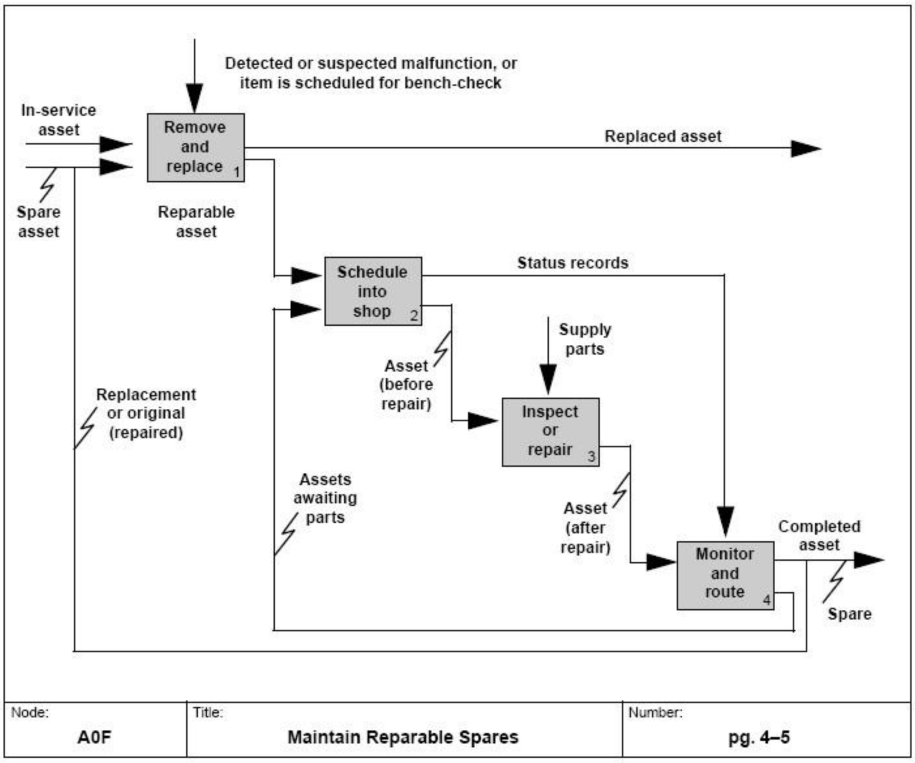

Figure 5-9 IDEF0 Diagram Example (Long, 2002)

IDEF0 is essentially an N2 Chart with some control definition capability. The key advantages and disadvantages of IDEF0 method is presented in Table 5-9 (Presley and Liles, 1995; Wu, 1994). Although the formulation of an IDEF0 system requires high level of detailed background knowledge on the functions, it's systematic mechanism for function decomposition, high level of formalism, acceptance amongst end-users make it a very valuable tool.

Table 5-9 Advantages and Disadvantages of IDEF0

Advantages	Disadvantages
• Effective, standardized and systematic method; • provides mechanism for decomposing function into sub-functions; • formalism leads to the creation of consistent, integratable models; • widely accepted amongst end-users	• requires consistency between different levels of modelling which is sometimes difficult to maintain • a business analysis tool rather than a good system development methodology • hierarchy of function model does not explicitly represent the conditions or sequences of processing

• provides ability to specify explicit feedback between activities • the placement of boxes does not imply a strict precedence sequence. • incredibly rich in information and glue together all the other architecture domains • offers a controlled manner for drilling down from high level views to more detail views	• Great deal of manual effort and interpretation may be required to identify appropriate functions • Indicates functional relationships but not specifies dynamic aspects in it

5.6.4.5 Use Case Diagram

A use case diagram in the Unified Modelling Language (UML) is a type of behavioural diagram to present a graphical overview of the functionality provided by a system in terms of actors, their goals (represented as use cases), and any dependencies between those use cases. As presented in the Figure 5-10, the actors, the content of the information shared between actors are clearly presented. One of the major advantage of a Use Case diagrams is communication. The diagram provide the functionality which will be included in the system, the actors who will be interfacing with the system and the scope of the functions. Use Case Diagrams can be used in many aspects of software development such as project planning (cost, complexity and timing estimates), object models, test case definitions, and user documentation. The disadvantages of the Use Case Diagrams are that the tool is not well known; usage of complex diagrams may require many pages, and multiple pages can make it difficult to see commonalities (Long, 2002).

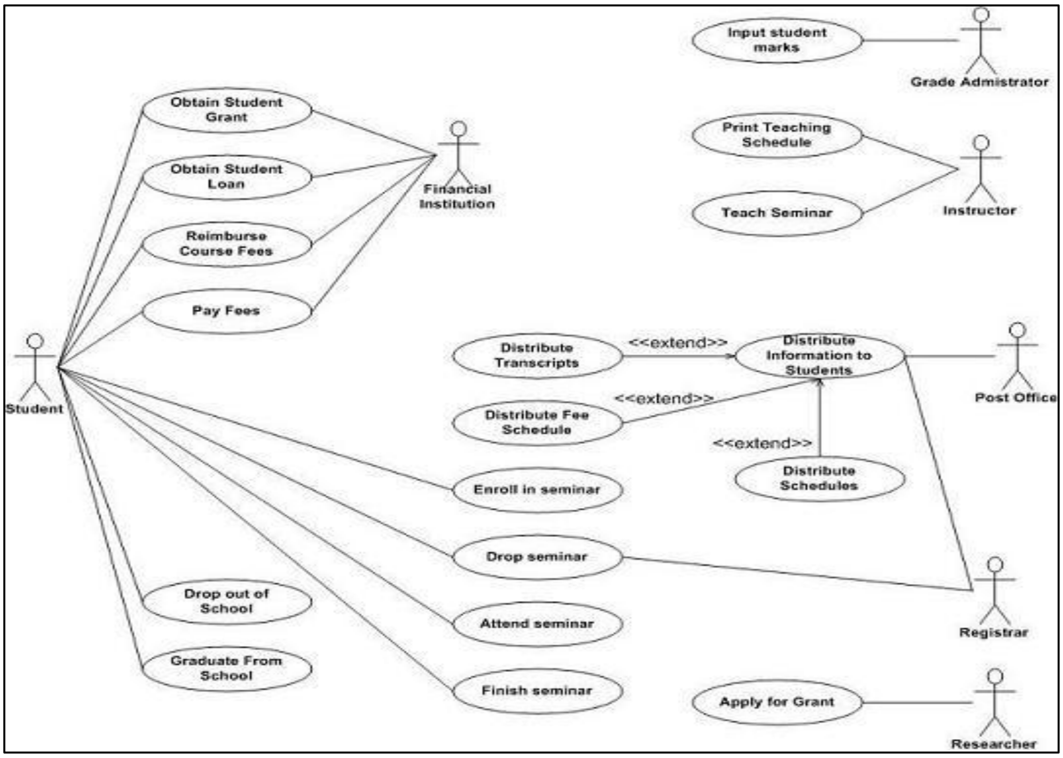

Figure 5-10 Example Use Case Diagram (Long, 2002)

5.6.4.6 Sequence Diagram

Sequence diagrams (See Figure 5-11) are used to present or model the flow of messages, events and actions between the objects or components of a system. Time is represented in the vertical direction showing the sequence of interactions of the elements, which are displayed horizontally at the top of the diagram (Long, 2002). The relationship between objects is not shown in a sequence diagram [Miller, 2001].

Sequence Diagrams are mainly used to design, document and validate the architecture of the system by describing the sequence of actions that need to be performed to complete a task or scenario. They are suitable in real-time specifications and for complex scenarios. Sequence diagrams are useful design tools since they provide a dynamic view of the overall system compared to static diagrams or specifications (Long, 2002).

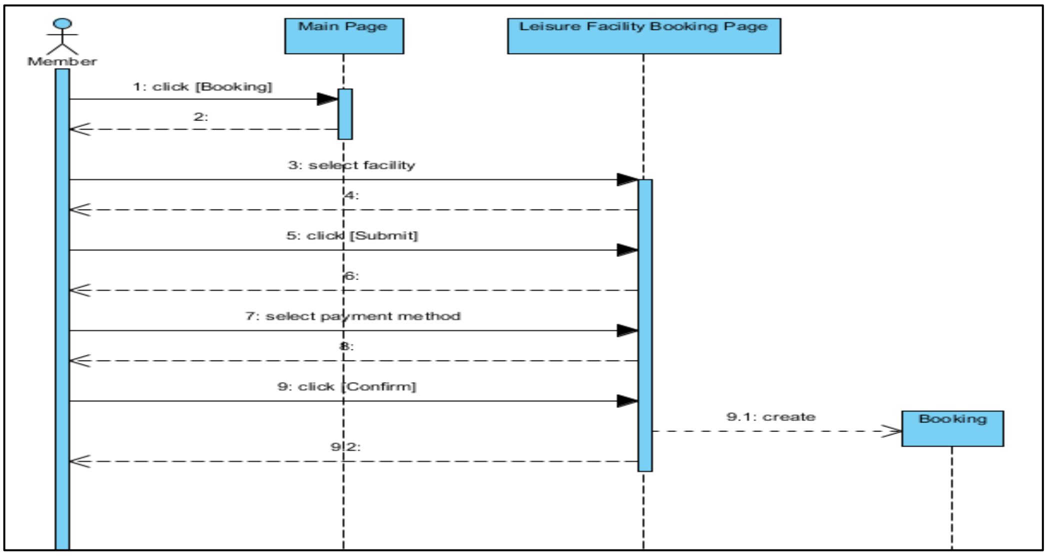

Figure 5-11 Example Sequence Diagram (Long, 2002)

As presented in Figure 5-11, the member (actor) represents an external person or entity that interacts with the system. The diagram has two dimensions, time which is represented by the vertical dimension and different objects and actors that are represented by the horizontal dimension. The ordering among objects in the horizontal dimension is of no significance. However, the objects are ordered in such a way that the call arrows (messages) are arranged to point in the same direction (to the right). Each object has a vertical dashed line which is called the lifeline of the object [Rumbaugh et al., 1997].

The main advantages of the Sequence Diagrams are its simplicity, and ability to show time ordering messages. The disadvantage of the method is it consumes too much horizontal space, this decrease the feasibility of the method to be used in complex systems [Rumbaugh et al., 1997].

5.6.4.7 The method Adopted for Framework Development

The methods, FFBD, DFD, IDEF0, N2 Charts, Use Case Diagrams, Sequence Diagrams are evaluated according to their suitability to the representation of the knowledge chain framework. It was revealed that IDEF0 method provides better level of decomposition, formalism, standardization, clarity, and familiarity for the end-users compared to the other similar methods as DFD, FFBD, N2 Charts. Although Use Case Diagrams are suitable to clearly map the interactions the supply chain actors, due to high level of SC interactions included in the knowledge chain framework, this method was not selected. The Sequence Diagrams is found to be complex and it does not guarantee clarity as IDEF0 guarantees. In future research this method has the potential to transform the knowledge chain framework to a software tool. However, due to clarity, simplicity, formalism and standardisation IDEF0 is selected to represent the 'knowledge chain' framework. The framework is explained in detail in Chapter Eight.

5.7 Chapter Summary

This chapter was divided into two main parts. The first part reviewed the research approaches and methods available for research. The second part outlined the methodologies adopted to achieve the aim and objectives of the research. This research study has sequential stages such as the literature review, case study analysis, framework development and finally the evaluation. Throughout these stages, combinations of research methods, both qualitative and quantitative have been used.

The following Chapter presents a case study conducted in a large scale construction company. It provides information on the findings of the preliminary interviews, which presents the perspective of a construction company on the issues of its supply chain management, and the findings of the interviews conducted with the key supply chain actors of a sample project are presented.

CHAPTER 6

6 CONSTRUCTION INDUSTRY CASE STUDY 1

6.1 Introduction

In this chapter, the case study conducted in Company A and the case study conducted in the supply chain (SC) of 'X High School Project' is examined. The background of Company A, the content and method of case studies are presented. The case study in Company A is concerned with the perspective of the company on its supply chain management (SCM) issues. The case study conducted in the SC of 'X High School Project' is mainly concerned with the knowledge flow through the project SC and the main SC issues which have direct or indirect effect on the management of knowledge during the project lifecycle.

6.2 Company A Background Information

Company A was selected as a case study for this project because it is a well-known large scale company working in the UK construction industry. It is operating in the public and private sectors mainly in the UK and also internationally. The company offers advice, design, construction and facilities management services for civil infrastructure projects and provides a range of plant and equipment in specialist fields. It has revenue of £1.9 billion and a workforce of 50,000 people worldwide in 2010.

Company A works on a variety of buildings and infrastructure projects such as hospitals, schools, offices, shopping centres, airports, prisons, industrial plants, bridges, waterworks and roads. It offers consultancy and services across the asset life cycle planning, building, supporting their clients' operations by maintaining the buildings and environments in which it works. The organizational structure for Company A is presented in Figure 6-1.

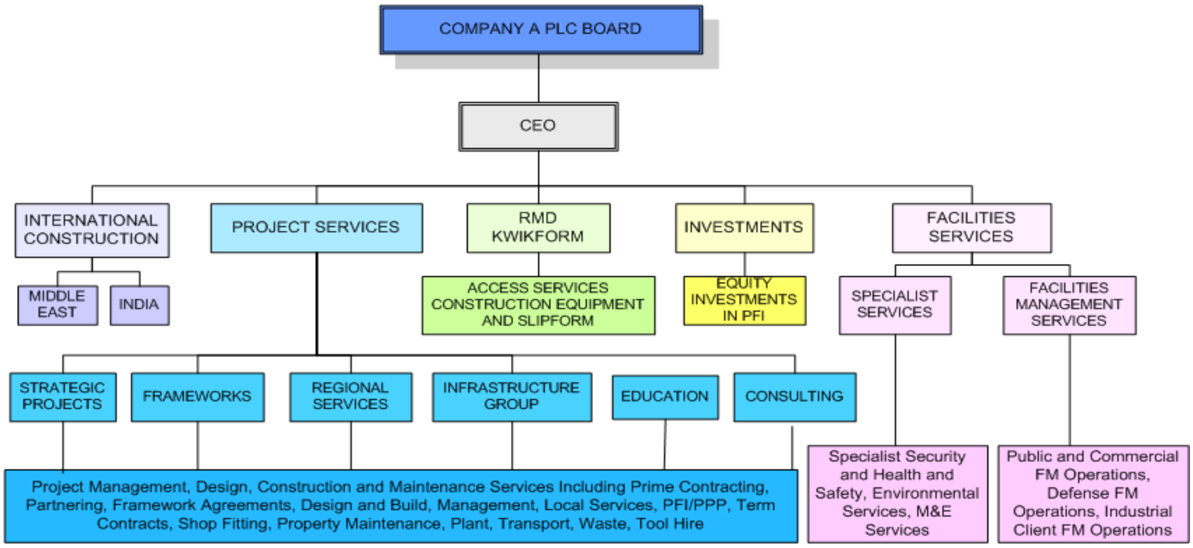

Figure 6-1 Company A Organizational Chart

6.3 Case Study Content

For the company-specific case study, a structured interview was conducted with the SC manager to obtain background information about SCM in the company. During this interview information was collected on the following areas:

- Number of Suppliers and Supply Chain Assessments;
- Supplier Selection Criteria and Supply Chain Relationships;
- Knowledge Exchange and Collaboration Issues; and
- Other Issues and Future Plans of the Supply Chain.

The interview questions are presented in Appendix A. Following this interview, The 'X High School Project' was selected to review the SC of the project within a project-specific case study. Two semi-structured interviews were conducted with the Bid Manager and the Project Manager. The Project Manager briefly explained the phases of the project in chronological order and provided information on the main suppliers in each phase. The Bid Manager provided the details relating to the project bidding phase, SC actors selection and the relationships with these actors.

Following these interviews, structured interviews were conducted with SC actors. In these interviews information was collected on the following areas:

- Project knowledge created/disseminated/shared/stored in each phase of the project;
- Methods and tools used for knowledge creation and sharing;

- Knowledge management (KM) issues and problems in the project supply chain; and
- Future Expectations for Construction Supply Chain.

The details of the interview questions are presented in Appendix B. Table 6-1 presents information on the 12 interviewees.

Table 6-1 Information on the Interviewees

Company/ Field of the Interviewee	Role of the Interviewee	Experience in Construction Industry	Experience in the Company
Contractor	SC Director	40	25
Contractor	Bid Manager	20	7
Contractor	Project Manager	16	16
Architect	Director	26	5
Landscape Architect	Architect	15	7
Education Specialist	Consultant	10	4
M&E Services Subcontractor	Director	30	23
Fire Eng. Consultant	Consultant	10	4
Furniture Supplier	Consultant	10	7
ICT Provider	Consultant	5	5
Facility Management Services (FMS)	Director	8	3.5
Building Control Services (BCS)	Building Controller	21	5

6.4 Findings Of The Company Specific Case Study

This Section presents the results of the company specific case study which are based on the review of the SCM issues. These issues have implications on how the project knowledge flows through the SC.

6.4.1 Introduction to Company A Supply Chain

Company A has three main business streams (divisions) within the construction business as follows:

- Strategic Projects (£15 million- £300 million) (These operate in Scotland, Plymouth, South London);
- Infrastructure (Civils, roads, water treatment);

- Regional Building Construction (9 independent regional offices around the UK).

The three main business divisions have their own SC and it is not possible to define the exact number of suppliers. However, Company A accepts its suppliers in two registration levels. The general level is where anybody can register on the database as a supplier; this is limited to10,000 companies. The second level is where only a selection of suppliers within the business is available; this is limited to 1000 companies. Currently, Company A has 600 suppliers within its construction SC.

6.4.2 Supplier Selection Criteria and SC Assessments

The main SC priorities for Company A are sales and customer satisfaction however it was stated that priority should be on KM within the SC.

Potential suppliers can be registered on the company database and need to provide relevant information (e.g health and safety policy, past training, certifications, in house design capabilities, availability of any sub-let work, geographical areas that the supplier can work, quality, environment, and safety systems, references (See Appendix C for The Prequalification and Database Registration Questionnaire). After being nominated as a potential supplier, the suppliers are subjected to several interviews for the selection process in order to identify the strengths, weaknesses, and competence of the SC actor. The list of SC members is regularly reviewed on a national database with particular focus on their performance and project delivery.

All SC actors undergo a performance assessment following the completion of their work. The suppliers are assessed in terms of health and safety, environment, quality, delivery, cost, ethics, outlook and openness. The average assessment score should be at least 7 out of 10 or higher for the project performance in order to keep a SC actor within the chain. The purpose of these assessments is to support continuous improvement of SC management practices in Company A. In the meantime, a similar assessment is carried out by subcontractors in order to evaluate Company A`s project performance, this process is managed by Company A.

In order to adequately control the risks on the project, all SC actors should be competent and have adequate resources to undertake the project work. When SC actors wish to further sub-let the project work, they need to seek the approval of Company A in accordance with their sub-contract conditions and working procedures to ensure the competence of those appointed.

6.4.3 SC Relationships

Company A has a completely different SC compared to 10 years ago due to a shift in focus from private sector to public funded projects. Public projects require another type of SC to carry out projects successfully. Therefore, the company has a combination of old and new suppliers in their chain. However, Company A aims to keep some previous SC actors within the projects. Their relationships with the suppliers are defined as good depending on reputation, well established trust, paying on time and paying fairly. Also, Company A prefers to use supplier protocols which define the responsibilities of both parties involved in the SC relationship rather than partnering agreements [SC Director].

6.4.4 Special Programmes/Actions to Improve SC

There are currently no specifically developed programmes in Company A for SC improvement. However, regional SC meetings are arranged once every two years in order to improve relationships and get closer to their SC actors. Also in 2005, Company A was involved in a SC development project sponsored by The Construction Industry Training Board (CITB). This project was part of a wider industry project aimed at supporting the development of construction SC. For this project Company A organized forums with its key SC partners (mainly specialist sub-contractors) to get their feedback on SC issues, improvement opportunities, and developed strategies. Apart from the annual meetings and this specific project, there are no other programmes developed to improve SC.

6.4.5 Information and Knowledge Exchange Methods and Tools

Company A does not have a collaborative database (repository) in order to store or extract information with its SC. Within some framework type public contracts, Company A uses BIW (Building Information Warehouse) collaboration software for sharing project information (design, specifications, documents) with its SC. Apart from this, knowledge transfer in the SC is usually arranged with formal presentations, workshops, face to face meetings, emails, phone conversations.

6.4.6 Knowledge Exchange and Collaboration Issues

The construction industry is extremely fragmented and there are lots of small sub-contractors with an unskilled workforce and skill deficiency problems. 92 % of construction companies employ less than 6 people in the UK, these figures reflect the difficulty of fragmentation and are indicative of the reasons for communication and collaboration problems [SC Director].

A lack of a KM system and strategy in the SC means that Company A has to review the tender package for every project rather than bringing in a SC partner to assist with some of the deliverables within the tender package at the early stages of the feasibility phase. Also, the lack of a collaborative database (repository) results in serious information and knowledge management (IKM) problems. In particular the downstream SC actors are not open to new technologies and they are not capable of using new systems and integrating them into new working models [SC Director].

Company A does not find the BIW user friendly and experiences difficulties in promoting its usage amongst SC actors. Within 20% of Company A's projects, the use of the BIW is encouraged through the contractual agreements with the client and SC. However, the rest of the projects continue to use the same SC actors and therefore, project knowledge is kept within the organizations. Consequently, for individual projects, it is quite difficult to use extranets (collaboration software) due to the lack of IT skills and infrastructure particularly in the downstream SC [SC Director].

6.4.7 Other Issues of SCM and Plans for Future

According to the SC Director, there needs to be more innovation in construction SCs in the future. Innovation is found to come from designers and diffuses through to material suppliers within the SC and results in efficient products. However, it is believed that architects do not generally contribute to innovation in live project conditions, therefore, the ideal practice should be to create a collaborative working environment at early stages of the project lifecycle. In this way, most of the SC actors can share ideas and produce better solutions. Therefore, in future, Company A would like to establish a decent KM tool where SC actors can collaborate and share knowledge effectively for more innovative solutions. Company A expects innovation to bring SC efficiency, improve profitability and increase turnover. On the other hand, it is noted that although innovation is good to share with the SC actors; there should be control on sharing commercial knowledge.

Company A has investigated the Far East market for better product options to be used in the future, however there are no arrangements or agreements yet [SC Director]. Therefore, Company A is unaffected by globalization due to having a local SC from both economical and organizational points of view. Since they do not have a standard work load coming through the clients, it is quite difficult to agree and outsource the SC outside the UK for future projects.

Company A struggles with the flexibility of their SC because clients do not provide any visibility on the forecasted work load. Clients could not agree on continuous work load due late allocation of the budgets . However they expect their clients to be more interactive to share work overload in future [SC Director].

Lean construction was identified as the next step for construction SCs. However, the construction industry is well behind the aerospace and manufacturing industry in terms of standardization of working principles and SCs [SC Director]. The most critical reason is that the construction industry does not have a standard end product and has a highly fragmented SC. This makes it difficult to create lean environment in the short term period.

As a consequence, in future, it is believed that their SC has to be leaner and they define the key driver for a better SC as *"to educate the people within the construction industry towards the leaner construction and integrated project delivery"*[SC Director].

6.5 X High School Project

6.5.1 BSF Projects

Building Schools for the Future (BSF) was launched in 2004 by the then Prime Minister Tony Blair. The aim of BSF was to rebuild or refurbish every secondary school in England over a 15-20 years period. Local authorities would enter into public-private partnerships, known as Local Education Partnerships (LEPs) with private sector companies. Funding for BSF came from Private Finance Initiative (PFI) and capital receipts, and was targeted at local authorities with the most deprived schools first. Each local authority would plan a co-ordinated renewal of their entire secondary schools estate through BSF. Funding for ICT was ring-fenced in the funding envelope for BSF (Partnerships for Schools, 2010).

There are two major reasons that a BSF project was selected as a case study in this project. The first one was it is the largest capital investment programme in the UK for 50 years which will provide world-class teaching and learning environments for all pupils, teachers and communities. The second reason is that it has a design challenge by its lead in changing from the conservative design to transformational education. *"Today in the UK, the buzz word in the education sector is transformational education* [Project Manager, Company A]". The main issue here was to investigate the knowledge sharing, and collaboration between the design actors amongst such a new and challenging project that they need to apply a different design perspective which they did not have before the BSF scheme started.

6.5.2 Project Overview

X High School is one of six schools included in Phase 1 of the X Local Council's BSF programme which started in April 2007 and completed in September 2008. The new X High School is a replacement high school, to accommodate approximately 1050 pupils aged 11-16 years plus post-16 pupils and a pre-schools Children's Centre. The existing schools at the same site remained operational during the construction period. 'The X High School Project' cost for capital building was about £28 million. The procurement method for the project was the Design-Build-Operate contract. This contract had several stages which are briefly described in the following section.

6.5.3 Project Lifecycle

In every bid, Company A uses different terminology to name each phase of projects and there is no unique terminology to name the project phases in the construction industry [Bid Manager]. The phases of this project were Feasibility and Design, Financial (Contract) Close; Construction and Operational Phase respectively. Table 6-2 presents the key tasks delivered in each phase, the design stage in each phase according to the RIBA (Royal Institute of British Architects) work stages and the key SC actors who worked in each phase.

Table 6-2 X High School Project Phases and Supply Chain Actors in each Phase

Phase	**Feasibility & Bidding Phase (12 months)**	**Contract Close Phase (4 months)**	**Construction Phase (15 months)**	**Operational Phase (28 years)**
Content	Business Justification-Procurement Strategy-Design Brief-Conceptual Design Approval	Detailed Design Approval-Planning Applications-Financial Close	Pre-Construction, Construction	Use of Building
RIBA STAGE	Preparation(A-B) Design(C-D)	Design (D-E-F)	Construction (J-M)	Use (M)
SC Actors of the Phase	Contractor-Designers-M&E Subcontractor-Specialist Consultants – Suppliers -Facility Management Services (FMS)-Building Control Services (BCS)	Contractor-Designers-M&E Subcontractor-Specialist Consultants – Suppliers -FMS-BCS	Contractor-Designers-Specialist Consultants-Subcontractors-Suppliers-FMS-BCS	Contractor-FMS-Specialist Consultant (Educational)-FMS's Suppliers

6.6 Findings Of The Project Specific Case Study

This Section presents the findings of the project specific case study which involves the main issues of the SC, key knowledge flow issues, general KM practices, and the expectations of SC actors for better knowledge sharing.

6.6.1 Knowledge Flow through the Project Life Cycle

In this Section, knowledge flow and issues associated with the knowledge flow in each phase of the project are presented. In Appendix E, the main elements of the knowledge flow between each SC actor through the project life cycle are presented in table format. The tables in Appendix E present:

- the information and knowledge requirements of the supply chain actors;
- the actors (in brackets) who provided the required knowledge;
- the information and knowledge created by each supply chain actor; and
- the supply chain actors (in brackets) who received the created knowledge.

6.6.1.1 Feasibility & Bidding Phase

This phase involves two stages: pre-bid stage and bidding stage. During the pre-bid stage, The Council prepared the **Strategic Business Case** where they set the specifications for the school, the option appraisal and the chosen procurement route. Then the contract with **Prior Information Notice (PIN)** was advertised to gauge interest amongst several contractors in the UK. Following this, the client sends **Prequalification Questionnaires (PQQ)** which gathers information on company profiles, technical and financial capabilities, and past work as a proof of delivery. As a result of a collaboration period between the Client, school and contractors, the Council short listed six contractors and sent an **Invitation to Negotiate (ITN)** to the short listed bidders (See Figure 6-2). ITN documents contained information on legal parameters surrounding the tender; description of the supplies, service or works to be provided; instructions for submissions; pricing and delivery schedules and form of tender.

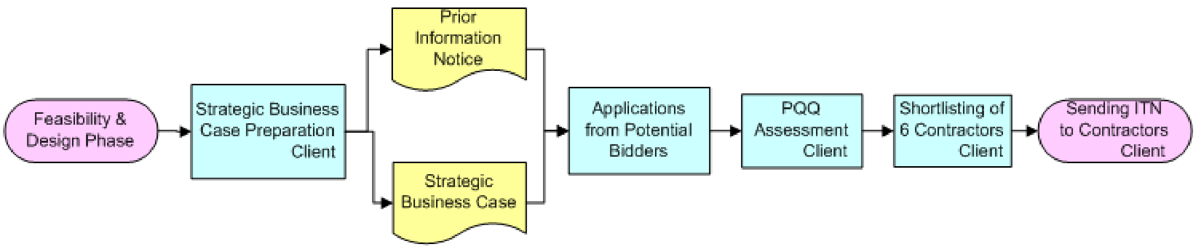

Figure 6-2 Feasibility and Bidding Phase (up to ITN)

Figure 6-3 presents the project work flow starting from the ITN Stage. The ITN was the main stage where the contractor worked closely with the SC, and shared bid documentation which included Output Specifications, legal documentation, a project schedule. The "Output Specification" provided information on the building, life expectancy, service life, main requirements on the structure, external and internal walls, doors and windows, functions, sizes and number of the rooms required, and the delivery time scale. The contractor also had access to the web databank which provided information on general social statements of education delivery for the council, the area, and statistics for the community. Following this stage, the contractor and it's SC started to work collaboratively. The information and knowledge created in this phase was presented to the client through several workshops until the contractor was selected as the preferred bidder. (See Appendix E-1 Table 1 which presents the main elements of the information and knowledge flow between the Contractor and the Client through the ITN stage).

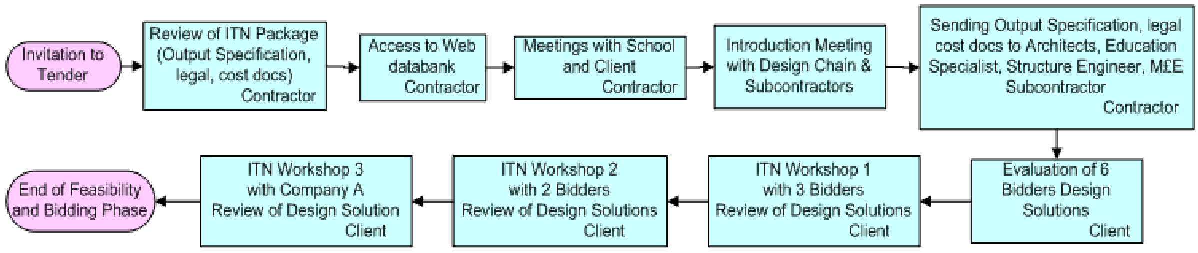

Figure 6-3 Feasibility and Bidding Phase (From ITN to End of the Feasibility and Bidding Phase)

The main SC members who contributed to the project at this stage were the Architect, Landscape Architect, Educational Specialist, MandE Sub-Contractor, and the Structural Designer. However, mainly the Contractor, the Educationalist Specialist, and the Architect maintained the client interface throughout the lifecycle of the project [Project Manager]. (See Appendix E-1 for further details on knowledge flow between the SC actors).

Highlights on the Feasibility & Bidding Phase

In this section some manifestations and causes regarding the issues which affect the flow of knowledge during the Feasibility and Bidding Phase are presented.

Issues on Contractor-Client Information & Knowledge Flow

- Client Specification was not only a mixture of technical specifications but also descriptive aids and aspirations. Therefore, it was difficult to understand the client requirements clearly [Project Manager].
- There were problems in the client's review process [Bid Manager]. There were many people from the client who interacted with the design team during the feasibility and bidding stage. After the bidding phase, this became more serious because of high turnover of employees in the client, thus there had been problems due a lack of understanding and continuity. Therefore, the contractor had to go on a undertake numerous clarification processes with the client.
- At the beginning of the project, because of the discontinuity of members in the Client team, it was difficult to get access to the right person. Also, knowledge from the client in meetings was very dependent on the confidence of the people, and their ability to react and deliver. This situation became more positive when the client reduced the number of bidders to 2-3 [Project Manager].

- This phase is defined to be as “*much more than just the design of the building*” and the importance of maintaining good relationships with the client was highlighted by the Architect. According to the Project Manager, it is very important to catch the thoughts and feelings of the client to understand the client requirements. However, the relationship with the Client was quite new and because of the high turnover in the Client’s organization, establishing good relationships and making collaborative decisions with the client in this phase proved difficult [Bid Manager].

Lack of Timely Interactions

- There were issues on the timing of appointments of specialist consultants to the project. Ideally, the Contractor should share design knowledge with the Specialist Consultants to receive feedback early on the design. Particularly for such a project involving lots of ventilation, noise was a big problem. However, the Acoustic Consultant has not been involved early enough [Architect]. Similarly, because the Fire Consultant was appointed at the end of this phase, the architects made assumptions about the fire strategy which caused issues in the later stages of the project. For example, the sprinkler tank has been located externally in the earlier stages of the design, when the location information was received; it was incorporated within the design. If it had been stated earlier, it could have been designed holistically within the scheme rather than being added later on.
- The Sport England (SE) ensures that there is no net loss of sporting provision and checks if the design provides SE requirements. Ideally, the Landscape Architect has to work with SE in the pre-planning phase. However, the Landscape Architect only had a generic meeting for all of the school projects after the bidding. Due to late engagements with SE, one of the pitches was designed shorter than the SE requirements. These kinds of changes cause stress on the design team, loss of time and money [Landscape Architect].

Knowledge Sharing and Communication Issues

- The biggest issue in this phase was the vast amount of information and knowledge which had to be shared in a very short time scale. This seriously affected the ability to share the knowledge in a way that was useful to all parties. The time frame of the project did not allow the SC actors to share sufficient feedback between design suppliers, client and the end-user [Education Specialist]. The duration of the feasibility and bidding phase was too short which resulted in the design work being rushed [Fire Consultant]. There was a huge information and knowledge overload particularly at the feasibility and bidding stage. According to the Architect, "*sometimes little knowledge is better than too much*".

- Each SC actor needed to filter out all the relevant information from the Output Specification and find their own requirements for the project. This was a time consuming process. This process could have been very difficult if they had received an insufficiently prepared brief from the Client. They had cases where they had to revise the requirements several times with the Client in other projects [Furniture Supplier].
- In the project meetings, some of the project knowledge was shared by the Client or the school verbally. Things changed vastly from the written brief and capturing this change verbally was very difficult [Education Specialist].
- The Architects and the Suppliers relied on the knowledge coming from the Client transferred by the Educational Specialist. However, ideally, the knowledge should be transferred to architects and suppliers should go through the main contractor [Architect].
- Knowledge sharing between the M&E Sub-contractor and the design team was inadequate. Priority and importance were not given to the M&E design and Sub-contractor's approach was quite traditional. In the recent years, the M&E engineers are also environmental engineers and they have a big impact on BREEAM, therefore sustainability and energy issues should have been considered early in the design. However, there is doubt about if their traditional role is still attractive, or if their fees are enough to cover their new role in the industry [Architect].
- Because of lack of communication between the Landscape Architect and M&E Sub-contractor, the Landscape Architect did not collaborate with the M&E Sub-contractor on time to enable their lighting design to be incorporated in the external areas [M&E Sub-contractor].

IT Tools to Create Design Knowledge

- The design team tend to use different software programmes to produce their drawings. In this project, the Architect used AutoCAD and REVIT; the M&E Sub-contractor produced 2-D design in AutoCAD, and the structural designer produced 3-D design with another software. They agreed on a format (dwg) to exchange design information between the team. However, it would be beneficial if the design team could start 3-D design early in the project [Architect].

- According to the Furniture Supplier, the visualisation methods used to impress the Client were inadequate. For visualisation purposes, the Architect presented entrance halls with people, interior decoration and some furniture in 3-D representation. However, the furniture used was just a representation and not the actual furniture. The furniture design aimed to present the Client's aspirations in 2-D form at this stage. However, early collaboration with furniture supplier would have been very helpful as innovative furniture solutions can have a big effect on impressing the client and increase job winning capacity [Architect].

6.6.1.2 Contract Close Phase

When Company A was selected as the preferred bidder, the Contract Close phase started. In the Feasibility and Bidding Phase, 85%- 90% of the design was fixed, however this phase involved detailing and refining the design, and reviewing the project's terms and conditions. From the preferred bidder stage to the financial close, the design team had some clarifications from the Client. The Contractor and the design team worked collaboratively with the Client to make sure that the specifications in the contract are compliant with the client requirements and the contractor's deliverables. At the end of this stage, all SC actors who contributed to the design signed a contract which describes the deliverables, cost, schedule, methods and procedures of the delivery. The Contractor, Architect, and The Client attended the Authority Requirements Meeting where the Client's Requirements and Contractor's Proposal Document for financial close was agreed [Project Manager]. (See Appendix E-2 for further details on knowledge flow between the SC actors).

Highlights in the Contract Close Phase

In this section some manifestations and causes' regarding the issues which affect the flow of knowledge during the Contract Close phase are presented.

Knowledge Sharing and Collaboration Issues

- In this phase, the Client became more open and shared more knowledge with the Contractor [Project Manager-Designers]. This provided a chance to increase design speed and produce solutions in compliance with the client requirements [Project manager].
- There was lack of direct knowledge flow from the design team to the sub-contractors. For example, the Architect did not provide information directly to the suppliers, instead the

Architect supplied information to the Contractor and the Contractor put together the tender package and created supplier specifications. Some aspects that the architect expected to indicate in the sub-contract packages were not available [Architect].

- Collaboration between the design team and the sustainability consultant was inadequate [Landscape Architect]. The contractor was the main contact between the design team and the consultant. For example, the Landscape Architect only benefited from the knowledge coming from the BREEAM web site and the contractual BREEAM requirements. Currently, in their new projects, there are lots of discussions on sustainability issues and they can benefit from the direct discussions with sustainability consultant at early stages.
- Before the planning phase, the landscape architect was responsible for hard and soft landscape design. After the planning phase, they were only responsible for the planting proposals, and the architect was responsible for hard landscape proposals. Due to inadequate communication, there had been lots of crossover between hard and soft landscape design and some points had been missed since the design had been done by two different parties.

Lack of Feedback Mechanisms on Supplier Selection

- Selection of the specialist sub-contractors and the material suppliers were managed by the Contractor. The Architect or consultants did not have any effect on the selection (Architect). On the other hand, in another project, the Landscape Architect was involved in the supplier interviews, and provided feedback to the contractor on the pros and cons of the potential suppliers and made collaborative decisions. This engagement highly improved the quality of the end product, the delivery process and collaboration throughout the project (Landscape Architect).

Timely Engagement of the Design Team to Suppliers

- There were issues on the timing of appointments of SC actors to the project. For example, when a specialist designer designs windows, this also dictates how ventilation or glaze strategy works, thus it has to be linked to the M&E Service's solution. Similarly, when the ventilation rate, opening of the windows, or when daylight factors changes, then the make of the glass in the window needs to be changed. Therefore, on time collaboration of the designers and the rest of the SC is essential [Bid Manager]. However, in this project, the architect started to collaborate with the sub-contractors just before construction and it was too late to incorporate the sub-contractor's knowledge into the design. It would be helpful if they could collaborate earlier in order to learn about the latest techniques and materials to be used in their design. This creates a huge knowledge gap between SC and architectural design environment [Architect].

IT Tools to Create Design Knowledge

- In the post contract close stage, the Architect used REVIT as BIM (Building Information Modelling) authoring tool, produced 3-D drawings and shared these detailed drawings with the Contractor, however the Contractor did not use REVIT. If the Contractor and the design team used the same tool, it would be a fully co-ordinated BIM model (architectural, structural, M&E design) which enables seamless collaboration between design and construction [Architect].
- Instead of seeing a block for the furniture in the design, the architect would prefer furniture suppliers to make 3-D design integrated with the architect's drawings, and produce room schedules from 3-D architectural design. In another project, they specified the fitted furniture and scheduled the 3-D furniture into the drawings. The ability to do this impressed the client [Furniture supplier].

6.6.1.3 Construction Phase

This phase had two stages, pre-construction and actual construction of the building. In the pre-construction stage, the design team and the subcontractors produced construction drawings, related information and knowledge which enabled them to build the project. At the beginning of this stage, the contractor, architect, M&E subcontractor, ICT provider and the furniture supplier went through **Reviewable Design Data Process** with the school and the Client to finalise the detailed design. Following this process, final specifications for equipment, installation procedures and schedules were agreed. Overall output knowledge of this phase was utilized as an input into the suppliers' manufacturing and construction process. During the construction stage, there was a whole series of phases in which the sub-contractors should work according to contractor's schedule. (See Appendix E-3 for further details on knowledge flow between the SC actors).

Highlights of the Construction Phase

In this section some manifestations and causes' regarding the issues which affects the flow of knowledge during the Construction Phase are presented.

Knowledge Sharing and Collaboration Issues

- The design and construction collaboration was inadequate as the team did not use real time project extranets on site. Design work was not transferred to the construction site at the right time which resulted in version control problems [Architect]. The construction phase was much faster than design revisions. This caused misinterpretations and buildability problems on site [Building Control Specialist].
- Due to the lack of effective collaboration between M&E Sub-contractor, M&E consultant and the specialist sub-contractors, the Architect could not fully update the architectural design before the construction phase started [Architect].
- In past projects, Facility Management (FM) information and knowledge was transferred to the construction team by the bid team and the FM team did not have an active role. Due to a lack of collaboration with the FM team, the specifications were not built up well before the construction phase. For this project, Facility Management Services (FMS) assigned a commissioning manager physically located on site to ensure that the requirements of the FM Brief were linked to the construction specifications as agreed. This provided continuity in the workflow, brought early notification of possible enquiries and problems during construction [Facility Manager].

Integration of Design Team to Suppliers

- There was inadequate collaboration between the design team and suppliers. For example, the Landscape Architect preferred to engage with suppliers during the construction phase and inspect the sub-contractor's work on site to ensure quality. On construction sites, there are always slight variations from the design. When the designer is present on site, it is easier and quicker to react to issues or problems [Landscape Architect]. Similarly there was lack of engagement between the fire safety consultant, and the suppliers who deal with the fire safety systems during the construction phase [Fire consultant].
- The quality of the sub-contractor's work and supplier's material has a great effect on the overall quality of the design and delivery. Therefore, the architect's control and feedback on the performance of the supplier and sub-contractor's work are important for future projects. However, they generally provide feedback during informal discussions and there is no formal process where the records are kept [Architect].
- FMS worked directly with the design and construction team to ensure that the installers of the large equipment have the first year's maintenance built in as part of their contract. In

past projects, working with different companies for the installation and first year maintenance created problems between the client and FMS [Facility Manager].

SCM practices

- Due to having a very fragmented and large SC in the past, the FMS recently changed their SCM strategy. The FMS now aims to work with some strategic suppliers to ensure better economies of scale [Facility Manager].
- At the end of this phase, the Contractor evaluated the SC actors' performance according to the standard assessment procedure. These scores were kept to select the best suppliers for future projects. However, they did not have formal meetings with the SC actors to assess the SC and project performance. The contractor does not have a Lesson Learned procedure within the company apart from informal discussions [Bid Manager].

6.6.1.4 Operational Phase

For this project, the Contractor was responsible for providing hard and soft services for 28 years. The Contractor sub-contracted the FM work to their sister Facility Management Services (FMS) Operator. When the school was handed over to the FMS, the operational phase started. An induction was given to the site, operation and teaching staff to provide familiarity on the operation and functionalities of equipment and the school. Following the inductions, the Facility Manager, Educational Specialist, and Contractor attended Post Occupancy Support Review meetings to check the operational status of the facility and user satisfaction. The Educational Specialist produced a report for the Contractor as a guidance for future projects (See Appendix E-4 for further details on knowledge flow between the SC actors).

Highlights of the Operational Phase:

In this Section some manifestations and causes' regarding the issues which affects the flow of knowledge during the Construction Phase are presented.

Knowledge Sharing between FM and Design Teams

- At the operational phase, there should be continuous collaboration between the contractor and FMS team. FMS can experience problems where some parts of the building were not designed or built properly so was not fit for purpose. In such cases, there is a need for a feedback mechanism to transfer knowledge for future design solutions [Bid Manager].

- The end users (school) have a tendency to blame contractors for any defect in the building, and expect contractors to sort out the issues. However, the FMS team is responsible for any fault affecting the FMS specifications. Therefore co-ordination between the Contractor and the FMS team needs to be improved [Facility Manager].

Good Effect of Past Experiences

- Due to completing five years of the BSF Scheme, FMS have experienced remarkable improvement in communication and knowledge sharing amongst their SC. The continuity of the work, particularly in the same location, with the same SC helped to develop a collaborative working culture and common experiences. However, nationally the FMS Operator still needs to have a leaner SC in order to benefit from the collaborative historical experience [Facility Manager].
- One of the best aspects of PFI is handing over the building management systems to the FMS Operator. This clearly changed the way of operating BSF schools. FMS had the responsibility of all staff in the building, and provided trainings for them. Training increased the knowledge and awareness of the staff. Therefore they feel valued and more motivated, and operation issues were sorted more quickly and easily [Facility Manager].
- When there is lack of trust and confidence between the operations and the school teams, even a little problem can cause tensions between these teams. Therefore relationships between these teams should be improved. For this purpose, FMS benefit from formal intensive meetings with schools on a regular basis [Facility Manager].

6.6.2 KM Throughout the project lifecycle

This section presents knowledge resources used by SC actors, methods and tools for knowledge sharing and storage, general KM issues of construction SCs and the expectations of SC actors for SCM improvement.

6.6.2.1 Knowledge Resources of the SC Actors throughout the Project Lifecycle

Knowledge resources of SC actors are an important part of the knowledge creation process of the project. Knowledge resources of the SC actors, which are identified through the interviews, are presented in Table 6-3. According to the Table, the technical literature, market surveys, CPD (Continuous Professional Development) courses, formal or informal events (such as BSA events, conferences, trade shows, workshops) play an important role in the knowledge resources of the project. Particularly, CPD courses, formal or informal events bring dynamism, improve knowledge, and provide the opportunity for meeting with other professionals, and sharing experiences. These events develop a collaborative knowledge sharing culture in the industry, however they are limited due to depending on companies budget, needs and interests [Fire Consultant-Building Controller]. Also a past projects' network or colleagues from other companies are the most common knowledge resources. Therefore, industry wide events, or collaborative events organised by contractors can serve as a good basis to improve relationships within the industry and encourage knowledge sharing.

Table 6-3 Knowledge Resources of SC Actors

SC Actor	Knowledge Resources (Apart from the supply chain actors for the project)
Architect	Own Company; technical literature
Landscape Architect	CPD courses; formal or informal events where they can share knowledge and collaborate with other consultants working on the same area.
M&E Subcontractor	Workshops, industry events
Fire Consultant	Collaboration with other practitioners such as Building Control Specialists, fire engineers, fire officers, fire testing people; a web based forum within the company to share knowledge between the projects
Educational Specialist	National conferences and trade shows; visits to projects which are delivered by other SCs and contractors; International visits to Best Practices; journals, articles and newspapers.
Furniture supplier	Other companies they know closely and who they have worked with before; relevant workshops particularly on sustainability.
ICT Provider	Market surveys; other companies they have previously worked with.
Building Control Services	Technical literature; governmental web sites and the latest building regulations standards and legislations; governmental events and talks about building regulations.
Facility Management Services (FMS)	Construction associations meetings as BSA (Business Services Associations) to meet and collaborate with practitioners working in the same area; knowledge transfer from the new employees coming from their competitors; workshops (particularly in newly developed areas such as BREAM) to meet practitioners and share Best Practice.

6.6.2.2 Methods and Tools for Knowledge Sharing

Company A does not have a KM business unit or department which could implement collaborative working tools for knowledge creation and sharing in every project. In this project, the Contractor provided an online web-based project collaboration system named

BIW Technology (BIW). It has been used for uploading and downloading project documents and sharing with consultants and sub-contractors. Basically, in BIW all information related to the project and the design was in one place and notifications were given to the related project members when new information was uploaded to the system. Apart from BIW, the SC actors used other communication methods such as face to face meetings and emails to exchange information and knowledge during the project.

6.6.2.3 Storage of Information and Knowledge

All SC actors kept electronic versions of project information, emails sent and received and the information they created during the project. They also kept hard copies of important project information in their archive. However, information retrieval is still a problematic area [Landscape Architect]. It is not easy to find the specific project knowledge easily from their archive. Although the emails are kept with a job number and subject line it is not easy to retrieve them, and generally they generally don't benefit from their archive.

The information uploaded to the BIW was kept by the contractor, and after the completion of the project, all the information was stored in their archive. The contractor did not share this archive with their SC actors.

6.6.2.4 Key Knowledge Management Issues

Apart from the project phase specific issues presented in the Section 6.6.1, there are other general KM issues discussed by the interviewees. These are presented in the following section:

Information and Knowledge Overload-Collaboration Tool Issues

According to the Fire Consultant *"it is very important to share information and knowledge, but it's equally important not to share too much so not to confuse people"*. During the project lifecycle, the overload of knowledge transfer discouraged project actors to review and learn all the knowledge shared within limited time allocations of the project. This created problems particularly in the design team meetings because SC actors were not capable of reviewing each others' reports on time to provide sufficient feedback in the meetings [Education Specialist]. The Fire Consultant also stated that they had cases where their reports were not reviewed before the meeting by the design team members, although it was essential for further discussions and the decisions they needed to make collaboratively.

The ineffective use of the ICT tools was one of the reasons for the information and knowledge overload problems. The contractor did not have an effective process of arranging, co-ordinating and controlling the information sent through in BIW [Furniture supplier-ICT Provider]. The SC actors were overloaded with emails sent through the BIW. These emails involved comments on the drawings, update notices. They had cases where the notices and information sent through BIW were not related to their work [Building Control-Fire Consultant]. After being bombarded with lots of irrelevant information, the team members started to interpret most of the information sent through the BIW as being irrelevant. This caused the project members to miss important information and notices during the project [Fire Consultant]. Therefore, project actors used the BIW as a storage tool rather than for communication and knowledge sharing [Building Control-Facility Manager].

Version control was another key issue during the project [M&E Subcontractor-ICT Provider-Architect-Fire Consultant-Furniture Supplier]. Keeping up with the latest design and to access the latest, up-to date project knowledge was quite difficult [ICT Provider]. When a change occurred, the design team sent out notices through the BIW. However, because of the vast amount of emails received through BIW, the SC actors showed a lack of interest in these emails, and worked on an old version of information [Furniture supplier]. Therefore it was better to have face to face meetings rather than sending queries or emails through BIW to the project team [Facility Manager].

BIW stores thousands of documents and it gets bigger as the projects progress. The BIW is found to be a particularly slow and tedious tool and uploading the revisions or new documents was a very time consuming process [Architect-Furniture Supplier]. Although the usage of the tools like BIW has been improved over the past few years, there are still barriers due to the lack of training, skill deficiencies and control [Facility Manager].

Knowledge Dependencies and Knowledge Sharing Issues

There are different views on the clarity of knowledge dependencies and knowledge sharing throughout the project life cycle amongst the suppliers. Knowledge dependencies were defined as “mostly clear” for the SC actors, however forms, formats and communication channels were still problems [Architect-Landscape Architect-M&E Sub-contractor]. The Contractor provided a standard responsibility list which was tailored for each project for the designers. However, there was not any guidance on dissemination and sharing of knowledge [Architect].

Because BSF involves many school projects simultaneously with different SC actors for each school, there were communication problems. For example, although the contract informed that the hard landscape design was the responsibility of the Architect, the landscape architect was expected to provide knowledge on the hard landscape design. This was mainly due to the lack of communication between the teams, (sometimes people in the same office do not talk to each other). This caused tensions or delays in the workflow [Landscape Architect]. The frequent design changes also had a major impact all the way down the SC. These changes caused lots of repetitions, misunderstandings, and slowed down the knowledge sharing process. After the financial close, knowledge dependencies became more clear and knowledge sharing became more frequent [Fire Consultant]. Additionally, the late engagements of specialist consultants to the project caused discontinuity in knowledge creation and the sharing process. If the suppliers were more time efficient on the project, they could have been more specific about their deliverables, knowledge requirements and requests [ICT Provider]. On the other hand the previous BSF experience helped the SC actors to make the knowledge request dependencies more clear compared to past projects.

It is important to understand the knowledge sharing practices and its differentiation in upstream and downstream SC (SC). Upstream SC consists of the activities and tasks leading to preparation of the production on site involving construction clients and design team. The downstream SC consists of activities and tasks in the delivery of the construction product involving construction suppliers, sub-contractors, and specialist contractors in relation to the main contractor. As presented in Table 6-4, most of the interviewees identified the knowledge sharing in the upstream SC better than the downstream. The main reasons for better knowledge sharing in the upstream SC are stated as the availability of closer relationships, historical experience, mechanisms that exist for a long time between organizations, trust based relationships and on time payments [Architect-M&E Subcontractor-Facility Manager-Building Control]. On the other hand, lack of historical experience, competition between SMEs, diversity of the organizations, discontinuity in relationships, and a lack of standards have a negative affect on the knowledge sharing across the downstream SC [Architect-M&E Subcontractor-Facility Manager].

Table 6-4 Evaluation of Knowledge Sharing Upstream and Downstream SC by Supply Chain Actors

SC Actor	Upstream Supply Chain	Downstream Supply Chain
Architect	**Strong** (Due to the availability of mechanisms which exist for quite a long time with the builder).	**Adequate** (Due to a diverse SC for every project) They also have their own SC which is lean, less formal, and quite effective.
Landscape Architect	**Adequate**	**No interaction with the downstream SC.**
M&E Subcontractor	**Strong** (Due to historical work experience)	**Weak** (Due to lack of common experience, huge competition, new SC for every project)
Education Specialist	**Adequate** (Due to the availability of huge amount of knowledge and short time scales, lack of effective communication and collaboration.)	**Strong** (They have their own control it, lean SC, easy to access the right people at the right time.)
Fire Consultant	**Adequate**	**No interaction with the downstream SC.**
ICT Provider	**Adequate** (More control needed.)	**Adequate**
Furniture Supplier	**Adequate**	**Adequate** (They also have their own SC where they try to be more proactive. They organise supplier days where they share knowledge about future workload, and they try to interact more during the project lifecycle.)
Building Control Services	**Strong** (Due to having long term relationships, historical work experience, on time payments for their work and developed trust)	**No interaction with the downstream SC.**
FMS	**Strong** (Due to longevity of historical work)	**Weak** (Very diverse, and there is a need for integration of the down stream SC to upstream.)

Inadequate Encouragement on Collaborative Knowledge Sharing

Most SC actors' work on many live projects. For all these projects, there are vast amounts of suppliers with whom they need to establish and maintain collaborative and active relationships. This brings complexity, conflicts, time consuming issues, and problems in the management of their SC relationships [Facility Manager].

The design meetings and programme of delivery dates for the information produced encouraged the SC members to transfer the knowledge. However, apart from this, there were few activities held by the contractor that encouraged collaborative knowledge sharing between the actors on the project [Architect-Landscape Architect-M&E Sub-contractor-Educational Specialist-Fire Consultant-ICT Provider].

According to the M&E Sub-contractor, the key performance indicators (KPI's) put together for continuous SC improvement by the contractor recently had a positive effect on collaboration. These indicators are mainly based on financial, health and safety and environmental performance areas. Although these indicators are not directly related to the transfer of knowledge, the M&E Sub-contractor believes that it helps to integrate the SC and puts pressure on the suppliers to perform better by collaborating with the other SC actors.

Workshops were also found to be an important accelerator for collaborative knowledge sharing [M&E Sub-contractor.] The M&E Sub-contractor organized a ventilation workshop at the beginning of the project where they discussed the ways of ventilation with the other SC actors (such as the Architect, M&E Consultant, and the Contractor). The outcome of this workshop helped enormously in terms of the challenges of ventilation in the project. Also, the 'lessons learned meetings' were also defined as an accelerator to share knowledge in the SC. However, for this project, they did not have a chance to attend such an event [Architect]. In the industry, lessons learned meetings are arranged for designers and generally the downstream SC actors do not attend these meetings. The main reasons for this is the commercial pressures, time limitations and lack of resources [M&E Sub-contractor]. The industry has a particular lack of activities or encouragement to create collaborative relationships between the upstream and downstream SC [Architect- Facility Manager].

The Contractor was not very proactive in terms of creating collaborative relationships to accelerate knowledge sharing. Most of their relationships were based on trust due to on time payment and successful delivery in past projects [Furniture Supplier]. According to the Furniture Supplier, Company A is quite traditional, and has a *"we'll go and get a price for these bricks"* approach. This creates a huge difference in terms of knowledge transfer and collaboration between suppliers. When suppliers work in a traditional way they only pass the knowledge they are asked for. However, when they are engaged as part of a team with the contractor and other suppliers, knowledge passes informally between the team members and there is a 'natural encouragement' due to a 'team approach'.

Capturing the Tacit Knowledge and Getting Benefit from Unsolicited Knowledge

Capturing knowledge was an important issue particularly while transferring the tacit knowledge in people's minds into an explicit and accessible form. In the design meetings, there were lots of debates and discussions on the best design practices in order to agree on a final design. The highlights of these discussions were kept in the minutes of meetings as soft copies. However, no one reviewed these copies unless a conflict occurred [Facility Manager]. Also, it was very difficult to capture the verbal knowledge shared throughout the meeting. In other projects, there were some LEP people who deal with the effective capturing and transfer of knowledge which makes the process more formal. In this project, there was lack of well defined procedures to extract verbal knowledge shared in the design meetings [Education Specialist].

When the project actors shared unsolicited knowledge, it was more like "*I went to a meeting and I heard that this school prefers a more traditional approach to school design" Or "my child goes to that school and I know that they prefer …"* [Furniture Supplier]. According to the M&E Subcontractor, unsolicited knowledge is mostly shared informally and generally stays in people's minds therefore, it is difficult to gain benefit from it [M&E Sub-contractor]. The frequency of sharing unsolicited knowledge depends on the relationship between the SC actors. If there is a close relationship and a 'team approach', they are more likely to benefit from unsolicited knowledge [Furniture supplier]. Similarly, the SC actors share informal and unsolicited knowledge when they attend some events and socialise with the project actors [Facility Manager]. This is particularly apparent in the workshop environment, project actors share all sorts of project knowledge, however there was little effort to keep this unsolicited knowledge and share it formally within the project teams [Education Specialist]. According to the ICT Provider, the most valuable information and knowledge came from the formal meetings and formal knowledge exchange processes. They did not appear to benefit from unsolicited knowledge because there are no standard procedures in place to transfer the unsolicited knowledge to the project teams [ICT Provider].

Confidentiality Issues-Are the Supply Chain Actors free to share Knowledge?

Commercial sensitivity causes issues for the SC actors while sharing their knowledge [Educational Specialist]. SC actors work in a commercial context. However, they do not always work with the same SC. This forces them to protect their intellectual capability from other actors of the SC, especially from architects. Before the preferred bidder stage, the architects are more careful about sharing their knowledge with the design team [Architect-Landscape Architect]. However, after the preferred bidder stage, this situation changes and it becomes easier to share knowledge with the other actors [Education Specialist].

The downstream SC is found to be very competitive and conservative in knowledge sharing [M&E Subcontractor]. Confidentiality issues particularly cause problems if there is not a strong, long term, trust based relationship available between SC actors [Furniture Supplier]. For example, the Furniture Supplier had cases where the contractors request furniture design information and drawings in order to send them to another furniture company to get alternative competitive price. Therefore, the Furniture Supplier is careful about knowledge sharing unless there is a contractual agreement or partnership in place. On the other hand, according to the Landscape Architect, partnering agreements may not even provide a fully secure environment.

Quality of Knowledge/ Skill deficiencies

"BSF is a new and very competitive market, and there are not enough design teams that have the capability of taking the BSF projects" [Bid Manager].

According to the Bid Manager, projects are predominantly won by design, therefore contractors seek skilled and talented designers. However, particularly in the education sector, there is a shortage of skilled people who have extensive experience in education sector design.

One of the main problems in construction SCs is defined as "*the actual knowledge itself*" by the Architect. For many projects, design knowledge which was disseminated effectively has been subjected to too many changes due to the lack of accuracy and quality of the knowledge created. Particularly, there is an inadequacy of the skill sets in some of the areas such as M&E Services (mainly), sustainability, ICT skills etc [Architect]. Also, facility management, and fire consultancy are not mature enough compared to other areas of the construction industry such as civil engineering, quantity surveying, construction [Facility Manager-Fire Consultant]. For the Building Control Services, fire safety, energy efficiency and disabled access were the most challenging and difficult part of their review process. Therefore, there is an urgent need to develop and improve the knowledge embedded in these sectors and to integrate them into the project knowledge, and improve skill set of the employees working in these areas [Facility Manager]. On the other hand, according to the Architect, there is no well developed long term SC strategy to improve the skills and knowledge in the chain. They usually work with different SC actors for BSF schemes. Therefore, the opportunity for developing collaborative experiences and knowledge, and to learn from each other is not always possible.

There are no standards in terms of the technical or managerial skills for same level of people in different construction firms. Some of the teams are better skilled, better organised, and have a much better understanding of the processes. There is also a huge difference in upstream and downstream SCs in terms of these skills [Furniture supplier].

Cost Driven Industry

We have a pot of cash to do the job on one side, and we have an aspiration what we will get on the other side; the difficulty in construction is to make these two sides meet at an optimum level, we mostly want to have a Rolls Royce but what we can afford is just a Mini! [Bid Manager]

In the construction industry, decisions on the selection of suppliers and sub-contractors are mainly taken on the basis of cost. However, once the decision is made, the client is only interested in the technical abilities and aesthetics of the end product, and the expectations of the client is beyond the budget [Bid manager]. Also, there is a remarkable confusion between the cost cutting and the value engineering in the industry. However, the overall quality of knowledge produced and the delivery of the work always depends on the budget allocated. The designers, suppliers or sub-contractors who are selected based on cost basis cannot satisfy the expectations of the budget. This puts too much pressure on the SC actors [Landscape Architect].

Lack of Standardization of the KM Process

Each contract dictates how the SC actors operate, create and share the project knowledge. This effects the ways project knowledge is created, transferred and stored in each project and there is no standardisation [Facility Manager]. According to the Architect, the industry lacks basic principles for any SC actor who signed up to do any design work or create design knowledge. This causes confusion on the formats, forms, tools, and transfer channels to share knowledge within the construction SCs [Architect].

Also in construction projects, particularly in the education sector, it is criticised that end users have big a impact on the creation of design knowledge. As long as the client or the end user does not violate the building regulations, there is the flexibility to change many aspects of the design. Every BSF project starts from scratch and there are minimum standards in the creation of design. All buildings differ and there is no uniform approach for design [Furniture supplier].

Having employees working full time job on construction projects and relying on these employees to share and control the project knowledge has never worked particularly in tight project phases. Therefore organizations have no standardized mechanism in place to control the circulation and diffusion of knowledge to the project teams [M&E Subcontractor].

Lack of Standardization on SCM

Being a cost driven industry, construction SCs have a lack of standardisation in the SCM processes. Most of the construction organizations apply their own criteria in the SC selection and management, and there is no standardisation on the SCM metrics, methods and tools used in the industry [Facility Manager]. All SCM processes in the industry are based mainly on cost, experience and/or personal measure of performance [M&E Subcontractor]. Lack of a standardized way of supplier selection highly affects the quality of the knowledge shared during the projects, thus it affects the performance, delivery and quality of the overall work [M&E Subcontractor- Architect]. Lack of formal procedure and objective tool to assess the supplier's performance and delivery slows down the improvement of the construction SCs.[Facility Manager].

There is no standard appointment process of SC actors to projects in the industry [Fire Consultant]. Moving from one region to the other, the consultants are subject to different SC strategies. For example, in one project, the Fire Consultant was contacted by an architect whereas somewhere else they are employed by a contractor. Architects and contractors have different requirements like aesthetics vs. affordability. These requirements affect the way and the detail of knowledge creation process. Moreover, there is no consistency in the timing of the appointment of Specialist Consultants to the projects [Fire Consultant].

As a positive outcome of early engagement to the projects, the Facility Manager explained the situation in their previous projects. Historically, the FM team was not involved in the design chain at an early stage of the project, and they only provided very brief knowledge to the design team instead of physically attending the design meetings, or preparing detailed operational requirements. Even the bid team was unaware of the deliverables of FMS and their effects on the operational aspects of the design. However, it has recently changed bringing an advantage in a job winning capacity [Facility Manager].

Lack of Project Pipeline Information from the Client

There is lack of information on future bids of the contractor from the client [Furniture supplier]. The SC actors often find things by accident or by talking to people in the industry instead of being informed by the contractor regarding the potential projects in the pipeline. The SC actors are generally contacted during the bidding process and it creates difficulties in terms of collaborative knowledge creation and sharing [Furniture supplier].

6.6.2.5 The Expectations of the Supply Chain Actors for the future

In this Section the key changes expected by the SC actors are presented.

Basic Principles for Design Information Creation & Sharing

- There should be basic principles for any SC actors who signed up to do any design work to create design knowledge. These principles should involve CAD protocols and data formats, agreed grids and zones for positioning of the building, naming and convention of CAD design objects and drawings. Design team should benefit from a fully co-ordinated BIM model which enables seamless collaboration between design and construction [Architect].

Better SC Integration

- Contractors should manage the appointments of the suppliers and sub-contractors at the right time. Knowledge flow between the design team and the downstream SC should be improved. [Architect-Landscape Architect-M&E Subcontractor-Fire Consultant-Furniture Supplier].
- More budget should be allocated for downstream SC actors and services. This would ensure specialist designers or downstream SC actors were available during the project to share their knowledge [M&E Subcontractor].

- Contractors should share their plans as early as they can so that the whole supply can plan and react to the demand in a more organised way [Furniture supplier].

Creation of a Strategic Supply Chain

- Instead of working locally for every project, contractors should look nationally for best partners and have a more strategic SC. This will improve historical and strategic relationships, better economy of scale, and continuity [Facility Manager]. Development of leaner SCs is the next step for the construction industry [Building Control].
- SC agreements and partnering are found to be the main element for better integrated SCs [Project Manager-Furniture Supplier]. Establishing partnerships and agreements put contractual obligations on confidentiality [Facility Manager]. These agreements do not take all the risks away but it takes away the fear of sharing knowledge [Furniture supplier]. Having shared aims and historical experience helps to increase trust between the partners and improve as a team [Landscape Architect].

Effective Use of ICT

- One of the most important improvements would be the effective use of electronic platforms where all the SC actors can collaborate and have access to up-to-date project knowledge. These tools should be more user friendly and it should be easier to navigate and access the required information [Building Control]. SC actors also expect to have training organised by the contractor which will help them to understand the functionalities and benefits of these systems [Building Control].
- Construction projects can benefit from the implementation of live knowledge sharing platforms running on projects’ collaboration tools such as a blog or twitter page where day to day project workflow and news can be shared. In this portal, SC actors can be informed about the problems and solutions developed by project actors. This will improve SC actors’ technical knowledge and general project knowledge [Facility Manager].
- Knowledge shared verbally during the design team meetings or the client meetings should be translated into an explicit form and shared by the design team members with the effective usage of ICT tools [Education Specialist].

Improvement of Downstream Supply Chain

- Large scale contractors can have a great affect in changing the way the construction SC works. Contractors should develop SC assessment metrics, and objective tools, and help the downstream SC to use and implement these tools [Architect].

Launching KM Units

- Contractors should lead the implementation of KM practices in construction projects [Educational Specialist]. Establishing KM units which can facilitate collaborative working and associated technologies, diffusion of project level knowledge to organization level, and improving the knowledge creation process in major projects where a huge number of people from different backgrounds are working together will be beneficial [M&E Sub-contractor].

Learning from Past Projects

- SC actors would like to benefit from past projects by reviving the success stories, collaborative decisions that they made on main issues. Therefore standardising company procedures needs to be established rather than sharing such knowledge verbally or informally with SC actors [Facility Manager].

More Dialogue between Clients and Contractors

- More dialogue should be established between clients and contractors. Establishing a clear understanding with the client about knowledge requirements of each SC actor; informing client clearly about the knowledge creation and transfer process are very important. This will help the client to understand the nature of the issues that the project partners face throughout the project [Educational Specialist].

Organizations and Actions for Better Relationships

- In recent years, BSF events and workshops have brought more dialogue to the upstream SC. If these kind of events could be more organized throughout the whole SC, this will improve the relationships and collaboration amongst SC actors [Landscape Architect].
- Relaxed forums or socialising networks are events where SC actors have a tendency to share knowledge freely [Facility Manager]. Contractors can benefit from these kind of events to improve SC relationships [Bid Manager].

6.7 Chapter Summary

In this Chapter, the main issues of Company A's SC; problems in knowledge flow amongst SC actors through out the 'X High School Project' lifecycle and KM issues were presented.

Summary of Company Specific Case Study

The main SC priorities for Company A were defined as sales and customer satisfaction. The selection criteria for the suppliers are cost, health & safety, past trainings, certifications, in house design capabilities, availability of any sub-let work, geographical location, quality, environment and safety systems, and references. The performance assessment of a supplier is mainly based on cost, health & safety, environment, quality, delivery, ethics, outlook and openness. However, amongst all these criterion, cost was defined as the major one.

Company A has a mixture of old and new SC relationships which were defined as good depending on reputation, well established trust, paying on time and paying fairly. Company A prefers to use supplier protocols which define the responsibilities of both parties involved in the SC relationship rather than partnering agreements. Company A does not have SC development programme apart from their supplier meetings organised once every 2 years.

Company A does not have a standard collaborative knowledge sharing tool for all projects. Collaboration software is not used effectively due to the lack of IT skills and infrastructure particularly in the downstream SC.

Company A is unaffected by globalization due to having a local SC. Due to lack of standard work load coming through the clients, it is difficult to agree and outsource the SC outside the UK for future projects. Company A also struggles with the flexibility of their SC because of lack of visibility on the forecasted work load.

The agenda for the future is establishing a decent KM tool where SC actors can collaborate and share knowledge effectively, exploring the Far East market for new supplier agreements, establishing leaner SC, creating collaborative working environment at early stages of the project lifecycle to bring innovation. The biggest challenge to achieve this agenda is lack of standard end product and having highly fragmented SC.

Summary of Project Specific Case Study

This project-specific case study revealed that feasibility and bidding phase is the most difficult phase in terms of information and knowledge sharing for the SC actors. The duration of the feasibility and bidding phase of the ‘X High School Project’ was short and the design was made in rush. This created information overload for the SC actors. Knowledge dependencies became more clear and knowledge sharing became more frequent after the financial close. However, the construction phase was much faster than the design revisions. The revisions were not given to the right parties at the right time due to lack of real time collaboration tools on site and inadequate communication between design and construction teams.

There is a need for a better knowledge sharing between SC actors. There should be more dialogue between the Client and the Contractor to establish a clear understanding about the client requirements and the knowledge requirements of each SC actor. Knowledge sharing in the upstream SC was better than the downstream SC. The main reasons for this situation were stated as the availability of trust based closer relationships, mechanisms that exist for longevity between organizations and on time payments. Lack of historical experience, competition between SMEs, diversity of the organizations, discontinuity in relationships, and lack of standards negatively affect the knowledge sharing across the downstream SC. Also late engagements of the Specialist Consultants seriously affected knowledge sharing through the project lifecycle.

Apart from the design meetings and programme of delivery, there were few activities held by the Contractor to encourage collaborative knowledge sharing between the SC actors. Industry wide events, or collaborative events organised by contractors can serve as a good basis to improve relationships within the industry and encourage knowledge sharing.

A lack of standardised KM caused misunderstanding on the formats, forms, tools, and transfer channels of sharing knowledge within the SC. Lack of interoperability between the software programmes used by the designers, lack of coordination and control on the information sent through the BIW caused serious information management problems. A fully co-ordinated BIM model including architectural, M&E and structural design supported by the product libraries of sub-contractors has great potential to improve information flow. The Contractors should find ways for effective use of electronic platforms where all SC actors can collaborate and access to up-to-date project knowledge. ICT trainings should be organised by the contractor which will help the suppliers to understand the functionalities and benefits of these systems. There is a need for KM units which can facilitate all collaborative working and associated technologies, effective communication, diffusion of project level knowledge to organization level, and improving knowledge creation process in major projects.

The Construction industry is still cost oriented and this heavily affects the supplier selection process and SCM procedures. There is need for standardised SCM procedures to improve the integration of SC actors. The contractors should manage the SC in a way where the designers and specialist consultants can support the preparation of supplier specifications and sub-contract packages, supplier selection process, and control of the suppliers' work during construction phase. Instead of working locally for every project, contractors should look nationally for best partners and have more strategic SC. Having shared aims, collaborative working culture, historical experiences, SC agreements and partnering, reviewing lessons learned with the SC can help to increase trust between the partners and improve as a team in the SC.

The issues summarised in this Section will be investigated further along with the results of the Company B Case studies which are presented in Chapter Seven and the Aerospace Industry Case Studies which are presented in Chapter Eight. This investigation will be the a basis of the 'knowledge chain framework'.

CHAPTER 7

7 CONSTRUCTION INDUSTRY CASE STUDY 2

7.1 Introduction

In this chapter, the case study conducted in Company B and the case study conducted in the supply chain (SC) of 'Y Community School Project' is examined. The background of Company B, the content and method of case studies are presented. The case study in Company B is concerned with the perspective the company on its supply chain management (SCM) issues. The case study conducted in the SC of 'Y Community School Project' is mainly concerned with the knowledge flow through the project SC and the main SC issues which have direct or indirect effect on the management of knowledge during the project lifecycle.

7.2 Company B Background Information

Company B is selected for the case study research because it is the largest privately owned construction solutions provider in the UK. It operates in both the public and private sectors, mainly in the UK and also across Europe, the Middle East, South Asia and Australasia. It has revenue of £4.3 billion and a workforce of 30,000 people worldwide in 2010.

Company B structures its business activities in line with the lifecycle of buildings and infrastructure. Company B has five main business groupings which are: Investment and Development, Manufacturing, Construction and Building Services, Infrastructure Services, and Support Services. They provide capabilities in all aspects of project management and delivery, through to operations, maintenance and decommissioning across a range of sectors such as lifestyle, business, social infrastructure, transport, power, mining and natural resources, oil and gas, and utilities and waste. The corporate governance framework for Company B is presented in Figure 7-1.

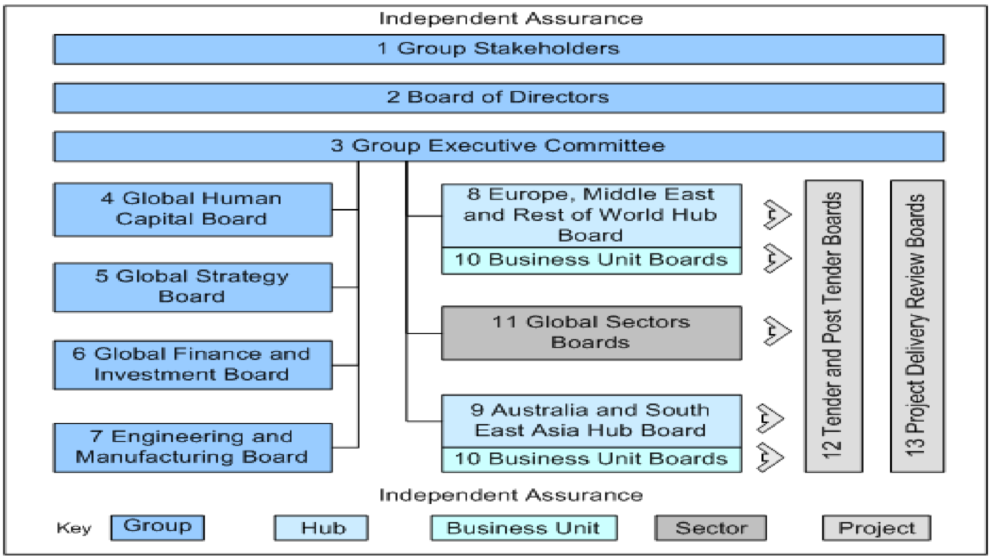

Figure 7-1 Company B Corporate Governance Framework

7.3 Case Study Content

For the company-specific case study, two structured interviews were conducted with the Supply Chain Manager and Collaboration Manager to obtain background information regarding the SCM in the company. In these interviews information on the following areas was collected:

- Number of Suppliers and Supply Chain Assessments;
- Supplier Selection Criteria and Supply Chain Relationships;
- Knowledge Exchange and Collaboration Issues;
- Other Issues and Future Plans of the Supply Chain.

The interview questions are presented in Appendix A. Following the company specific case study, the 'Y Community School Project' was selected to review the SC of the project within a project specific case study. Two semi-structured interviews were conducted with the Procurement Manager and the Project Manager of the project. The Project Manager explained briefly the phases of the project in a chronological order and provided information about the main suppliers in each phase. Contact details of the main SC actors were obtained for further investigation. Details related to the SC actors' selection, and relationships with these members, were discussed with the Procurement Manager.

Following these interviews, structured interviews were conducted with the SC actors. In these interviews information was collected on the following areas:

- Project knowledge created/disseminated/shared/stored in each phase of the project;
- Methods and tools used for knowledge creation and sharing;
- Knowledge management issues and problems in the project supply chain; and
- Future Expectations for Construction Supply Chains.

The details of the interview questions are presented in Appendix B. Table 7-1 shows the details of the 17 interviewees.

Table 7-1 Information on Interviewees

Company /Business Area of the Interviewee	The Role of the Interviewee	Experience in the Construction Industry	Experience in the Company
Company B	SC Manager	25	25
Company B	Collaboration Manager	20	12
Company B	Project Manager	12	10
Company B	Procurement Manager	8	4
Company B	ASITE Manager	10	7
Architect	Director Architect	26	5
Landscape Architect	Landscape Architect	15	3
Structural Designer	Structural Designer	7	2
M&E Consultant	Mechanical Systems Consultant	10	3
M&E Consultant	Electrical Systems Consultant	30	23
M&E Consultant	Sustainability Consultant	10	5
Fire Eng. Consultant	Consultant	40	17
Furniture Supplier	Consultant	10	7
Acoustic Engineer	Consultant	5	5
M&E Services Contractor	Director	8	3.5
Joinery and Glazed Partitioning Cladding	Manager	10	6
Metal work Sub-contractor	Manager	8	7

7.4 Findings Of The Company Specific Case Study

This Section presents the results of the company specific case study which is based on the review of the SCM issues. These issues have implications on how the project knowledge flows through the SC.

7.4.1 Introduction to Company B Supply Chain

Company B has recently undergone important changes in its SC. They have reduced their SC actors from 2500 companies to 330 in the last 12 months. For example, for scaffolding they reduced the SC actors from 75 to 13; for dry lining from 170 to 45; and for brick and block work from 95 to 14 [SC Manager]. Company B also has 200 design suppliers who manage the relationships and KM with the design SC. The reason for the reduction of the number of SC actors was the desire for the creation of a leaner SC and the use of preferred suppliers [Collaboration Manager].

7.4.2 Supplier Selection Criteria and SC Assessments

The main SC priorities for Company B are consistency, client satisfaction, driving productivity, design for manufacture and assembly for reducing labour and material on site, leanness and agility throughout the SC [SC Manager, Collaboration Manager].

In order to identify the preferred suppliers for the next five years, Company B uses a pre-qualification questionnaire and a health and safety audit for scoring individual companies within a predetermined matrix. The main selection criteria for the preferred suppliers are: health and safety, financial stability, willingness to collaborative working, cost, past completed projects (references), and innovation capability. Selected sub-contractors and suppliers are assessed for financial robustness before being contractually engaged and full contingency planning is also undertaken in case there is a risk of financial instability of the suppliers [SC Manager].

To make a decision on keeping a designer in the SC for future projects, Company B uses an Objective Performance Management (See Appendix D) tool on a web based software, which identifies the best performances of suppliers regarding the categories and attributes on design management performance, quality, commercial, responsiveness, commitment, and innovation. Live projects are reviewed according to a monthly evaluation of project leaders and design managers. The results are reviewed quarterly by the board members.

7.4.3 SC Relationships

Company B has, generally, mature relationships and they would like to keep these as long as they operate according to their requirements, but they also seek new actors for improving their project delivery and job winning capacity.

As a standard procedure, following the performance evaluations, Company B arranges collaborative workshops with all segments of the SC in order to establish and maintain close relationships. The aim of the workshops is to share best practice and compare the relative performances of the suppliers. Beyond these, they share their views on future innovation capabilities and abilities of preferred suppliers for future engagements.

7.4.4 Special Programmes/Actions to Improve SC

The following are some programmes which have been on-going within Company B for establishing and maintaining better SCs.

Collaborative Working for the Identification of the Relation between Cost and Quality

Company B endeavours to identify the relation between cost and the quality of the products provided by suppliers. In order to achieve this, Company B aims to work closer with suppliers and analyze the factors affecting their SC member's cost policy. They create bespoke solutions depending on the project requirements and eliminate unnecessary cost items due to inefficient design. This ensures that they have better control of the cost of the projects throughout the lifecycle and increases the suppliers' competitiveness in the market. The strategy for implementing such a working methodology with suppliers is to establish very close relationships and share knowledge through collaborative workshops. It is believed that if suppliers become best friends then they will share information and knowledge easily. Company B would like to work with suppliers even at the design and development phase of their products so that they can, ultimately, have more innovative and cost effective solutions.

Building Constructive Relationships (BCR): In 2005, Company B implemented a BCR framework in order to select and work collaboratively with the best preferred designers for the delivery of large scheme projects. BCR is a five year partnership and framework agreement between Company B and its designers SC in order to create strong relationships and working principles. Within this framework, the suppliers are supported to provide consistent delivery, higher reliability, and strategic positioning. The suppliers are reviewed at the end of their two years according to the framework criteria. The key issue is to have up to date detailed knowledge on the SC members in terms of turnover, direct employee numbers, financial position and their working partners. The best way to capture continuous information on the SC members is to create closer relationships and arrange regular visits to their working environment.

Managing Supply Chains Expectations: It is critical that the workload within the organization is fairly allocated to the SC actors so that, as a corporate organization, Company B maintains good relationships within its SC. Therefore, for the long term Company B will evaluate its SC actors regarding their performance management and eliminate the actors who are not qualified to work with them. Those remaining will be responsible in delivering the service according to following criteria: best price, best support, health and safety, and work prioritization.

IIF- Incident and Injury Free Construction: IIF is a special Health and Safety programme established to improve the health and safety on sites. SC actors are trained on the programme (workshops, training) in order to deliver incident and injury free work at sites.

Preferred Supplier Agreements: Company B provides opportunities to its sub-contractors and manufacturing suppliers regarding the procurement of stationery, health and safety equipment (personal protection). The level of provision depends on the agreements with each supplier. In this way, Company B helps its sub-contractors to reduce their operational costs through benefiting from cheaper prices than the actual market.

Early Notification of Project Scheme: Company B informs its sub-contractors and manufacturing suppliers monthly through e-mails about the potential projects in the pipeline and their characteristics so that they can arrange their design and production capacity, organization and potential cash flow.

7.4.5 Information and Knowledge Exchange Methods and Tools

Company B uses ASITE for collaborative information and knowledge sharing amongst SC members through the projects. SC members share the drawings, technical queries, specifications, and related project information through this collaboration tool.

Company B has a Collaboration Centre where project teams interact in an immersive environment. The centre has two digital prototyping theatres which have the ability to produce fly-through simulations. It has proved invaluable in demonstrating virtual prototypes to clients [Collaboration Manager]. The centre is a core element and facilitator of integrated team working.

Especially for international operations, video-conferencing became the most popular method and will replace face-to-face meetings for knowledge exchange with the SC. However, some technical problems may occur before or during the video-conference which sometimes make knowledge exchange inferior to the face-to-face meetings.

Company B encourages clients, product manufacturers, sub-contractors and designers to get together in order to understand new products, requirements of projects and adaptability to real life conditions. The knowledge transfer between these parties is usually arranged with formal product presentations, workshops and informal meetings.

7.4.6 Knowledge Exchange and Collaboration Issues

According to the SC Manager, knowledge transfer between SC actors leads to better cost effective solutions for current and future projects. Effective knowledge transfer within their SC is strategically important for Company B in order to increase best practice, innovation, efficient use of resources and collaborative working between SC members.

The main issue in their SC is the lack of diffusion of the knowledge from the SC to other parts of the business [SC Manager]. Particularly, project knowledge is retained with people and there is no mechanism to acquire benefit from this knowledge after the completion of the project.

Another important barrier for knowledge sharing within the SC is the competition between various suppliers. PFI (private finance initiative) projects are the most likely to have better knowledge sharing due to working with the same project team for similar types of projects. In some cases, knowledge transfer between manufacturers and contractor has negative impacts on the relationship. In particular, at the bidding phase, knowledge sharing is based on confidentiality agreements and trust oriented relationships problems can arise if the knowledge is not used within the confidentiality framework [Collaboration Manager]. SC members might share best practice and competitive knowledge with the competitors of Company B. Therefore, it is important to have some internal agreements and develop trust within the SC in order to keep the knowledge secure [SC Manager].

Another problem, which they improved recently, is inadequate collaboration between design consultants and Company B. Company B benefits greatly from the Building Constructive Relationships (BCR) framework (See Section 6.3.4) which allows them to collaborate early in the design stage and develop standard design parameters and specifications.

According to the Supply Chain Manager, knowledge transfer between architects and product manufacturers is the key enabler for eliminating waste and decreasing the cost of projects. As an example, in hospital and school projects architects and glass manufacturers had a collaborative working and knowledge sharing environment which led to waste minimization on site. At present, Company B has no existing contractual agreements with SC members to share and manage their knowledge.

7.4.7 Other Issues of SCM and Plans for the Future

Client Request and Cost Concerns: Clients are looking for cheaper costs and different suppliers. However, Company B is trying to work with a standard set of suppliers from the bidding stage to handover with a minimum cost. Company B sees benefits in its supplier engagement approach and is keen to inform their clients about these benefits. However, it is a challenge to convince their clients about these benefits, and cost is still the most important element for clients.

Geographical Cultural differences: Company B operates in four different hubs: Europe, Middle East, and Asia and Australia. In the European Hub, there is a major objective to improving collaboration within the SC. However, the other markets are at the development stage and the priority for these hubs is the cost of construction.

Organizational Resistance: The major problem is the internal resistance to changing working principles with an identified standard set of SC members. Individual project members tend to work in their own way with their existing suppliers. However, Company B`s vision is to employ a certain amount of suppliers depending on the performance management tool.

Waste Management: Monitoring and managing the waste created by suppliers during the project lifecycle is very critical in order to improve profitability and sustainability. Therefore, there should be agreements with the SC actors in order to minimize the physical waste produced on sites. In the meantime, collaborative working between the design and manufacturing SC improves the waste and cost management, and innovation within the project lifecycle.

Inadequate Innovation: Innovation in the SC is critical for project delivery and strategically important for Company B [SC Manager]. They expect their SC actors to find better ways of working and produce more efficient products in terms of cost, quality and service. To achieve product innovation, Company B aims to create relations between manufacturers, design consultants and architects so that new products coming into the market can be tested and used in the current projects. Process innovation is more difficult than product innovation to diffuse into the business due to having various business units and processes. However, the critical processes which need to be addressed are the payment and procurement processes.

SC Budget: Currently, Company B spends most of the SC improvement budget on operational excellence in order to complete projects quicker, smarter and better, but it is clear that there should be more budget allocation for innovation in the SC for the future [SC Manager].

Corporate Responsibility: Company B has a corporate responsibility agenda which drives a proportion of procurement to be sourced from local resources. This is an important barrier when trying to find competitive prices in global markets. However, there is a huge opportunity to explore the global markets, especially the Far East, to supply various products.

7.5 Y Community School Project

7.5.1 BSF Projects

As stated in Chapter 6.5.1, being the largest capital investment programme for 50 years in the UK, Building Schools for the Future (BSF) projects are one of the main focuses of large scale contractors. For a better comparison of Company A and Company B, another BSF project was selected as a case study in Company B, the ‘Y Community School Project’.

7.5.2 Project Overview

Company B’s consortium won a £200m school-building contract from the ‘Y Local Council’. Under the BSF programme, the consortium will rebuild four schools, remodel and refurbish nine schools and equip all secondary schools with state of the art ICT equipment installed and supported by their ICT partner. The programme will deliver cutting edge design and ICT solutions in three phases, with the entire first phase of sample schools planned to be built and open by 2011/12.

‘Y Community School’ is one of six schools included in Phase 1 of the BSF programme of the ‘Y Local Council’. The school consists of 11,299m^2 of new floor space including 70 classrooms, a new dance hall, community classrooms and hearing-impaired provision areas. The procurement route for the project was the Design-Build contract. This contract had several stages which are briefly described in the following section.

7.5.3 Project Lifecycle

Table 7-2 presents the key tasks delivered in each phase, the design stage in each phase according to the RIBA stages and the key SC actors who worked in each phase.

Table 7-2 Y Community School Project Phases and SC Actors in each Phase

Phase	**Feasibility & Bidding Phase**	**Contract Close Phase**	**Construction Phase**
Content	Business Justification-Procurement Strategy-Design Brief-Conceptual Design Approval	Detailed Design Approval-Planning Applications-Financial Close	Pre-Construction, Construction
RIBA STAGE	Preparation(A-B) Design(C-D)	Design (D-E-F)	Construction (J-M)
SC Actors of the Phase	Contractor-Designers-Specialist Consultants-Suppliers (ICT-Furniture)- Building Control Services (BCS)	Contractor-Designers-Specialist Consultants-M&E Sub-contractor-Suppliers (ICT-Furniture)- BCS	Contractor- Designers-M&E Sub-contractor-Specialist Consultants-Suppliers-Sub-contractors- BCS

7.6 Findings Of The Project Specific Case Study

This Section presents the findings of the project specific case study which involves the key knowledge flow issues, general KM practices, key SC issues and the expectations of SC actors for better knowledge sharing.

7.6.1 Knowledge Flow throughout the Project Life Cycle

In this section, knowledge flow and issues associated with the knowledge flow in each phase of the project are presented. In Appendix F, the main elements of the knowledge flow between each SC actor through the project life cycle are presented in tables. The tables in Appendix F present:

- the information and knowledge requirements of main supply chain actors;
- the actors (in brackets) who provided the required knowledge;
- the information and knowledge created by each supply chain actor; and
- the supply chain actors (in brackets) who received the created knowledge.

7.6.1.1 Feasibility and Bidding Phase

This section presents the main highlights of the feasibility and bidding stage which affected the knowledge flow between parties. (See Section 6.6.1.1 for further details on the pre-bid process and Appendix F-1 for further details on knowledge flow between the SC actors)

Highlights on the Feasibility and Design Phase

In this section some manifestations and causes regarding the issues which affect the flow of knowledge during the Feasibility and Design Phase are presented.

Appointments of the Consultants

- At the beginning of the project, an M&E Consultant was appointed and provided the performance specifications, ventilation, and maintenance strategy. However, they did not continue with their work due to disagreements on cost. Once the design had been developed, the performance criterion was changed. There was no M&E Consultant appointed between RIBA Stages C-E [Architect]. It is stated that in construction projects, M&E Consultants are generally not involved during the conceptual design (RIBA Stage A and B), and they are appointed around Stage C. However, earlier engagement of M&E Consultants could add great value in terms of sustainability [M&E Consultant 1].
- It would be very helpful if the Structural Designer could interact with the Fire Consultant, and the Cladding Sub-Contractor to include their knowledge in structural design. However, contractors do not want to appoint the Specialist consultants and sub-contractors before the tender because of cost constraints [Structural Designer].
- A Sustainability Consultant worked at the beginning of the project and provided BREEAM pre-assessment. However, there had been discontinuity in their engagement and no sustainability check was done until RIBA Stage C [Landscape Architect]. In landscaping, the sustainability issues should have been considered and implemented at the beginning of the design phase. However, due to discontinuity in the engagement of the Sustainability Consultant, the Landscape Architect could not collaborate with the Sustainability Consultant [Sustainability Consultant].
- An acoustic consultant was involved quite early in the project. This helped the design team to include the acoustic requirements earlier so they did not need to change their selections in the future [Acoustic Consultant].

Different Tools for Design Knowledge Creation

- There was no coordination concerning software and programmes used [Landscape Architect]. All consultants used different software and this caused a lot of compatibility problems while sharing the drawings [Structural Designer-Architect]. This project was a pilot scheme for the Architecture Company to implement a new platform called ArchiCAD which gave them the possibility of presenting and working with the scheme in 3D. In order to save time in the design, the architect company decided to switch to REVIT. The Contractor also implemented a REVIT platform to be used by each design member [Architect].

Lack of Design Coordination and Frequent Changes

- In the ideal case, the Contractor should have fixed the layout by the end of RIBA Stage A-B and dealt with the preferred option in Stage C. However, for this project the Contractor was dealing with different options by Stage C and the design was subjected to lots of changes. This led to the approval process being repeated many times. The main reason for the delay was the lack of design co-ordination and inadequate interface with the client. The discontinuity of key project actors, frequent people changes, inadequate collaboration with the Client adversely affected this phase [Fire Consultant].
- The Contractor forced the Architect to offer detailed design at the early stages of the project. The design team had to work through Stage D while they normally should be in Stage C [Fire Consultant].
- The stage that the Contractor should evaluate the alternatives through value engineering is at the detailed design phase because the designer would know which parts of the design could be revised according to budgetary limitations. However, at the beginning of the project designers are forced to make incorrect revisions on the design [Fire Consultant].
- The Acoustic Consultant received different requirements (re-design according to hearing impaired students) from the Contractor through the end of this phase. The main issue of such a requirement was lack of clarity on the client requirements [Acoustic Consultant].
- The Architect used junior architects without continuity on the same project and it resulted in frequent design issues. This is an industry wide problem where contractors should have more control by taking into account the fee issues. [Fire Consultant].
- At Stage D, the M&E Services consultant left the project. However, according to the Fire Consultant, the Contractor could be open about their strategy and explain the reason why

they wanted to work with the M&E Consultant until Stage D. They would have agreed to the level of detail from the beginning of the project so they were better aware of their responsibilities. This kind of approach is found to be more trustful [Fire Consultant].

- Due to frequent changes, the Fire Consultant was unable to develop the first draft of the Final Fire Strategy Report. The main reason was the lack of design co-ordination and inadequate interface with the Client [Fire Consultant].
- The Contractor was unable to submit the design to the Building Control Inspector for approval due to lack of communication with the Architect. At the end of Stage D, the design package was not submitted and approved. During Stage E, it was still not approved. Due to re-appointment of the Building Control Inspector approval process was delayed further [Fire Consultant].
- Despite the fact that the consultant informed the Building Control Specialist about the need for collaboration with firemen at the beginning of the project, they did not have a chance to collaborate. At the approval process, due to lack of timely collaboration, the firemen produced a list of bullet points of the required changes [Fire Consultant].

Lack of Clarity on Knowledge Request Dependencies

- At the beginning of Stage C, a spreadsheet which involves the brief responsibilities of each SC member was provided by the Contractor. There was lots of confusion with the roles of different suppliers. For example, the Contractor asked the Fire Consultant to comment on suppliers' work, however according to the Consultant; it is not their responsibility but the Building Controls Specialist. Unlike other projects, the Consultant had an opportunity of clarifying their brief from the start [Fire Consultant].
- The Client and Contractor Brief do not clearly describe the interface between the design team Specialist Consultants and Suppliers. For example, according to the original brief the Fire Consultant should have checked the door schedules. However, the Fire Consultant declined this request and assumed that checking door schedules was the architect's responsibility [Fire Consultant].
- The acoustic scope of the project was not well defined to the design team members. It differs significantly from project to project depending on how and when the consultant got involved. The consultant needs to be assigned to the project at a very early stage in order to provide the list of partition thicknesses which will achieve different acoustic

requirements before the architectural design. Otherwise, it is difficult to change and achieve the acoustic requirements of the project [Acoustic Consultant].

Inadequate Understanding of the Speciality Knowledge

- The acoustic performance specifications of supplier products used in the buildings are not widely known. There is inadequacy in the laboratory data that the suppliers can offer. It is important to work with suppliers who can provide laboratory specifications of the products [Acoustic Consultant].
- The Contractor's bid management team made decisions without solid evidence from the acoustic consultant. At the beginning of the project, due to cost limitation, the acoustic consultant was unable to conduct a noise survey. Also, the Contractor had very strong ideas on the ventilation method to be used and instructed the consultant to write a report explaining that the school would be naturally ventilated [Acoustic Consultant].
- At the beginning of the project, there was a lack of understanding on the scope of landscape design by the construction project team. Some aspects of their design were ignored or not prioritized. During the Output Specification preparation, the Architect prepared the landscape design brief which was not feasible in relation to the budget [Landscape Architect].

7.6.1.2 Contract Close Phase

When Company B was selected as the preferred bidder, the Contract Close phase started where the Contractor and the designers worked on the detailed design and prepared the final financial proposals to be signed off (See Appendix F-2 for further details on knowledge flow between the SC actors).

Highlights of the Contract Close Phase

In this section, some manifestations and causes' regarding the issues which affects flow of knowledge during the Contract Close Phase are presented.

Lack of Design Coordination

- Generally within the industry, RIBA stages which specify the interactions between the project members are not followed properly. Tasks for each stage are sometimes combined together. In general, Stages E, F and G are combined and delivered within the same stage [Structural Designer].

- Due to discontinuity in the appointment of the M&E Consultant during RIBA Stage C-D-E, the design was delayed and the designers faced problems. There was no co-ordination between designers. For example, the Structural Designer designed the beams in the corridors, however when the new M&E company was employed at the end of Stage E, it was revealed that there were clashes with the beams and the services design [Architect].
- Due to the late engagement of the new M&E Consultant to the project, they had problems in implementing the required changes. There had been inconsistencies in the progression of design between disciplines [M&E Consultant 1].
- At the end of this phase the architectural design was at Stage E, however the M&E design was at Stage D+.
- The value engineering process, which was forced by the Contractor, resulted in a lot of changes. The architect first changed the external material from brick to render, then revised the decision again and changed back to brick. Due to these changes Structural Designers changed the type of the columns several times [Architect].
- There was lack of consistency in the Contractor's project team. There was no proper record of early engagement meetings or consultation meetings. The design manager was unavailable during RIBA Stage E, and this was a serious difficulty because there was no-one to make decisions [Architect].
- The M&E Consultant stated that the Architect and the Structural Designer were very inflexible and unable to tolerate the new M&E requirements of the design. This was mainly because the architectural and structural designs were working ahead of the M&E design. This also caused lots of changes such as designing a bigger plant room or repositioning or changing the size of a riser. These delays and changes bring extra cost to all parties [M&E Consultant 1].
- When the M&E engineer used an electronic model to make the daylight analysis it was realised that their simple calculations based on RIBA Stage A/B design did not work and 80% of the rooms with windows did not fully comply with the BREEAM criteria. This was mainly due to the late usage of the model and being behind on the architectural design [M&E Consultant 2].
- M&E engineers could not collaborate with the Fire Consultant and they were unable to provide their requirements (such as terminating the AV system when the fire alarm goes off, or to install a disability switch to turn off the fire detection etc). The M&E

Consultant’s involvement ended at Stage E, but the fire report was still under development [M&E Consultant 2].

- There had been conflicts in the design team when the M&E Consultant revised the previous consultant’s design and requested changes. Particularly the requirements of the M&E engineers were not well understood by members of the team, for example, the architect found the equipment rooms to be oversized despite the maintenance requirements [M&E Consultant 2].
- The M&E Consultant stated that there was no M&E Co-ordinator in the Contractor’s team and so they always had senior level collaboration with the Contractor. Senior level interaction caused a lack of co-ordination and interaction at the project design level. The interface between the M&E Consultant and architect could not be established, particularly in Stage D. When the co-ordinator was assigned to the Contractor’s team, he had a lack of direction mainly because he had come from a construction background rather than a technical design background [M&E Consultant 2].
- Due to frequent changes in design, when the Fire Consultant finished the Fire Strategy Report, they had to review ASITE in order to find the revised drawings. They commented on the new version of drawings despite the fact that consultants had not been informed of the latest changes by the Contractor [Fire Consultant].

Integration of Design Team to Suppliers

- At this stage, the sub-contractor and supplier selections were made by the contractor based on cost rather than their overall project performance and delivery. On the other hand the design team prefer to give feedback on this process and select the ones with whom they can work collaboratively. For example, the Structural Designer worked on a complex project with another contractor where they interviewed 5-6 steel sub-contractors. When Structural Designers take part in the interviews they are able to better evaluate the capacity of the sub-contractors and save huge amounts of money by selecting the best supplier. This resulted in better collaboration and knowledge transfer with the selected supplier[Structural Designer].
- Similarly the M&E Consultant did not collaborate on the sub-contractor selection. In other projects, when the M&E Consultant finishes the RIBA Stage E design and sends out for tender, the consultant starts collaborating with the Contractor for the sub-contractor selection [M&E Consultant 1].

- The M&E Consultant was appointed at the end of Stage E; therefore they were unable to collaborate with the M&E Sub-contractor. In normal conditions, they check project drawings and their compliance with the client requirements [M&E Consultant 2].

Lack of Clarity on Knowledge Request Dependencies

- Although, in the Fire Consultant's contract structural fire engineering was specifically excluded, in this phase, the consultant was asked to share knowledge several times by the Contractor instead of creating this knowledge with the Structural Designer. In addition, the Contractor contacted the Fire Consultant several times to reply to Building Control questions about fire protection. This was because the Architect and Structural Designers are not adequately compatible in fire safety aspects of the design [Fire Consultant].

Different Tools for Design Knowledge Creation

- At the end of this stage, the M&E Contractor received 3D drawings from the architect, and 2D drawings from the M&E Consultant. It would have been very beneficial to make the design in 3D earlier and with the same design tools. Different companies have different design tools but it is difficult to agree on particular software because this would incur extra cost to the companies [M&E Consultant 2].

7.6.1.3 Construction Phase

This phase has 2 stages, the first is the pre-construction and the second is the actual construction of the building. In the pre-construction stage, the design team and the sub-contractors produce construction drawings, related information and knowledge which enable them to build the project (See Appendix F-3 for further details on knowledge flow between the SC actors).

Highlights on the Construction Phase:

In this section some manifestations and causes' regarding the issues which affects the flow of knowledge during the Construction Phase are presented.

Lack of design and construction information coordination

- The late appointment of a new M&E Consultant also had an impact on the construction phase. For example, when the M&E design was at Stage E, the architect was at RIBA

Stage F. The architect was developing construction drawings and it was too late to make changes to window elevations [M&E Consultant 2].

- Because the changes were made too late in the construction process, this affected the installation work and incurred extra cost. The main reason was poor communication back to the client. There had been cases where the client had not been informed about the changes on time, and installation was made prior to discussions with them. This caused tension between the parties [Fire Consultant].
- At the construction stage, the Steel Contractor and the Contractor had a conflict about the fire strategy. This was because the Architect did not realise there was a fire door in the Fire Consultant's drawings, and interpret it into the design. This mistake cascaded through the SC and the sub-contractors followed the wrong drawings. The Fire Consultant and the Architect should have worked collaboratively from the beginning of the design [Structural Designer].
- In this phase, the M&E Consultant prepares a performance specification which applies the fire strategy and provides further detailed advice about the fire systems. However for this project it was not done since the M&E services consultant was excluded from the project. When the M&E Consultant makes the design there is always continuity whereas when it is left to the specialist sub-contractor there are always problems [Fire Consultant].
- There were situations where the Architect did not have time to collaborate with the other design members and comment on their drawings. They were sometimes still within the allocated deadline for commenting on the drawings but things had already been installed on site and it was too late to make decisions [Architect].
- BREEAM requires an ecologist to work collaboratively with the Landscape Architect; however no one in the project was aware of this. The Landscape Architect collaborated with the ecologist at the construction phase and due to their late engagement they had to redesign the planting plans [Landscape Architect].
- The Sustainability Consultant who produced the BREEAM pre-assessments was not involved during the detailed design stage. Due to discontinuity, the design had moved substantially forward without the BREAAM assessment. Another Sustainability Consultant was appointed on the BREEAM when it was forced by the Client in construction phase. However, due to discontinuity, the pre-assessments moved from an excellent status to very good status [Sustainability Consultant].

- The new Sustainability Consultant needed to produce a report on the evidence confirming that the design could achieve the targeted rating. However the consultant was unable to access any evidence in order to update the report due to lack of sustainability awareness of project members. In addition project members' fees did not cover extra costs for providing evidence to the consultant. This report should have been completed by RIBA Stage E [Sustainability Consultant].

Integration of Design Team to Suppliers and Sub-contractors

- When the Structural Designer had an issue, they were unable to collaborate with the supplier directly. They had to interact with the Contractor and Architect and the required knowledge was transferred through the Contractor and Architect. It was a repetitive and time consuming process [Structural Designer].
- Due to the late appointment of the M&E Consultant, the M&E design was not produced fast enough to keep up with the programme of installation or construction. This problem was relayed to the M&E Sub-contractor. Therefore, the M&E Sub-contractor was constantly behind the construction programme [M&E Consultant 2].
- The Structural Designer had a problem due to lack of communication with the M&E Sub-contractor. The sub-contractor had different teams for design, build and install, but there was no co-ordination between the teams [Structural Designer].
- In projects, ideally after RIBA Stage E, at construction phase, the M&E Consultant and the M&E Sub-contractor should work collaboratively. The sub-contractor should send the construction drawings to the consultant and the consultant should provide feedback. For this project, although the M&E Consultant was not involved at this stage, they still received queries from the M&E Sub-contractor through the whole construction phase which caused tensions between parties [M&E Consultant 1].
- There had been cases where the Contractor changed suppliers or sub-contractors at the construction phase due to a very harsh value engineering process [Structural Designer].
- The Landscape Architect was not aware of the supplier appointments until the last minute. The suppliers and sub-contractors were not engaged in the project until the construction phase [Landscape Architect].
- The selection of the suppliers is only done by the Contractor. However, it can be beneficial to have a feedback mechanism for the selection of the suppliers and the sub-contractors from the design team [Landscape Architect].

- Due to the late appointment of the Secondary Steelwork Sub-Contractor at the construction phase, the Structural Designer had to change their design according to the new requirements provided by the Sub-Contractor. If they could have engaged earlier, the Structural Designer could develop the structural design in compliance with their requirements. Also the selection of the secondary steel work sub-contractor was done by the Contractor without any consultation with the designer [Structural Designer].

Construction Site Issues

- Although some changes were agreed collaboratively during design meetings they were not reflected in the construction drawings. This caused frequent mistakes at the construction site, for example the structural amendments were not completed properly by the Structural Designer, the Contractor could not route the duct work [M&E Consultant 2].
- On site, M&E Sub-contractors generally follow 2D drawings and are unable to access 3D drawings or models. Therefore there are always mistakes and issues on site due to rushing, mismanagement or lack of information or process (Cladding Sub-contractor). The metal work sub-contractor also added that the quality of the drawings, which was shared by the sub-contractors were not sufficient for the adjacent sub-contractors to understand the dimensions and interfaces. Therefore, they had to request extra information several times [Metal Work Sub-contractor].
- When a sub-contractor installed equipment in the wrong place, this mistake cascaded through the SC [M&E Consultant 2-Steel Sub-contractor]. Therefore, there were always changes on site due to tolerance from preceding trades or buildability issues. There were no tools on site where the contractors could see the exact location, dimensions or update the instant changes and inform other SC actors [Steel Sub-contractor].
- According to the Fire Consultant, the Contractor forced the boundaries of fire safety and the Fire Consultant could not price the changes on site. During the construction phase, the Fire Consultant was expected to check every single door schedule, the alarm detection system. This was not within the scope of work which they had agreed with the Contractor. This caused tension between the Consultant and Contractor [Fire Consultant].

Innovative Applications and Approaches

- Innovative use of 3-D models by specialist sub-contractors has a potential to improve information flow. For example, The M&E Sub-contractor receives a 3D design of the equipment from their suppliers such as valve manufacturers or boiler manufacturers and they directly feed their 3D design with their equipment designs. The main issue here is to make sure the equipment is fit for purpose. Sometimes, for lack of small scale suppliers who cannot provide 3D designs, the M&E Sub-contractor models their products in 3D form for use in projects [M&E Sub-contractor].
- According to the Cladding Sub-contractor, production of 3D design by all sub-contractors and implementing the sub-contractors' design in 3D architectural design would be a great help on site. Instead of looking at a piece of paper, project members can see the effects on the interfaces from different angles on a model [Cladding Sub-contractor].
- The M&E Sub-contractor selected suppliers based on cost, quality and on time delivery. Being a European company they gain advantage from working in a better location to find the best prices. However, they intend to make a leaner SC which will benefit from closer relationships and preferential treatment from the suppliers [M&E Sub-contractor].
- The Contractor had robust procedures in place related to sustainability issues and CO_2 monitoring [Sustainability Consultant].

7.6.1.4 Operational Phase

For this project, the Contractor was not responsible for providing the facility management service.

7.6.2 KM throughout the Project Lifecycle

In this section, knowledge resources used by SC actors, methods and tools for knowledge sharing and storage, general KM issues of construction SCs and the expectations of SC actors for SCM improvement are presented.

7.6.2.1 Knowledge Resources of the SC Actors throughout the Project Lifecycle

Knowledge resources of SC actors are an important part of the knowledge creation process for the project. Knowledge resources of the SC actors, which are identified through the interviews, are presented in Table 7-3. According to the Table, past project experience between project team and designers, sub-contractors, suppliers plays an important role for the knowledge resources of the project. From past experiences and project teams they learn about technological improvements, new materials, specifications, and new processes. Collaboration with the other suppliers in the preferred list, visits to factories, internet and non-governmental organizations (NGOs) are other sources of collecting information for SC members. All of these resources address that industry wide collaboration, events and organization can improve resources for the construction SC.

Table 7-3 Knowledge Resources of SC Actors

SC Actor	Knowledge Resources (apart from the supply chain actors for the project)
Architect	Visit to factories for special requirements such as acoustic ceilings, absorption of sound.
Landscape Architect	Collaboration with other sub-contractors and suppliers; exploring material supply websites in order to have an understanding of new materials and their specifications.
Structural Designer	Collaborative meetings with their preferred suppliers regularly for an update on technological improvements; inspections to production lines.
M&E Consultant	Manufacturers and material suppliers in their own preferred list.
M&E Contractor	Organizations such as BSRIA, CIBCE, workshops, industry events
Fire Consultant	Internet, suppliers, collaboration with other practitioners such as building control specialists, fire engineers, fire officers, fire researchers.
Acoustic Consultant	Manufacturers, material suppliers, trade documents, library data on acoustic requirements.
Sustainability Consultant	Collaboration with the suppliers and manufacturers for technical information particularly material insulations, volatile organic compounds, reviewing BREEAM qualifications regularly.
Metalwork Sub-contractor	Materials suppliers, finishing sub-contractors as external painting, powder coating, polishing
Furniture Supplier	Past project partners; relevant workshops particularly on sustainability.
Cladding Sub-contractor	Alternative sub-contractors and suppliers in their preferred list.

7.6.2.2 Methods and Tools for Knowledge Sharing

In this project, the Contractor provided an online web based document system, named ASITE. ASITE is a tool used for managing all the project information uploaded by the design team, consultants, sub-contractors, suppliers. The tool is surrounded with commenting, red lining and marking out abilities which makes it a single point of collaboration tool rather than using emails and paper based drawings for information sharing. The tool is also used for approvals at the construction stages and gives the chance for users to comment, make changes, or reject. It is also a good audit trail for the Contractor because they can monitor the log in/out information, the actions taken, printing history.

When a project is set up, the SC actors are given access to the website with a certain limit depending on their role. There is a strict protocol which puts certain procedures in place for naming and convention of the documents, revisions, update purpose of the issue status, uploading, distribution, commenting. At the beginning of the project, SC actors complete a distribution matrix where they select the main recipients of the information they upload. When the SC actor uploads a document they issue it to the ASITE controller. The ASITE document controller and the design manager decides on the main recipients and the action expected. The controller then sends the information to the relevant parties with a schedule of completion of the actions required. If the design manager is not available to check all the information, the design team members issue the information to the relevant consultants and document controller [ASITE Controller].

Apart from ASITE, SC actors used other communication methods such as face to face meetings and emails to exchange information and knowledge during the project [Designer, Consultants].

7.6.2.3 Storage of Information and Knowledge

All SC actors kept an electronic version of the project information, emails sent and received and information they created during the project. They also kept the hard copies of important project information in their archive. However, information retrieval is still a problematic area for most design members. The majority do not benefit from the knowledge of past projects.

The information uploaded to ASITE was kept by the Contractor and after the completion of the project all the information was stored in their archive. At the end of the project all the information on ASITE is uploaded to a disc, which is available to the design team members at an additional cost [ASITE Controller]. However the Fire Consultant feels this knowledge pack should be shared, free of charge.

7.6.2.4 Key Knowledge Management Issues

Apart from the knowledge flow issues specific to each phase presented in the highlights sections, there are other general KM issues discussed by the interviewees. These are presented in the following section:

Collaboration Tool Issues

- In this project, because the design manager was not available during some stages of the project, ASITE was structured in a way that the Architect had to approve all drawings. The architect found it convenient to comment on most of the drawings, however, in the areas where he was not the expert such as the schematics of electrics, he did not want to make approvals and distribution [Architect].
- The ASITE controller had inadequate technical knowledge on which kind of information needed to be sent to the SC actors. The Controller had the responsibility of two or three projects at the same time, therefore there was inadequate control on the information shared [Fire Consultant].
- There were lots of irrelevant actions sent through ASITE to the SC actors and the members wasted too much time with the notifications [M&E Consultant 1, M&E Consultant 2, Acoustic Consultant, and Landscape Architect]. Also, the Contractor did not advise the SC actors when important information went onto the system [M&E Sub-contractor]. Because the users were overwhelmed with many irrelevant actions sent through ASITE, there was a possibility of missing important information [M&E Sub-contractor]. According to the Sustainability Consultant, the project members also did not check their emails regularly to review, and comment on their reports on time.
- Version control was another issue on ASITE. For example the Structural Designer revised a drawing and uploaded it to ASITE and sent the notices to the relevant people, however, the sub-contractor fabricated the drawing based on the old version [Structural Designer]. Sometimes the information was also sent through by emails but there was no consistency and they needed to check two sets of information all the time [M&E Sub-contractor].
- The Contractor used ASITE effectively because they had trainings and were always logged in the system. However, the SC actors were not trained on the effective use of the tool [Landscape Architect]. Due to this lack of training, it was difficult to find some easy applications. At the beginning, most of the drawings or information uploaded to ASITE by the consultants was rejected [Structural Designer]. For the sub-contractors who could

not use ASITE, the ASITE Controller sent their drawings; however in some cases, the level of detail provided was inadequate and this slowed down the process [Architect].

- For every project, there is a different protocol on the procedures for uploading the information on ASITE. During the pre-tender and pre-construction stages of this project, information was mainly sent by email. After a certain stage consultants started to pull the information on ASITE [M&E Consultant 2].
- The approval time was very quick, it was impossible to comment on a drawing within two days once they were put in ASITE [Architect]. On the other hand, the M&E Consultant stated that when they put information on ASITE, it was not immediately available to the relevant people and sometimes there was too much delay on it.
- ASITE is found to be simple and easy to use [Architect]. Most extranet sites are relatively simple unless they are Oracle based like BIW [Fire Consultant]. The good thing was that the Contractor provided procedures for naming and convention of the documents therefore, documents were always organized and easy to access [M&E Consultant 1].

Lack of Clarity on Knowledge Request Dependencies

The suppliers did not have clear guidance from the Contractor on the responsibility matrix and knowledge dependencies of SC actors. There was no flow chart available showing the details of the SC actors responsibilities for certain types of work [Architect]. There were cases where the design team and the specialist consultants did not understand the knowledge requirements of the other SC actors [M&E Consultant 2]. There were also arguments and confusion on the content and timing of the information to be shared by the SC actors. Particularly, as stated in Section 7.6.1, there were severe problems on the content and availability of specialist consultants' knowledge such as fire, sustainability to the design team. The Contractor blamed the architectfor such problems although the issue originated from the Contractor's misguidance of the suppliers for the knowledge they needed to produce and share [Architect]. According to M&E Consultant 1, knowledge dependencies were unclear, particularly at the beginning of the project; however, collaborative meetings with the architect and Structural Designer made it clearer at further stages of the project. On the other hand from the sub-contractor's point of view knowledge dependencies were generally clear [Metal Sub-contractor; Cladding Sub-contractor].

Lack of Holistic Lessons Learned Approach

The Contractor organized a lessons learned meeting for the project. The meeting was mainly based on a presentation made by the Contractor [M&E Consultant 1]. It was stated that the meeting was "lessons learned by the consultants, but not the Contractor". All the points shared and issues discussed were on the performance of the consultants rather than providing a holistic view of the real issues. It was a one way approach [M&E Consultant 1, Architect, and Structural Designer]. According to the Structural Designer and Landscape Architect, specialist consultants and key sub-contractors should also have been invited to these meetings. According to M&E Consultant 1, other contractors were more open in discussing the mistakes with the SC actors and getting feedback for lessons learned.

Inadequate Collaboration and Knowledge Sharing

The knowledge sharing between the Client and Contractor was very critical. Client requirements were not well transferred to the design and sub-contractor requirements and this was forced down onto the designers and the rest of the SC [M&E Sub-contractor]. Collaboration with the end user was also very limited. Specialist consultants did not have a chance to collaborate with the school authority [Acoustics Consultant]. The project team and the key design chain members were not proactive in knowledge sharing and establishing collaborative relationships particularly due to late engagements to the team and lags in the design (See Section 7.6.1). For example, M&E engineers were in a position to request information all the time despite becoming a part of a team aiming to solve the same problem [M&E Consultant 1-M&E Consultant 2]. Within the Contractor's project management team there was a high turnover of people in and this adversely affected the relationships between the project members [M&E Consultant 1]. Also according to the Sustainability Consultant, the sub-contractors were more willing to share knowledge within the agreed timescales than the designers.

The Contractor's approach in encouraging knowledge sharing between the SC actors is not consistent. In a past project they had a very proactive project team so that the design team was encouraged to collaborate and share knowledge on time, but for the 'Y Community School Project' there was no encouragement [Sustainability Consultant]. At the beginning of the project, the Contractor organized a collaborative meeting to introduce the knowledge sharing strategy and provide guidance to the Architect, however, the other design members were unavailable at that meeting [Architect]. Apart from the design team meetings, there was no encouragement on knowledge sharing by the Contractor [Structural Designer-Metal Work Sub-contractor-M&E Consultants].

According to all project interviewees, knowledge sharing enhances the value of collaborative relationships. As long as there is a smooth knowledge transfer, the relationship flourishes and the SC become more collaborative. According to M&E Consultant 2, whenever knowledge was shared on time, the project went smoothly, and there were fewer problems for the project members. However, when the shared knowledge was not taken on board and there was no mutual understanding of the knowledge, then the knowledge sharing process was both inefficient and ineffective [M&E Consultant 2]. According to the Sustainability Consultant, knowledge sharing also becomes smoother when there is trust based relationship. According to the Fire Consultant, by sharing knowledge, project members have a better understanding of the process and requirements. The joint experience in similar projects naturally teaches everyone about the knowledge sharing process. For example, the start up of the project was subjected to lots of issues and clashes. However, when the project team had the chance to work with the same SC for similar types of projects, they learnt from past projects, developed trust, and knowledge flow became smoother [Landscape Architect].

As presented in Table 7-4, knowledge sharing across the upstream SC was evaluated as adequate to weak by the interviewees. The main reason for this was described as the lack of a design co-ordinator during the detailed design work, inappropriate appointment times of designers and consultants and lack of long term relationships. In the cases where the upstream SC actors could interact with the downstream, knowledge sharing was defined as adequate-strong. However, most of the designers or consultants were unable to collaborate with the downstream SC actors in the right sense. The knowledge flow through the downstream SC was mainly provided by the Contractor and the Architect.

Table 7-4 Evaluation of Knowledge Sharing in Upstream and Downstream SC by Supply Chain Actors

SC Actor	Upstream Supply Chain	Downstream Supply Chain
Architect	**Adequate** (Due to not having a design co-ordinator in some parts of the project knowledge sharing was adversely affected the)	**Strong** (They have their own control on the project's SC). They also have their own SC which is lean, less formal, and quite effective.
Landscape Architect	**Weak**	No interaction with the downstream SC.

Structural Designer	**Adequate** (Mainly depends on the background of the project manager)	Limited interaction with the downstream, only deal with reinforcement detail designer)
M&E Consultant 1	**Weak-Adequate** (Mainly due to discontinuity of their work, lack of control on knowledge flow from the Contractor	Limited interaction with the downstream, only deal with reinforcement detail designer)
M&E Consultant 2	**Weak-Adequate**	Limited interaction with the downstream, only deal with reinforcement detail designer)
M&E Sub-contractor	**Adequate** (When the appointment times are in the right order, it is stronger)	**Weak** (Due to managing things with low budgets and limited timescales and hiring people with limited education who cannot fully understand the benefit of knowledge sharing)
Sustainability Consultant	**Weak**	**Adequate**
Metal work Sub-contractor	**Adequate-Strong**	**Adequate**
Cladding Sub-contractor	**Adequate-Strong**	**Adequate-Strong**
Fire Consultant	**Weak-Adequate (**Particularly on building type projects, due to lack of long term relationships)	**No interaction with the downstream SC.**
Acoustic Consultant	**Adequate**	**No interaction with the downstream SC.**
Furniture Supplier	**Strong-Adequate**	**Adequate** (They also have their own SC where they try to be more proactive. They organize supplier days where they share knowledge about future workload, and they try to interact more during project lifecycle)

Inadequate Design Co-ordination

The design co-ordination was mainly budget oriented and specialist consultants were not involved effectively in the design phase. It was very difficult to marry up the approaches with the Contractor [Fire Consultant]. As also discussed in Section 7.6.1, The Contractor could have achieved better value from the specialist consultants' knowledge if they had design co-ordination which had continuity from start to finish. Due to the change of the project design co-ordinator, the specialist consultants had to restart the whole process for each change [Sustainability Consultant]. The Contractor did not seriously consider the abilities of the specialist consultants and could not obtain their knowledge effectively at the right time [Fire Consultant].

Designers need more collaborative meetings to discuss the design changes and implement these changes effectively in design. Recently, construction programmes have become shorter and 'design and build' contracts do not allow design teams to progress before the project starts on site. This is a fundamental issue for the industry; design is developing during the construction and inadequate co-ordination causes mistakes [M&E Consultant 2].

Design Tools

There was Interoperability between software tools used by the supply chain actors. During the conversion process from the different software to the DWG format, there were problems. They always needed to double check after this conversion process (Structure Engineer). In addition, there had been some problems when the 3D architectural drawings were converted to a 2D format. It was mainly due the interoperability between software tools and some of the files were too big to operate or became corrupted [M&E Consultant 1].

According to the Landscape Architect, 3D representation of design is very beneficial to impress the client. Similarly 3D M&E design and the structural design produced at the early stages of the project can be helpful in understanding the interfaces particularly in complex projects [M&E Consultant 1, Structural Designer]. As discussed in Section 7.6.1.3 the implementation of 3D design libraries of suppliers in 3D architectural design would be a great help on site. This can help the suppliers to understand the dimensions and interfaces and minimise mistakes on site.

Culture

The managing style of Company B was found to be very aggressive. They had cases where the project managers did not establish good communication and there was a heavy blaming culture against the SC actors [Cladding Sub-contractor, M&E Contractor 1, M&E Contractor 2]. According to the M&E Consultant 2, "*the criticism is just one way and unless criticism is 360°, it is worthless*". The Contractor's attitude towards the consultants was described as *"we are big, we are the boss, you do what you are told!"*. This approach was found to be unconstructive and unfair [M&E Consultant 2].

Contractor B is a big company which has several offices all over the UK. There is no overriding company culture in any of the offices but there are many cultural differences between the northern and southern offices. The northern offices are found to be more proactive and less confrontational compared to the south [M&E Consultant 1]. According to the Fire Consultant in the north offices, there is continuity of project teams and particularly design co-ordinators generally work from the beginning of the project through to the end. However in the south, there is a higher employee turnover which causes discontinuities in knowledge flow. It is believed that the Contractor should benefit from the knowledge of the people who continuously work on the projects [Fire Consultant].

According to M&E Consultant 2, a knowledge sharing culture does not exist in most construction organizations. Instead, there is a heavy blaming culture, and inadequate knowledge sharing encouragement. For clear understanding of knowledge requirements of each SC actor, the organizations should create a proactive knowledge sharing culture [M&E Consultant 2].

Confidentiality

The nature of the bidding process impedes knowledge sharing enormously. The main focus at the feasibility and bidding stage is to design and win the bid. However, collaborative relationships and knowledge sharing are regarded as "too time consuming, very experimental and risky in terms of confidentiality" [Landscape Architect]. Confidentiality becomes an issue when there is a company who offers a variety of services in the SC. Many consultancy companies have several branches such as fire, acoustic, M&E consultancies or structural design. For the Architect, confidentiality becomes an issue, especially when they make strategic decisions. It is defined as a game between the Contractor and the Architect, and it is the nature of their work [Architect]. However, according to the M&E Consultant there are no severe issues about sharing technical knowledge. It is stated that the construction industry is producing buildings and it is not rocket science or heart surgery, and there is no point not to share knowledge [M&E Consultant 2].

In the downstream SC, sub-contractors tend not to talk to each other on site because their competitors can pick up tips from their knowledge and processes [Metal Work Sub-contractor]. According to the cladding sub-contractor, when they experience problem on site, they do not share it with the other sub-contractors not to loose their credibility [Cladding Sub-contractor].

Supply Chain Strategy

There are some strategic issues which affect the SC strategy of the Company B, which are presented as follows:

- Contractors started to reduce the number of preferred designers and increase common experience between designers. However, for this project, it was the first time the key design members worked together [M&E Consultant 1].
- On design and build contracts the quality of the work has the risk of reducing because supplier selection and appointments are all based on cost. The contractors are trying to transfer the risk to the sub-contractors, whereas, in a traditional contract the financial risk is mainly on the client [M&E Consultant 2]. According to the Structural Designer, the consultants select sub-contractors and material suppliers according to quality and performance whereas the contractors' selection is mainly based on cost [Structural Designer]. For example, there were some school projects in the same geographical area, the Contractor used different list of suppliers due to cost constraints [Metal Work Sub-contractor].
- Due to inadequate co-ordination, the performance assessments of the consultants were not regularly shared with them. These assessments were generally shared if they were a part of a scheme such as the Procure 21 Framework (health sector) or some BSF projects, otherwise the designers do not receive these assessments from the Contractor.
- In the last two years, stock is no longer held by the suppliers and everything is made to order. However, delivery times requested by the client are very short. This start to challenge the SCM approach of construction industry. It needs better planning for procurement of materials to prevent delays. Client requests affect the overall SCM and procurement [Metal Work Sub-contractor].
- Innovation is still not a strategic element of the Contractor's SC. Innovation is very limited since the suppliers think innovation will cost a huge amount of money, enormous research effort and extra time [Acoustics Consultant].

All these factors such as the selection of suppliers, establishment of lean and long term SCs, sharing the assessments of the SC actors clearly, and allocated budget for innovation has an indirect effect on the project knowledge created and shared by the SC actors. Therefore, the contractors need to establish their SC strategy in accordance to their KM needs if they would like to support the knowledge sharing process in their SC.

Knowledge Inadequacy

There are some knowledge inadequacies in areas such as M&E design, sustainability, fire consultancy, ICT which severely affect the knowledge creation process in the industry as described in Section 6.6.1. Moreover, M&E Consultant 2 stated that specifically there is inadequacy in technical electronics side of the M&E design. There is a need for better defined electrical specifications for different sectors [M&E Consultant 2]. According to the Sustainability Consultant, designers particularly the architects have to be aware of the BREEAM requirements. For example, architects have to specify materials from the Green Guide Specifications however; many architects do not have knowledge of these specifications. Also, most of the documents provided by the designers during the BREEAM process do not address the specific phrases and words for the assessment. Also, Fire safety is a developing area and project managers, architects and structural designers do not have adequate knowledge to implement fire strategy in their design [Fire Consultant].

7.6.2.5 The Expectations of the Supply Chain Actors for the Future

Clear Knowledge Requirement Dependencies

The Contractor needs to explain the elements of the knowledge flow through the joint meetings with designers from the early stages of the project [Landscape Architect]. A clear understanding should be created in the SC on the roles, abilities, knowledge requirements, and knowledge sharing responsibilities of the SC actors [M&E Consultant 1]. Particularly, if the architect and contractor can understand the capabilities and abilities of the consultants, they can benefit more from the suppliers. Therefore the consultants will not be forced to complete irrelevant tasks during the project [Fire Consultant]. Also, The ASITE controller should be fully aware of the knowledge requirements of each SC actor [Landscape Architect].

The Contractor also need to establish a more proactive project management approach to foster knowledge sharing and needs take control when knowledge flow is not working [Sustainability Consultant]. Contractors need to make sure that certain tasks need to be completed at certain design stages [Sustainability Consultant].

The whole design team members, including the specialist designers, should attend meetings for a week at the beginning of the project and review the Client Brief. It is believed that this will help the project actors to understand each other's knowledge dependencies. They had such cases in their previous projects where all the design team reviewed the package together. However, it was just the individual efforts of project managers. When there is encouragement from the design co-ordinator and project manager on knowledge sharing between the project members, everything goes smoother [Fire Consultant].

Formal and Structured Lessons Learned Meetings

Design team members would like to take part in a structured and formal lessons learned meeting where all the problems can be clearly explained. These meetings should have been organized in a way that all the key SC actors can attend and express their problems. It will be more beneficial for the Contractor to organize the new process for new schools in a more effective way [Architect]. In these meetings the main aim should be creating a mutual understanding in the SC and the Contractor should provide constructive criticism on the project issues [M&E Consultant 2]. Also, the Contractor should invite the downstream SC actors to such meetings [Cladding Sub-contractor].

Integration of Upstream and Downstream Supply Chain

There needs to be a better integration between the upstream and downstream SC. The SC members should be appointed at the right time in the project to prevent delays in the knowledge creation process [M&E Consultant 1]. Designers should be aware of the content and timing of the service, product or knowledge which needs to be provided by the suppliers related to their work [Structural Designer]. The sub-contractors need to collaborate with the designers early enough to accommodate their requirements. The sub-contractors expect a better SC and procurement planning to prevent interface problems with other sub-contractors [Metal Work Sub-contractor].

Design Standardization

There are 400-500 schools in the BSF programme and there is no standardization in design [Fire Consultant]. The consultant believes that there is lots of space for repetition; however, all the schools designed are very different from each other. If the Contractor could discuss with the client their basic design (up to Stage C) then update the design according to the client's feedback, this may be a cost and time effective solution to the client. However, contractors generally work with different architects with the same type of projects and start from scratch to design. There are circumstances where architects can make special designs for different requirements, however, to a certain extent contractors can decide on the repeatability and can spend more time on detailed design [Fire Consultant]. The design can benefit from Design for Manufacturing and Assembly (DFMA) solutions. Off site construction can bring range of benefits such as reducing the construction time, standardization of the structures used, and increased quality. The structures can be arranged and standardized in architecturally pleasing configurations and during design process these standardized units can be used in a BIM model (Architect).

Better Collaboration Tools and Processes

If contractors can simplify the extranets in terms of information uploading, distribution and searching process and train the SC actors on the usage of the tool, the collaboration amongst the SC actors will improve enormously [Fire Consultant].

The companies in the Fast Moving Consumer Goods (FMCG) and retail sectors recognize the information management systems and make these systems specifically to work for them and use the systems in a standardized process. They have very good training on the tools and they also arrange training for the sub-contractors. The top level manager understands the collaboration tools and processes and implements them in the company very quickly. They also make their sub-contractors use the same tools effectively so that they can work well. Lack of well defined procedures in construction affects all the processes and the discipline in the industry. Knowledge about the procedures and the ability to persuade people to apply these procedures are not mature across the industry. For example, Sainsbury's and Ford use BIW in the best effective way and the construction industry has to benchmark between these sectors. Tailoring the collaboration tools according to the industry needs and standardization of the collaboration process are believed to improve the knowledge sharing and delivery of construction projects [Fire Consultant].

Better Design Co-ordination

The continuity of the design co-ordination is defined as an essential element of project success. The design co-ordinator is defined as the key person who understands the capabilities and abilities of the designers. Therefore, the design co-ordinator has to be a friend of the client, designer and the consultants for better co-ordination [Fire Consultant].

More Emphasis on Education and Training

There needs to be more value put into projects in terms of quality and technical reliability and less emphasis on cost [M&E Sub-contractor]. To achieve this, more training in some particular areas such as fire consultancy or sustainability to improve people's technical knowledge is essential [Fire Consultant]. If people are educated, they will be able to understand the knowledge dependencies over other SC actors and they will be aware of the actions which needed to be delivered at the design stage [Sustainability Consultant].

7.7 Chapter Summary

In this chapter, the main issues of Company B's SC; and the knowledge flow issues amongst SC actors through out the 'Y Community School' project lifecycle are presented.

Summary of Company Specific Case Study

The main SC priorities for Company B were identified as consistency, client satisfaction, productivity, design for manufacture and assembly for reducing labour and material on site, leanness and agility of the SC. The selection criteria for the suppliers are cost, health and safety, financial stability, willingness to collaboration, innovation capability and references. Their designer selection criteria depends on design performance, quality, cost, responsiveness, commitment, and innovation. However, cost is still the major criteria.

Company B has mature relationships in their SC. They have recently decreased their number of suppliers in the SC. Their aim is maintaining the SC leaner with key preferred suppliers. Company B developed and implemented programmes/agreements for the improvement of suppliers and their relationships such as BCR, collaboration, partnership agreements. Having internal agreements or partnerships and developing trust within the SC helps the Company B to keep the knowledge secure and improve confidentiality.

For knowledge sharing they use their Collaboration Centre with immersive environment, videoconferencing, emails, phone calls and a standard collaboration software. Formal product presentations, workshops and informal meetings are used as major encouragement methods for knowledge sharing. Barriers for knowledge sharing are defined as the lack of diffusion of the knowledge from the SC to other parts of the business, lack of usage of lessons learned knowledge, competition between various suppliers at bidding phase, inadequate collaboration between Company B, design consultants and product manufacturers.

The agenda for the future is to work with leaner SC, allocating more budget for innovation, progress in process innovation, exploring the global markets while keeping a proportion of local procurement, agreements with the SC actors in order to minimize physical waste, more collaboration with the client to convince them about their SC priorities, and finding solutions for the organizational resistance to the required changes.

Summary of Project Specific Case Study

The project-specific case study revealed that client requirements were not well transferred to the design and supplier requirements due to inadequate collaboration between the design team, the client and the end-user. Therefore, there was lack of clarity on the knowledge requirements of the SC actors. The Specialist Consultants' knowledge was not fully understood by the Contractor and the design team; thus their knowledge could not be implemented properly in design particularly in areas such as sustainability, acoustics, fire strategy, landscape design and M&E design. For a better understanding, the whole design team members should attend meetings for a week at the beginning of the project and review the client requirements.

RIBA Stages were not followed properly in the project as well as other projects in the construction industry. The design was subjected to lots of changes due to lack of design coordination and discontinuity in the appointment of the SC members. The interfaces between the designs could not be well established. The designers could not collaborate with the downstream suppliers during design and construction. There was no direct communication between the designers, material suppliers and subcontractors.

Project information could not be transferred effectively due to lack of standard distribution procedures, lack of control on the shared information, and lack of training of the SC actors on the usage of the tool. Also, lack of interoperability between the software programmes used by the designers caused problems while sharing the drawings. Due to inadequate use of collaboration tools, the changes agreed in design meetings could not be reflected in construction drawings. This caused mistakes and buildability issues on site. Early start to 3D design and fully co-ordinated BIM model including architectural, M&E and structural design supported by the product libraries of sub-contractors are identified as a effective ways to improve information flow throughout the project lifecycle and impress the Client during the bidding process.

Knowledge sharing across the upstream SC was evaluated as adequate to weak due to the lack of timely appointment of consultants, inadequate coordination and lack of long term relationships. The Contractor does not have a consistent approach for encouraging knowledge sharing between the SC actors. The company also does not have a corporate knowledge sharing culture. A lessons learned meeting was organized to encourage knowledge sharing; however, it was found to be one way, and not constructive. Neither the specialist consultants nor the key sub-contractors were involved in the meeting. Confidentiality became a barrier for knowledge sharing when there is a company who offered a variety of services in the SC. In the downstream SC, sub-contractors tended not to talk to each other on site because their competitors could pick up tips from their knowledge and processes.

Lack of well defined procedures in construction affects all the processes and the discipline in the industry. Standardization of the design process would improve the knowledge creation process and will leave more time for detailed design. DFMA solutions and BIM applications can help in the design standardization process. Also, construction SC needs better planning due to the recent stock reductions and shorter delivery times.

During the project, SC actors benefited from the collaboration with the other suppliers in the preferred list, visits to factories, internet and non-governmental organizations (NGOs) as knowledge resources. All of these resources address that industry wide collaboration, events and organizations can improve resources for the construction SC.

In construction industry, contractors' supplier selection is mainly based on cost whereas designers were more focused on quality and performance. Construction SC can benefit from the feedback mechanism between the contractor, designers and specialist consultants on the supplier selection and supplier performance evaluation.

The issues summarised in this Section will be investigated further along with the results of the Company A Case studies which are presented in Chapter Six and the Aerospace Industry Case Studies which are presented in Chapter Eight. This investigation will be the a basis of the 'knowledge chain framework'.

CHAPTER 8

8 AEROSPACE SUPPLY CHAIN CASE STUDIES

8.1 Introduction

This chapter is concerned with the KM practices and the main supply chain (SC) issues which have direct or indirect effect on the management of knowledge in aerospace SCs. Four major aerospace companies (Company C, Company D, Company E, and Company F) were the primary SC contacts. The SC managers in these companies were interviewed to collect data on the perspective of these companies on the supply chain management (SCM) issues. Following the preliminary interviews, two major projects were selected in Company C and Company D to review the knowledge flow and the issues which affects the knowledge flow during the project lifecycle. A brief background is provided in each company before detailed exploration of their SCs in specific projects.

8.2 Company Background Information

Company C is a high performance engineering company that specialises in engines and electronics for automobile racing (motor sport), mainstream automotive and defence industries. It has a revenue of £85m and employs 650 people worldwide. It was founded in 1958 and its headquarters are in Northampton, UK. It operates in the UK, North America and India. Company C is based in Northampton, England, with North American facilities in Torrance, Indianapolis and Mooresville and an Indian facility in Pune. They have had a long and distinguished career in Formula One, beginning in 1963.

Company D is a UK registered company operating in the civil aerospace, defence aerospace, marine, energy, and nuclear sectors in 120 countries. It was founded in 1907 and privatised as a plc in 1987 with its headquarters in London, UK. Company D designs and produces the world's broadest range of engines in the civil and defence aerospace sector. In the marine sector it is the world's leading system provider and integrator. In energy it is the world leader in oil and gas. It has a revenue of £10.4 billion, employs 39,000 people worldwide and has a strong record of investment in research and development (around £900m a year). They develop a broad range of products with risk and revenue sharing partners and strategic long term relationships.

Company E is a European joint venture in the field of aerospace technology with a revenue of €27.5 billion. The company was founded in 1970, with headquarters in France, and employs around 57,000 people at sixteen sites in four European Union countries: Germany, France, United Kingdom and Spain. In addition to the sites around Europe, Company E has subsidiaries in North America, China and Japan, an engineering centre in India, and a joint engineering venture in Russia. The company produces around half of the world's jet airliners.

Company F is a US registered aerospace company operating as one of the largest aerospace and defence suppliers in North America, UK, and Europe. It has headquarters in North Carolina and has revenue of $7.1 Billion with a workforce of 25,000 people. It has 140 years of operating history and over 80 facilities in over 18 countries. It produces actuation systems, aircraft wheels and brakes, landing gear and engine components, sensors and integrated systems, engine control and power systems, nacelles and interior systems.

8.3 Case Study Content

This study was started with the company specific case studies. For the company specific case studies, structured interviews were conducted with the Supply Chain Managers of the aerospace companies (Company C-D-E-F) to collect background information about their supply chain management practices. In these interviews information on the following areas were collected:

- Number of Suppliers and Supply Chain Assessments;
- Supplier Selection Criteria and Supply Chain Relationships;
- Knowledge Exchange and Collaboration Issues;
- Other Issues and Future Plans of the Supply Chain.

The interview questions are presented in Appendix A. Following these company-specific case studies, two projects were selected for the project specific case studies (Company C and Company D). Two semi-structured interviews were conducted with the project managers of the selected projects. The project managers explained briefly the phases of the projects in a chronological order and provided information about the main suppliers in each phase. Contact details of the main supply chain actors were also obtained for further investigation. Details related to the selection of supply chain actors and the relationships with these members were discussed with the project managers. At the last stage, structured interviews were conducted with the supply chain actors of the particular project. In these interviews information on the following areas were collected:

- Project knowledge created/disseminated/shared/stored in each phase of the project;
- Methods and tools used for knowledge creation and sharing;
- Knowledge management issues and problems in the project supply chain;
- Future Expectations for Supply Chain Management

The details of the interview questions are presented in Appendix B. Due to confidentiality issues, the supply chain actors of Company D could not be interviewed. However the interview results of Company C Supply Chain Actors are presented in Section 7.5.

In the following section (Table 7-1), the details of the interviewees are presented.

Table 8-1 Information on Interviewees

Company/Business Area of the Interviewee	The Role of the Interviewee	Experience in Aerospace Industry (yrs)	Experience in the Company (yrs)
Company C	SC Manager	25	3
Company C	Production Manager	25	15
Company D	SC Director	22	6
Company E	SC Manager	17	5
Company F	SC Manager	20	6
Company C	Project Manager	15	7
Company D	Project Manager	26	15
Company C Foundry 1	Project Manager	15	3
Company C Foundry 2	Production Manager	8	5
Company C Shot-peening Sub-Contractor	Business Manager	10	3

8.4 Findings Of The Company Specific Case Studies

In this section, the results of the company specific case studies which covers the four aerospace companies are presented.

8.4.1 Introduction to Companies Supply Chains

Company C has supply chain actors in the aerospace and manufacturing industry. They have contact with 3000 suppliers. The suppliers are divided into two categories: stock items and non-stock items. The number of supply chain members for stock items is around 300 and the remainder, 2700 suppliers, are for non-stock items.

Company D has a supply chain with five main divisions: 30 Control and Instrumentation suppliers (instrumentation, batteries, sensors etc); 100 Machining and Fabrication suppliers; (coatings, fabrications, machining, bearings, springs and fasteners); 25 Pumps and Valves suppliers (pumps, valves, test rigs, strainers, TGs); 70 Raw material suppliers (forgings, castings, special alloys, bars, plates, forming/press, pipe work and tube) and 1000 Indirect Suppliers (resourcing, IT, manufacturing, logistics, consumables, facilities, build and test etc). Company D (UK operations) mainly use UK suppliers and only 10% of their suppliers are located in Europe. These are mainly forgings, castings, pipe-work, vessel and raw materials companies.

Company E produces aircraft wings in the UK. They have suppliers in three main groups which are materials suppliers (aluminium details, composites, hardware, fasteners, raw materials), aero structures, materials (little bids which fit in 1 m^2), and general procurement (anything not used in aircrafts). They have around 200 suppliers from the UK and they send the end products to the final assembly lines in Toulouse and Hamburg.

Company F has 230 design and manufacture suppliers within four main groups: 60 Machinery and Casting Suppliers, 70 Coarse and Winding Suppliers (plastic insulations, screws, washers etc), 95 Electronics and Major Boards Out Suppliers and 5 Distribution Suppliers (electronic systems such as circuit boards, etc).

8.4.2 Supplier Selection Criteria and SC Assessments

Company C's quality assurance team makes annual revisions to assess the performance of supply chain members which they worked with that year. According to the result they evaluate the suppliers' future work. For new suppliers, Quality Assurance engineers and the buyer do audits before starting working with them; this could take a couple of days depending on certain processes and procedures. Another important control criterion is to review their financial security. The key criteria for keeping a supply chain member in the organization are cost, delivery and quality. During the relationship with the supplier, it is possible to review their scores on a central system. This scoring system was developed by the company. The main priority of the supply chain is reducing working capital, reducing supply chain cost, increasing quality and improving delivery.

Company D makes annual reviews of their supply chain members. The selection criterion for new suppliers is based on the assessments where their trained auditors assess the new supplier on the process, procedures, facilities, ISO standards and cost of service or products. For indirect suppliers, Company D requires ISO certificates only. The decision to keep a supply chain member in the chain is made on a scoring system called the Balanced Quality Score Card. The key metrics scored are supplier's performance, delivery, quality, relationship and cost. All elements of the score card are equally weighted. This card was based on the Score Card which was adopted from the SC21 (Supply Chain 21st century) Balance Score Card in 2009. Each category of supplier is assessed with a different strategy. The main supply chain management priority is based on reducing supply chain cost, increasing quality and improving delivery. Company D do not drive the suppliers too hard and would like them to stay financially healthy.

Company E has suppliers in South America, Central America, UK, China, Korea, Australia, New Zealand, Russia, and Europe. Although they are based in different countries, all supply chain actors need to have AS9100 (Global quality standard for aerospace) to become a supplier. They also have to be approved through the company standards GRAMS (General Requirements for Aero-structure and Material Suppliers) and GRESS (General Requirements for Equipment & System Suppliers). Primarily, the availability of the knowledge, equipment and facility to do the job, the location of the supplier (if it is a place that they think of selling an aircraft), financial stability, total cost of acquisition (TCA) (all costs associated with buying goods, services and assets) are the main criteria to become a supplier. To stay in the chain the suppliers are assessed and scored annually in terms of quality, delivery, financial stability and cost. A risk assessment (technical and financial) is also performed. The main priorities of the supply chain management are increased customer satisfaction, reduced supply chain cost; extraction of more value from existing suppliers and customers.

Company F always looks for new technologies; therefore for the projects in the pipeline, supplier selection is an ongoing process. To become a supplier for the company, suppliers fill in a supplier assessment form which covers various criteria such as performance (past projects, delivery, performance, quality and references), quality, financial stability and cost breakdown (manufacturing, equipment), subcontract management. For the key suppliers, Company F evaluates performance monthly in a matrix to understand whether these suppliers are performing well in terms of delivery. The key criteria for keeping a supply chain member are on-time delivery, quality of the deliveries, their approach to the returns and defects (performance of corrective actions), response to queries, and purchase price. The main priorities of the supply chain management are improving delivery and customer satisfaction, reducing supply chain cost, and increasing delivery. It is noted that the quality is found to be developed in the aerospace industry since majority of the suppliers are fulfilling the required quality. The most critical issues are delivery, performance and cost.

8.4.3 Supply Chain Relationships

Company C has both mature and new relationships. They generally keep the mature suppliers in their motor sport sector. Due to moving to the aerospace industry three years ago, they started to deal with different suppliers. They take their key customers' advice on potential suppliers in the aerospace sector. This is very helpful for them since these companies have already passed their customer's quality and performance approval. They would like to develop long term relationships in aerospace and limit the number of suppliers to a certain level so that they can manage them easily and effectively.

With their old suppliers, the relationship is based on trust. This makes everything easy through the project. They generally try to understand the reason behind the problems with their suppliers. This approach builds trust between them and their suppliers. However the suppliers generally build a close relationship and pay attention to their requests if they have a good amount of work from Company C. If the percentage of the workload they provide to the suppliers is high enough in the overall workload of the supplier then the supplier puts in more effort to solve problems. The strategy towards the suppliers is to improve the relationships in a constructive and trustworthy way. Failures on the part of a supplier do not mean that the supplier is not going to be used anymore. Instead of removing the supplier from the chain, the attitude is to try to improve the relationships and operations.

Company C's customers' priorities are mainly quality and delivery; cost follows these main priorities. Open and close relationships with customers can also be helpful to improve their supply chain. For example, one of their customers found an alternative supplier that could provide similar quality and delivery at a better price.

Company D has mature relationships, and in general there is no tendency to work with new suppliers. In the last 5 years, the company reduced the number of suppliers to have a leaner and higher quality supply chain. Their main aim was to improve the relationships with the key supply chain actors and keep consistency in their supply chain. The sectors they are looking for new suppliers are the new markets such as civil nuclear or the areas in which they can find innovative solutions such as manufacturing, building and testing, and instrumentation. However, because the cost of entry to the sector is quite high with respect to the other sectors, their supply chain has mainly mature relationships.

One of the most important issues which have an adverse effect on Company D’s supply chain relationships is long-term project durations. Due to employee turnover there is a possibility of losing the relationship with the key contacts. To overcome this, they try to establish programs which help to maintain a close relationship with the companies rather than individuals.

Company E has constantly narrowed down their supply chain because it was difficult to manage too many suppliers. Most of their relationships are old and mature. However, they are open to new markets. Most of the work in the aerospace industry is very unique and needs high capability. There may only be a few firms capable of doing such specialist work. In these circumstances, it is very difficult to transfer the knowledge and ability from one supplier to another supplier. Therefore, when the company starts to work with these companies, it is generally a life time relationship. An aircraft’s life is typically 40 years and when a part of an aircraft needs to be replaced, they need to work closely with the other firms for a replacement. Therefore, it is essential to keep the old relationships in their supply chain.

Company F has generally old relationships in their supply chain. There are new suppliers in areas such as rapid prototyping and electronics where technology is rapidly changing. The companies in their supply chain are generally small suppliers. In small organizations, there is a lack of some organizational skills such as risk management, corporate culture and experienced personnel. This has adverse affects on the communication and understanding with the supply chain actors. Also, due to high employee turnover in these organizations there is always a possibility of losing key contacts within these companies.

8.4.4 Special Programmes/Actions to Improve Supply Chain

Company C has suppliers mainly divided into three different categories: manufacturing; heat treatment; and materials. These suppliers have different order book structures depending on their project delivery nature and timeline. Therefore, these should be treated in a different way depending on the nature of their business. In order to achieve this, there is an existing performance control system where the details about the performance, delivery, quality and relationships are recorded and discussed with the suppliers at the end of every project. These discussions help Company C to understand the issues of their suppliers and suppliers can also understand the expectations of their customer. Apart from this, the company registered for the SC21 (21st century supply chains) programme in 2010. SC21 is a change programme designed to accelerate the competitiveness of the UK aerospace and defence industry by improving the performance of its supply chains. SC21 aims to create knowledge sharing culture, encourage innovation, supports members in delivering through life solutions, supply chain performance measurement. Benefits which SC21 continues to reap for companies and their supply chain include cost reduction, increased efficiency and better relationships (ADS, 2011). Company C finds these kinds of programmes very sensible because it provides a common way of understanding and measuring the suppliers. SC21 provided a guarantee and a reference for the quality and delivery level of the suppliers, despite the fact that their clients may still have different requirements. Company C used to organise annual supply chain conferences. However, they had to stop this due to cost constraints last year.

Company D developed Category Management, Risk Management, Supplier In Distress Programme and Supplier Engagement Programme to improve their SC. Before the launch of the "Category Management" programme in 2007, independent consultants participated in a feasibility study with the main partners of Company D. In this study, the issues surrounding the industry supply chains were examined. A second study was undertaken by Company D to understand the issues specific to the different sectors of Company D such as aerospace and nuclear. At the end of the study, an organizational reconfiguration was made. Some of the staff in each procurement category for different sectors were removed and a central procurement team was created. This central team is responsible for supply chain strategy development in each category, establishing supplier intelligence network, implementing a category management approach and establishing continuous risk management process. The central team works closely with the operational team which works closely with the customers in each specific category. Each category is a group of components with similar characteristics in terms of engineering design, manufacturing process and supply chain. With the help of their new programme, category strategies have been developed to address supply chain issues, reviews of category and supplier strategies for accommodating business and market changes. Reorganization has helped them to establish teams focusing on creation of strategic, long term and sustainable supply chains. All these efforts led to a group developing top level supply chain strategy rather than individual strategies in each procurement group

Within the new Category Management scheme, Company D established the Risk Management Programme where they assess their suppliers. Through this programme risks are identified for each category and the potential impacts of the risks are assessed based on a risk matrix. Their Supplier In Distress Programme, where they assess the financial stability of the suppliers, feeds their risk management programme. All these assessments are used to define the supply chain strategy for each business.

Company D is playing a leading role in the implementation of the SC21 scheme in the industry. SC21 also feeds their Category Management programme. This programme helps their suppliers to manage their own improvement. Seventy five percent of their suppliers are registered for the SC21 programme.

Within the Supplier Engagement Programme, they have individual meetings with suppliers where they discuss the performance of each supplier based on the results of their Balanced Score Cards and provide forecasting for future work and programmes. The reviews keep the supplier in contact, support their performance, and increase the trust level.

Company E implemented the Supply Chain Relationships in Aerospace (SCREA) programme developed by one of the big aerospace players of UK industry as one of the first programmes to improve their supply chain. It involved the performance assessments of the suppliers and regular meetings with their suppliers to discuss the outcome of the programme. It was a good system to understand the issues of their suppliers. However, due to lengthy assessments (which lasted a week), it was not very effective. To improve the relationships with their suppliers, Company E developed a Relationship Management Matrix (RMM). Their suppliers were provided with a questionnaire based on 20 questions, mainly about the issues in their relationships. There was a scoring system which provided them an objective measure rather than a subjective measure about their relationship. This was very good to clarify the problems and improve awareness in the areas that they need to focus, and make plans for improvements.

Currently Company E is registered in SC21 which is an improved version of SCREA. Because Company E is a global company which deals with lots of suppliers all over the world, this UK based initiative may not be applicable for their whole supply chain. Therefore, it is not yet widely accepted. However, they plan to implement the programme for their UK based suppliers so as to help them to have a robust supply chain in the future.

For **Company F**, SC21 is an important programme for improving the supply chain partners. This programme is strategic for the key suppliers, and Company F continuously encourages their suppliers to join this programme. In total, they have 20 key suppliers signed up to SC21.

Before SC21, there was a government funded project called Supply Chain Groups. They grouped their suppliers in the same sector and regularly arranged meetings to share their knowledge, experiences, and resources. Currently they still meet the same groups they created. They also invite their customers to these meetings so that every party can have a clear understanding of each other's requirements and expectations. This dramatically improved their supply chain relationships. During these group meetings, they build informal partnerships where they share a long term vision with their suppliers. They do not want to form formal partnerships since they would like to be flexible during price negotiations.

During projects, they regularly organize meetings with the designers, supply chain managers, and project managers so that the relationships are better developed for the collaboration through the project. In this way, design information is transferred to the manufacturer with higher accuracy, and this decreases the conflicts and problems at further stages of the project.

8.4.5 Information and Knowledge Exchange Methods and Tools

Table 8-2 presents the main knowledge exchange methods and tools of the companies. According to this list, face to face meetings, emails, phone calls, video and audio conferences, steering groups, and tools such as SAP or web based systems are the main information and knowledge exchange methods and tools.

Table 8-2 Information and Knowledge Exchange Methods and Tools

Company	Information and Knowledge Exchange Methods and Tools
Company C	• Regular face to face meetings with customers to understand the specifications, requirements, and make collaborative decisions; • E-mails, phone calls; • Video and audio conferences with suppliers depending on their geographical location around the world.
Company D	• Regular face to face meetings with suppliers and customers; • E-mails, phone calls.
Company E	• Regular face to face meetings with suppliers and customers; • E-mails phone calls; • Video and audio conference, net meetings where the project actors can log into the same platform and share project knowledge; • DMU (Digital Mock Up) tool on the intranet to share the design information during the projects. However, the design information is not up to date and there is no real time platform. • A platform called Suparworld where the suppliers are allowed to log into SAP, display the orders, and forecast plans.
Company F	• E-mails, phone calls. • Web-based real time system to monitor the purchase order information and performance measurement information of their suppliers. Their suppliers can log into this system to make invoice payments, and check their account status. Linked to the purchase order, they can enter the technical specifications, and quality specification information into this system. • A Web-based system which is used for Request for Quotation (RFQ) with the suppliers for the potential orders and pricing of the requests. All sorts of queries and questions can come through this system. • Steering groups are organized where Company F encourages their suppliers to share their experiences, knowledge and expectations.

8.4.6 Knowledge Exchange and Collaboration Issues

Table 8-3 presents the summary of the main knowledge exchange and collaboration issues of the companies. The key issues are summarised in the following part of this section.

Table 8-3 Knowledge Exchange and Collaboration Issues

Company	Knowledge Exchange and Collaboration Issues
Company C	• Complexity in knowledge sharing with the downstream supply chain due to heavy reliance on the design procedures of the design authority (their client); • Inadequate documentation and information management from the client • Problems in the transfer of knowledge from the small scale suppliers at the right level of detail and at the right time; • Slow change management process in the large scale aerospace firms; • Inadequate interoperability in the tools to create design, need for agreed standards for drawing and modelling processes; • Need for progress in relationships with downstream suppliers by getting help from non-disclosure agreements
Company D	• Long project durations and long durations between similar projects cause knowledge gaps due to employee turnover; • Difficulties to find suppliers who have skills to work with both latest and out-dated technology; • Problems during the transfer of the design knowledge into manufacturing specifications particularly during outsourcing. Initiatives to encourage collaboration with suppliers during conceptual and detailed design phase in particular. • Security and sharing of knowledge is not a big issue because of the national (MOD) protection.
Company E	• Lack of encouragement in the use of the project information database, inconsistency in the shared information through database; • Lack of collaboration technologies and procedures for sharing lessons learned knowledge; • Lack of KM people/unit/department/ who can lead the KM

	implementation and change; • Lack of knowledge sharing culture, difficulties coming from heavy blaming culture; • Lack of encouragement to transfer knowledge through informal channels; • Need clear set of knowledge sharing goals and rules; • Difficulties coming from language and cultural differences in their global SC. Email communication does not always provide clear understanding; • Difficulty in providing accurate interface design among global teams; • Need for more understanding on the requirements of suppliers (Downstream suppliers has a tendency to keep information due to confidentiality); • Huge amount of paperwork, difficulties to access the right document when a failure occurs.
Company F	• Knowledge loss due to high employee turnover; • Lack of collaboration technologies; • Keeping the right balance in terms of confidentiality and knowledge sharing in high technology products.

Based on the information presented in Table 8-3, the company-specific case studies revealed the following collaboration and knowledge exchange issues in aerospace supply chain:

- Aerospace supply chains are defined as a complex, slow to move and change. It has very long project durations which can cause serious knowledge loss and gaps in relationships due to employee turnover or gaps between similar projects.
- In the aerospace industry the projects can involve both the latest and out-dated technology together and it is difficult to find suppliers who have skills to work with both latest and out-dated technology.
- There are well developed procedures to create design knowledge in the industry. In the case where first tier suppliers work for a design authority (client), there is heavy reliance on the design procedures of the client, although this puts well defined design procedures across the supply chain, any small change from the second, third tier suppliers need to be informed to the client which slows down the process. There is huge amount of paperwork

which delays the design process and can cause difficulties to access the right information when a failure occurs.

- Due to working on high technology products, knowledge is extremely valuable and there is a tendency to keep knowledge among employees. This tendency also takes place among suppliers in the downstream supply chain working as competitors, however non-disclosure agreements are found as a solution on the confidentiality issue.
- The transfer of technical knowledge from the downstream suppliers at the right level of detail and at the right time is problematic. There is a need to encourage knowledge sharing through formal and informal channels in the aerospace supply chains. There is lack of knowledge sharing culture and heave blame culture in the industry.
- The industry has problems during the transfer of the design knowledge into manufacturing specifications particularly during outsourcing. There is a need to understand the global supplier requirements better. There are difficulties in providing accurate interface design among global teams.
- There is inadequate interoperability in the tools to create design, and there is a need for agreed standards for drawing and modelling processes;
- Due to having global supply chain, aerospace firms have difficulties coming from language and cultural differences. Email communication does not always provide clear understanding.
- Large scale actors have information systems in practice however, there is a need to encourage usage of these systems, also there is lack of collaboration technologies implemented for the use of supply chain actors for collaborative decision making. Downstream suppliers are in need of ICT implementation and training.
- There is lack of procedures for sharing lessons learned knowledge which is mainly reported by the large scale global aerospace company. This shows that there is awareness on lessons learned approach, however the industry is still in need of well defined procedures. There is a need for clear set of knowledge sharing goals and rules.
- The large scale organizations do not have KM people/unit/department/ who can lead the KM implementation and change.

The following solutions are implemented in the supply chain by the companies to over come some of these issues:

- For interoperability between Knowledge Management Systems (KMS) and design tools Company E has generated standard processes and tools for all countries. For example, even the versions of Microsoft used in different countries were different and this was causing problems when sending a document to a branch in another country. They still need to progress on standardization of the knowledge creation process within their supply chain
- Company D encourages the transfer of knowledge through formal channels during the tender stage and contract stage in particular with face to face normal meetings and Board to Board Agreement with critical suppliers.
- Relationship management is found to be the key element to encourage the transfer of knowledge through formal and informal channels. Long term relationships of Company C improved the transfer of the knowledge, design or products with fewer delays. In particular, collaborative sharing and transparent communication with the supplier from the early stages of the project has been the key element to create a "win-win" situation for both parties in the long term. For example, Company C had a case where they shared the difficulties in their supply chain with their client. They worked on the problem together, and at the end their client suggested an alternative supplier that could provide better quality and delivery at a lower price. Also the non-disclosure agreements between their customers, and supply chain members improved the confidentiality between parties.
- It is believed that innovation comes from the knowledge transfer in the conceptual and design stages of the project despite the fact that it causes longer delivery times and requires working with technically complex knowledge collaboratively in the supply chain. However, in the long term providing innovative solutions to the market makes Company D more competitive.

8.4.7 Other Issues of SCM

Table 8-4 presents the summary of the other SCM issues of the companies. The key issues are summarised in the following part of this section.

Table 8-4 Other Issues in Aerospace Supply Chains

Company	**Other Issues**
Company C	• Depending on limited number of suppliers specialised in old technology and materials, difficulties in finding suppliers who produce old materials. • Lack of information from the client (design authority) on future workload which forced the company to look for innovative processes which can shorten design and production time. • Inadequate quality in their outsourcing locations as Far East which is in the trend of a positive change; • Inadequate financial stability; • Lack of quality in the downstream supply chains as opposite to the situation in the upstream supply chain;
Company D	• Maintaining continuous improvement in demand management and technology forecasting. • Continuing in lean approach which has brought more control on the supply chain and reduces risks. • Need for longer term view of requirements and forecast of part visibilities to the supply chain • Keeping their old and loyal supply chain
Company E	• Challenges in providing innovation focused on flexible solutions according to the customer's needs and requirements rather than producing standard design and selling it to the market • Need for major emphasis on sustainability in their supply chain (long life products with less carbon emissions, alternative fuels and materials which will last longer.) • Outsourcing in Fare East combined with lean approach, more serialized production, and building up a lean aircraft starting from the conceptual design phase is a significant target. • Need to improving the forecast demand to properly position inventory and other resources.
Company F	• Need to providing accurate design and manufacturing requirements and collaborating early with the suppliers for more innovation;

	• Need to work with financially healthy suppliers; and be aware of financial situation of suppliers in advance of any possible crisis. • Life cycle management and sustainability have great affect on innovation and need to be managed for more innovation; • Recent outsourcing efforts make the SC more fragmented which is difficult to manage

In summary, the company-specific case studies revealed the following SCM issues:

- Due to working on very old technology in some of the projects, the aerospace firms have difficulties to find companies that can provide old technology and materials.
- Although there are efforts in large scale aerospace firms (that work as design authority) to provide future workload as a result of close collaboration with the main clients, this information has not yet cascaded through to the downstream SC. This has forced the suppliers to look for innovative processes which can shorten design and production time.
- Recent outsourcing efforts make the SC more fragmented, making it difficult to manage. There is inadequate quality in the outsourcing locations as Far East, however it is expected to change positively in the near future.
- Upstream aerospace supply chain is focused on quality and delivery however, downstream supply chains need to progress more in providing higher quality.
- Firms are challenged to provide innovation focused on flexible solutions according to the customer's needs and requirements rather than producing standard design and selling it to the market.
- Firms have difficulties in providing accurate design and manufacturing requirements; however there are efforts to collaborating early with the suppliers for more accuracy and innovation;

8.4.8 Plans for Future

Maintaining the lean approach: Although the large scale aerospace organizations already implemented a lean approach, they need to make the downstream supply chain to recognize lean manufacturing and the value-quality approach instead of a cost-based approach [Company C]. They also need more efficient ways to reduce stock, standardize, and decrease the time spent for dealing with the suppliers. This means reduction of waste and improving efficiency, thus increasing profit [Company E]. Besides lean processes, the firms also need to have leaner supply chains with less but high quality suppliers in the long term [Company D].

Better planning: Companies in the aerospace industry need to better understand the value of the balance between keeping the stock and a demand-driven supply chain. They would like to find better ways to reduce the stock, and be flexible enough to provide solutions with a better time management to their client [Company E].

Information on future workload: Aerospace firms need to provide better order forecasts to their suppliers. The ERP systems need to be checked regularly with realistic data [Company E]. Also, the information on future workload needs to be shared with the suppliers. The more knowledge they can get from their clients, the better they can position in the industry [Company C].

Knowledge Sharing Culture and Trust: The aerospace organizations need to establish a knowledge sharing culture. They need to benefit from the knowledge embedded in the minds of their own employees and the people in their supply chain. The knowledge gained through informal channels is found to be highly valuable because when a relationship is established between people it is easy to access the knowledge and experiences of these people. Two way knowledge sharing builds trust between parties. Trust was found to be a natural driver of knowledge transfer. To improve the current culture, they need to get benefit from informal meetings, live ICT platforms, forums and workshops to establish closer relationships [Company E]

Standardisation: There should be agreed standards for drawing and modelling processes in the aerospace industry. Standards should be established by the main players in the industry despite the fact the large scale aerospace companies are slow to move and implement change [Company D].

Getting benefit from national programmes: Firms need to get the most benefit out of the national schemes as SPACE (French), Supply Chain Excellence in Aerospace (SCEA) in Northern Ireland, SC21 (UK). All these programmes are being implemented to improve standards and quality in delivery for the aerospace supply chains [Company E].. Rather than communicating the necessary changes to the suppliers themselves, these programmes are a great help to encourage the suppliers to improve their processes in a systematic way. National programmes provide a dramatic change in a positive way [Company D].

Sustainability: The life cycle of the products are at least 30 years in aerospace industry. Therefore, sustainability is an important challenge and aim for aerospace firms [Company E]. Firms need to focus on life cycle management and sustainability, this is believed to have great effect on producing innovation in aerospace SCs firms [Company F]

Financial Stability: Firms need to improve their supplier selection methods with a risk based approach that considers many aspects to guarantee the long term viability of the supplier. This is essential to be more aware of financial situation of global suppliers in advance of any possible crisis [Company F].

8.4.9 Key Findings of Company-Specific Case Studies

The company based case studies revealed that aerospace organizations have common standard supplier evaluation and assessment criteria which are based on performance, quality, delivery and cost. The main SCM priorities are based on reducing supply chain cost, reducing working capital, increasing quality, improving delivery, and increasing customer satisfaction. All of the companies interviewed have mature relationships with their suppliers. They improve these relationships with industry wide SC development programmes. These programmes encourages the suppliers to use same metrics to evaluate the performance. This brings standardization to the industry.

The industry uses traditional information and knowledge exchange tools such as face to face meetings, emails, posts, and also video and audio conferences. However, even in the large organizations, information transfer databases were found to be poorly managed. These tools are not used consistently to share and keep the project knowledge during projects. Due to long project durations; there is always a danger of losing knowledge and key skills. It is also difficult to identify the skills needed to adapt new and old technology during projects. Moreover the industry has a very conservative culture. There is too much competition amongst employees, and a heavy blaming culture. Besides all these bottlenecks, the industry benefits from its well defined standard project processes and collaboration with the client and suppliers at the early stages of the projects. Early collaboration during the conceptual design and continuous collaboration during detailed design phases were defined as the main basis for innovation.

Globalisation challenged the aerospace companies significantly. The aerospace firms had to cope with barriers such as culture, language, usage of different systems, standards and quality issues, difficulty to understand the financial stability of the global suppliers and different time zones. However, these challenges caused improvements in the aerospace supply chains such as better planning, implementation of lean approach, decreasing stock, improving the processes, decreasing the number of suppliers and the number of the employees dealing with the suppliers.

8.5 Company C Project-Z

8.5.1 Introduction

In this section the outcome of project-specific case studies are presented.

8.5.2 Project Overview

'The Z Project' started in February 2008 and was completed by August 2009. For the project, Company C had a Client (Company D) who is one of the big players in the UK aerospace industry. The Client's primary need was to replace the stock for the engine of the minesweeper damaged in a fire. For this project, Company C had to:

- Recreate drawings using original drawings and supplied parts;
- Provide engineering support to resolve technical issues;
- Manufacture high quality parts;
- Supply parts with full documentation;
- Provide regular feedback on progress and issues.

The typical parts produced during this project were the crankcase assembly gear, carrier case, oil pressure pumps and sandwich plates. In total, 25,375 parts were produced with 475 different part numbers. For the project, over 25 suppliers were involved, 9 of these suppliers produced the majority of the external work. The external work consisted of scanning, sand casting, forging, billet supply, shot-peening, chrome plating, line boring, vacuum impregnation and heat treatment.

8.5.3 Project Lifecycle

The project consists of the following main phases: reverse engineering, casting manufacturing, production engineering, and manufacturing of samples, and batch manufacturing. Table 8-5 presents the schedule of the project.

Table 8-5 Phases of the 'Project Z'

	2008												2009			
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Reverse Engineering		■	■	■	■	■	■									
Casting Manufacture								■	■	■						
Production Engineering								■	■	■						
Manufacture Samples											■	■	■			
Manufacture Batch														■	■	■

These phases have the following stages:

- Measurement (Scanning, CMM, metallurgical analysis)
- Design (Fully parametric 3D model and 2D drawing)
- Approval (Overlay of CAD model with original scan results)
- Manufacture (CAM & CMM data created directly from the CAD model. Machined components are assembled in Company C.)
- Validation (Finished components supplied with full First Article Inspection reports, which can be scanned and overlaid with original scan and CAD model.)

For this case study, 3 suppliers were interviewed. Foundry 1 and Foundry 2 were responsible for tooling, casting, heat treatment, and inspection for castings. Foundry 1 has been working for 15 years and Foundry 2 has been working for 25 years for Company C. The third company was responsible for shot-peening process (See Appendix G) and has been working with Company C for the last 15 years.

8.5.4 Findings of Project Specific Case Study

In this section, KM practices, issues in the project SC and the expectations of supply chain actors for better knowledge sharing are presented.

8.5.4.1 Knowledge Flow throughout the Project Life Cycle

Appendix G shows the main elements of the knowledge flow between each supply chain actor through the project life cycle in table format. The Tables present:

- the information and knowledge requirements of the supply chain actors;
- the actors (in brackets) who provided the required knowledge;
- the information and knowledge created by each supply chain actor; and
- the supply chain actors (in brackets) who received the created knowledge.

8.5.4.2 Knowledge resources of the SC actors throughout the project lifecycle

Knowledge resources of supply chain actors are an important part of the knowledge creation process in a project and are presented in Table 8-6. According to Table 8-6, manufacturing events, industrial organizations, conventions and exhibitions, materials suppliers, specialised companies on casting are all knowledge resources outside the supply chain. From these resources they learn about technological improvements, new materials, specifications, and new processes. According to the project manager of Foundry 1, it is very important for the suppliers to review their knowledge resources regularly. For example, in one of the exhibitions, they learned about a CT (Computed Tomography) machine which is used to check the wall thicknesses to model the products and verify the components dimensionally instead of chopping a casting to review the sections. The whole process became quicker (Foundry 1).

Table 8-6 Knowledge Resources of SC Actors

SC Actor	Knowledge resources (Apart from the SC actors for the project)
Foundry 1	Visits to manufacturing events, industrial organizations, internet.
Foundry 2	Specialised companies on casting for new techniques and procedures, material suppliers for new materials. (Casting companies are a very small pool of resource with 2 casting company based in the UK, 1 in France, 2 in Italy, and 4 in North America)
Shot-peening Sub-contractor	Conventions and exhibitions. (There are around 6 Shot-peening Sub-contractors in the UK.)

8.5.4.3 Methods and Tools for knowledge sharing

To exchange information and knowledge the SC members use emails, post, phone calls, and regular face to face meetings.

8.5.4.4 Storage of information and knowledge

The main information storage tools used by the companies are intranets and organizational servers. Foundry 1 has a New Product Introduction system running on their intranet where they keep soft copies of drawings, specifications and lessons learned documents in this system. Similarly, Foundry 2 is transferring to a new electronic system where they will keep project information, however the old projects archive is mainly based on hard copy. All of the suppliers have to keep past project information for a certain period of time, as stated in their contract. Information they keep specifically are technical data sheets, quality requirements, specifications and test results. Thus, in the case of failure there is full traceability back to the original supplier (Foundry 2).

8.5.4.5 Highlights on the project

- Company C was unable to find out the companies who originally made the parts because some of them had gone out of business. However, Foundry 2's name was still engraved on some of the castings. Company C approached Foundry 2 to get quotations for four or five different parts.
- Due to being the old manufacturer of the engine parts, there had been a lot of knowledge transfer between Foundry 2 and Company C during the re-engineering process. Foundry 2 provided the actual weights, material specs, quality procedures because they had been in business for over 25 years (Foundry 2).
- When the contract ended for the original project which was in place 25 years ago, Foundry 2 destroyed most of the original tooling apart from the cylinder block tooling. They kept this because it was large and difficult to destroy. It was a tool that had been forgotten on their site and it was pure luck that they were able to reuse it for the company.
- Twenty-five years ago, when the original foundry produced the castings, they made some changes to their design during production; however, the original foundry company did not update the drawings after these changes. Therefore when the CT scan of the original casting was overlaid on the 3-D model, the differences were realised and the 3-D model was updated. The tooling was updated as well. This resulted in a delay in the work (Foundry 1).
- Due to technological changes over the last 25 years, Foundry 2 updated the technical sheets used when the engine parts were first produced in their company. These updates

included the usage of modern materials and processes. They used different sands, different thermal sleeves, and different sand knocking procedures such as vibration table for the project.

These highlights revealed the importance of long term collaborative relationships between the organizations. Although the aerospace industry has challenges due to work with very old and new technology, old collaborative relationship with the old supplier helped the Company C during their project. It also revealed the necessity of updating design records after the changes during the production or construction process.

8.5.4.6 Key Knowledge Management Issues

Confidentiality

There are generally more than one casting supplier working on the project. This can be an issue in terms of knowledge sharing during projects. To improve confidentiality, Foundry 1 makes agreements with their clients to not share their casting processes and tools with their competitors. This is essential because it is a very competitive market. Foundry 2 also established a technical partnership with Company D which involves contractual requirements for knowledge sharing and keeping the specialised knowledge confidential.

Knowledge Sharing and Collaboration

Suppliers had regular briefings with Company C to discuss progression, issues, programme. Apart from this they had meetings when a technical problem occurred. These meetings, the accessibility of Company C when an issue arose, and their proactive approach are the factors regarded as encouragement for knowledge sharing (Foundry 2).

Table 8-7 presents the evaluation of the knowledge sharing across the supply chain. The Shot-peening Sub-contractor and the Foundry 2 interviewees defined the knowledge sharing in the upstream supply chain as between ‘adequate’ to ‘strong’. They have stronger knowledge sharing with those whom have confidentiality agreements or partnerships. According to the Foundry 1 interviewee, due to working with a few long term suppliers they can maintain a good level of knowledge transfer during projects. According to the Shot-peening Sub-contractor, the small suppliers in the downstream SC have a lack of systems to share information on time. This slows down the process; however in general knowledge sharing is defined as ‘adequate’ to ‘strong’. The shot peeing supplier also described the knowledge sharing across the downstream as ‘adequate’.

Table 8-7 Evaluation of Knowledge Sharing Across Upstream and Downstream SC by SC Actors

Supply Chain Actor	Upstream Supply Chain	Downstream Supply Chain
Foundry 1	**Adequate** (It is stronger with big players)	**Strong** due to simplicity and their own control
Foundry 2	**Adequate-Strong** (It is stronger with the companies they have confidentiality agreements or partnerships.)	**Adequate-Strong** (small suppliers have a lack of systems to share information on time)
Shot peening	**Adequate-Strong** (It is stronger with big players since they are working collaboratively to improve quality and performance)	**Adequate**

According to Foundry 2's Production Manager, knowledge sharing enhances the value of collaborative relationships. For example, Foundry 2 and Company C worked in collaboration during the review of the sample casting test results. When they had any dimensional queries or quality issues regarding the metallurgical quality of the casting, they got full support from Company C. There was liaison between their materials laboratories regarding the quality of the material. The two teams worked together to improve the quality and it was very helpful (Foundry 2). In another project, Company D had an internal foundry but they closed it recently to sub-contract the foundry work. However, they kept their foundry teams to deal with the suppliers. There had been very beneficial knowledge transfer between the teams in Company D and Foundry 2. Having a win-win situation for all parties, Company D became the only customer whom Foundry 2 allowed to work closely with them on site during the projects. The collaboration and knowledge sharing to improve the foundry's processes strengthened their relationships. Collaborating closely with their customer improved their capability (Foundry 2). Similarly, in recent years, the Shot-peening Sub-contractor became more open to their customers and started to work collaboratively to improve their processes. They started to share the technical problems and expectations. Their customers understood their capability and potential for further development. For example, when working with Company D, the Shot-peening Sub-contractor's processes have to be signed by Company D's laboratories. Some of these processes were developed 30 years ago and they were impractical and very time consuming. As a result of collaborative work with

Company D and the supplier, the signing process has been revised according to the needs of the two parties (Shot-peening Sub-contractor).

Improvements in collaboration in the supply chain within the aerospace industry are still found to be very regimented and rigid. Particularly in big projects, suppliers still have difficulties in finding the right avenue to approach and to make decisions (Foundry 2). Due to producing a high technology end product, it can be a very lengthy process to get useful feedback in projects where there are many people involved in decision making (Shot-peening Sub-contractor).

Knowledge Request Dependencies/ Clarity of Information

Knowledge dependencies are defined as clear for all parties during the project (Foundries 1 and 2). In the aerospace industry, everything produced or processed has to comply with aerospace industry standards or specifications. As such, the contracts or even the requirements during quotation are very clear. The standards help customers to define their requirements with more clarity (Foundry 2). In particular, the clarity of the initial knowledge when they make a quotation is very important (Foundry 1).

The Foundry 2 Supplier had cases where they did not receive the necessary knowledge in time due to time limitations rather than confusion in knowledge request dependencies. The drawings or specifications which were transferred at later stages caused mistakes on the quotation or caused technical problems (Foundry 1). For the Shot-peening Sub-contractor, there had been some cases where the information provided was unclear. The information provided for repair scheme advises the company to apply the shot-peening process to certain areas. However, these areas were not always clearly presented. It would be much easier if it was presented clearly on a drawing. In these cases, they had to contact Company C to get more information. It is very time consuming for the supplier and it slowed the process down (Shot-peening Sub-contractor). However, in recent years, common experience has increased the accuracy of the information provided. The large aerospace organizations put good systems in place for their suppliers. The Shot-peening Sub-contractor tries to consolidate and get that information and uses something similar across all their customers (Shot-peening Sub-contractor).

Overload of Paperwork

In the receipt inspection process they receive the parts for shot-peening, (See Appendix F) and once a defect is detected, they need to report it back to the customer and stop the whole process. This results in too much paperwork which slows down processes in the aerospace industry. In addition the company has to comply with different standards on new manufacture and for engine service components. This also adds complexity to the process (Shot-peening Sub-contractor).

Supply Chain Events

The key industry players, such as Company D in the aerospace industry, organize annual supplier meetings for performance and quality improvement in the supply chain. This improves knowledge transfer and encourages suppliers to share knowledge (Shot-peening Sub-contractor). There had been some industry wide developments in recent years and therefore large suppliers of these key players are signed up to standardize the procedures and requirements across the whole supply chain. This was because they all had their own requirements, standards, and quality assessments which were confusing and time consuming to adapt for the supply chain members (Foundry 2). However, the suppliers interviewed were not yet affiliated to the SC21 programme (See Section 7.4.4 for further information on SC21). Other events organised for the supply chain by the key industry players were meetings to discuss lessons learned and open forums. The meetings revolve around informing the suppliers on the aspects in which they could improve and are generally regarded as one way by supply chain members (Shot-peening Sub-contractor).

Trust Based Long Term Relationships

All three suppliers in the project were in the preferred list of Company C. Foundry 1 has worked with Company C for the last 20 years, therefore there is a certain level of trust between the companies. This is an essential element to be a preferred supplier of Company C. Good performance and delivery of the supplier, and on time payments and good amount of workload provided by Company C in the long term are the elements needed to improve the relationship (Foundry 1). In the downstream supply chain, Foundry 1 also used their preferred suppliers for material supply and X-ray inspection supply (Foundry 1). Foundry 2 sub-contracted the refurbishment work of the existing tooling to their preferred pattern maker supplier. The Shot-peening Sub-contractor also works with a few material companies whom they have used extensively in projects.

Comparison of Aerospace and Motor Sport Industries

The companies interviewed work for both the motor sport and aerospace industries. The main differences are defined as the high level of documentation and longer time spent during decision making in the aerospace industry. It takes longer for different materials to be approved and accepted within the industry (Foundry 2). Also, the motor sport industry is constantly under pressure to change and be more competitive. Therefore the processes and knowledge transfer between the parties are more organized (Shot-peening Sub-contractor).

Information Systems

The key players have good systems to supply information. However, there is a breakdown of communication in the downstream supply chain. Most of the small machine shops do not have very good systems so they cannot provide the information to their customers on time (Foundry 1). Also Foundry 1 has different departments in the company operating their own software and they are isolated from each other. They are currently developing new software from which all departments can access the project data (Foundry 1).

Inaccurate Order Information

The build requirements for aircraft engines fluctuate very quickly and this information does not always filter down from their customers. There have been situations where Foundry 2 manufactured parts that have been effectively pushed back from their system before the requirements have been agreed. This is mainly because the large aerospace companies do not have enough personnel to deal with the production systems (Foundry 2).

Integration of Old and New Technology Knowledge/ Skills Shortage

A specific industry issue originates from dealing with very old and very new high technology for projects. The companies need to supply the products which were built 30-40 years ago as well as manufacturing for a latest technology. They need a workforce who knows today's technology and understands the old design, processes and materials. There is more integration needed between the new designers and the old workforce. The old workforce is generally not capable of CAD applications and the new generation is not capable of the core aerospace design skills (Foundry 2). There is a need for people who can understand the product and are capable of making right technical decisions. Many companies have lost several experienced people and have not been able to replace them (Foundry 1). Also, due to employee turnover during long project durations, in large companies like

Company D, it is difficult to establish and maintain a good understanding about the suppliers' work and issues (Shot-peening Sub-contractor).

Partnership Agreements

Partnership agreements provide guaranteed work for a certain amount of time. However, there may be influences which affect cost and, due to the agreement for the duration of the contract suppliers have to absorb any cost increases (Shot-peening Sub-contractor).

8.5.4.7 The Future Expectations of the Supply Chain Actors

Future Workload Information

The future workload information provided by the key players to the suppliers is defined as rarely accurate. Medium scale companies such as Company C are subjected to change very quickly so they are not able to provide this kind of information to them (Shot-peening Sub-contractor). They would expect more accurate knowledge on future workload from their client (Foundry 1).

Leaner Supply Chain

Over the last few years, there has been a tendency of companies to narrow down their list of suppliers. They benefit from working with fewer suppliers which decreases complexity in their chain. This, in turn, has increased the workload of their preferred suppliers which has improved the relationships and trust between them. In the future, they expect to have leaner supply chains (Foundry 1).

Establishing Partnerships and Maintaining Long Term Relationships

Establishing partnerships can improve relationships and efficiency in the supply chain. It is believed that parties are prepared to communicate in an open way and share more knowledge once a partnership has been established (Foundry 2).

More Collaboration between the Upstream and Downstream Supply Chain

The Shot-peening Sub-contractor would expect more collaboration and knowledge sharing from the upstream supply chain. They have benefited greatly from collaboration with Company D in the past, and they would expect this collaboration to be an industry culture. Working on the processes and products together on site, moving the technology forward as a team, sharing potential future business would give the suppliers confidence on their decisions for future investments (Shot-peening Sub-contractor)

8.5.5 Key Findings of the Company C 'Project Z' Case Study

This analysis revealed the following key findings of the Company C 'Project Z' Case Study:

- All of the interviewees were in the preferred supplier list of the client (Company C) and the suppliers also have long term relationships with their own suppliers.
- Collaborative decision making processes with their Client helped the suppliers to improve their processes and solve technical problems during the project.
- Knowledge dependencies were defined as clear for all the parties due to standardization of the processes.
- As every project in the aerospace industry, there was too much paperwork which slowed down delivery.
- The downstream supply chain members are aware of the industry wide supply chain events and activities. These activities are believed to improve knowledge sharing, and the quality of the processes and end products.
- The downstream supply chain members do not have good information systems in place to maintain on time knowledge sharing.
- To protect company knowledge suppliers need to make confidentiality agreements with their clients
- The build requirement fluctuate very quickly which cause waste in the industry, there is an inadequacy in the number of people assigned to control these systems in the upstream supply chain.
- The downstream supply chain also suffers from a skills shortage who can deal with old and new technology.
- The suppliers expect accurate future workload information; have leaner processes, establishing partnerships to share knowledge freely and more collaboration between their clients to improve their processes.

8.6 Company D Project-W

8.6.1 Project Overview

Project W was started in 1998 to redesign and replace the current reactor of the MOD. In this project, bidding is made at the end of each phase for the following phase instead of bidding before the start of the project. This is mainly because of the difficulty of figuring out the cost and deliverables for all phases of such a long and unique project. Because the company is the leader in its area, it was certain that Company D is the preferred bidder for the project. However, the high technology and the cost are the major challenges for Company D to convince their client.

8.6.2 Project Lifecycle

In this section, the knowledge produced in each phase and the supply chain issues related to each phase of the project are presented. Due to security reasons, the suppliers of the project could not be accessed and interviewed.

Conceptual Design Phase

The Conceptual Design Phase was a 2 year phase where Company D utilised a high level analysis of possible options for the system architecture required to meet the client's requirements. At the beginning of this phase, the MOD provided a very high level requirements list which consisted of 10 main requirements for the new reactor design. Company D broke down the requirements list in detail and figured out other possible requirements apart from those defined by the client. During this phase, Company D had no interaction with any other supplier and worked on the requirements analysis in house in collaboration with the client. Having a managerial level technical person from the MOD (Client) based in Company D and working closely with the Client from the beginning of the project provided clarity of the knowledge requirements of each party. This also improved the relationship with the client. At the end of this phase, Company D produced a high level requirements list for four system architecture alternatives, associated with cost and affordability.

Assessment Phase

The Assessment Phase is a 4 year phase during which Company D searched and evaluated the alternative suppliers who could work to deliver the majority of the detailed design. Company D contacted a hundred suppliers and conducted telephone interviews. As a result of these interviews, they reduced the suppliers from 100 to 20. In the following 6 months, Company D made supplier visits and reviewed the suppliers' technical capability, track record system, and financial stability. At the end of this stage, 3 large organisations were selected as design suppliers.

Although Company D establishes partnerships with their suppliers instead of competing, due to working on a very high technical project, they tested these three suppliers by a mini technical project. These three suppliers were given a task on one of their on-going projects which was the redesign of an electronic card. Their performance in terms of technical capability, documentation of the project, cost, programme, and collaborative working and financial stability were evaluated. These assessments were shared with the Client of the project, and a collaborative decision was made on one of the companies, Company X. Then, the 3-4 system architecture developed in house was provided to this company. Detailed specifications were checked collaboratively to limit the variations from the original system architecture developed. Company X had similar supplier selection criteria to Company D. Therefore, Company D left the selection of their suppliers to Company X. However, Company D made visits to the suppliers of Company X during the design phase to maintain control of the project. At the end one system architecture was decided upon by the collaborative work of Company C and Company X. The knowledge produced in this phase was the philosophy of detailed design of the selected system architecture, prototyping, testing, verification and validation. This knowledge was shared with the client, as a proposal which presents the deliverables of this phase and the demonstration of evidence of progress. The main highlights of this phase were:

- Due to having a systematic start with the design supplier, keeping the design simple, getting all specifications and configuration set up together with the supplier improved the accuracy of the design.
- Close relationships with the supplier prevented the supplier from varying from the original requirement list.
- Company C undertakes a lessons learned scheme for every project, and records the knowledge of design challenges, key issues during project lifecycle. This enables the company to learn from experience. Having such a scheme and keeping records of the technical issues helped them in dealing with technical problems during the design phase.

Design Phase

The Design Phase was a 4 year phase which was a huge challenge for the company. This was a significant project and resulted in new knowledge to the company. Because this was a redesign and rebuild project, all the old detailed designs were investigated in detail. Electronic Design Automation was utilized produced in this phase. The main highlights of this phase were:

- Recruiting people who could deal with new and old technology together was a huge challenge. The industry has a major problem in having qualified people who has the ability of understanding the old technology and implementing new technology in old designs.
- A high turnover of people in the firm was another challenge. The project lasts for a long duration, and people have a tendency to move internally when they find a suitable position. The turnover of people results in the turnover of this specialist knowledge, and this creates a huge problem especially in this phase.
- The major issue in this phase was achieving a design with a "Safety Case". A safety case was defined as the ability of the design to survive and if it fails, it fails safely. The partnership agreement made with Company X helped them to share the same values and same working principles thus working collaboratively for a safety case. This was the only way to succeed in such a sensitive challenge.
- The main conflict came from the legislation changes by the MOD; it was difficult to adjust the changes collaboratively with the supplier.
- It was also explained that the senior level generally works quite well, however because of the technical challenge and a high turnover of employees, it is difficult to manage the knowledge from a working level in this phase.

Manufacturing-Inspection-Demonstration Phase

The Manufacturing Phase is an on-going 4 years phase which started 2 years ago and will be completed in 2012. After the manufacturing phase all the related tests will be performed to identify any possible defects on the end product. Finally, it will be demonstrated to the Client.

8.6.3 Key Findings of the Company D 'Project W' Case Study

The summary of the key findings of the Company D 'Project W' are identified as follows:

- There had been collaborative work with the client on site from the beginning of the project. This helped them to understand the client requirements better and to provide better solutions to the client.
- Due to the systematic collaboration with the design supplier from the beginning of the project, the specifications and configuration set up could produced with high level of accuracy.
- The company benefited highly from partnerships with the design supplier, and the standard lessons learned practices which they apply to every project.
- The main challenge of the project was a high employee turnover within the organization, dealing with old and new technology, adjusting to legislation changes of the MOD, and managing the knowledge at the working level.

8.7 Chapter Summary

In this chapter, the summary of the company-specific and project-specific case studies in aerospace industry were presented. The summary of these case studies are presented as follows:

Company Specific Case Studies:

The company-specific case studies were held in four aerospace organizations. These case studies were based on the structured interviews with the supply chain managers of the organizations. The analysis presented the key findings on the overall SCM approach of the companies including their supply chain organization, supply chain priorities, supplier selection and evaluation criteria, maturity of supplier relationships, information and knowledge exchange tools used in their supply chains, key information and knowledge exchange issues, general SCM issues and future supply chain plans of the organizations.

The company based case studies revealed that aerospace organizations have industry wide standard SCM procedures. The supplier evaluation and assessment criteria are mainly based on performance, quality, delivery and cost and the main SCM priorities are based on reducing supply chain cost, reducing working capital, increasing quality, improving delivery, and increasing customer satisfaction. All of the companies interviewed have mature relationships with their suppliers. They improve SC relationships with industry wide SC development programmes which encourages the suppliers to use same metrics to evaluate the performance.

In the aerospace industry, due to long project durations; there is always a danger of losing knowledge and key skills. It is also difficult to identify the skills needed to adapt new and old technology during projects. Also, even in the large case study companies, information transfer databases were found to be poorly managed. These tools were not used consistently to share and keep the project knowledge during projects.

The aerospace industry has a very conservative culture. There is too much competition amongst employees, and a heavy blaming culture. Besides all these bottlenecks, the industry benefits from its well defined standard project processes and collaboration with the client and suppliers at the early stages of the projects. Early collaboration during the conceptual design and continuous collaboration during detailed design phases were defined as the main basis for innovation.

Globalisation challenged the aerospace companies significantly. Recent outsourcing efforts make the SC more fragmented, making it difficult to manage. The aerospace firms had to cope with barriers such as culture, language, usage of different systems, standards and quality issues, difficulty to understand the financial stability of the global suppliers and different time zones. However, these challenges caused improvements in the aerospace supply chains such as better planning, implementation of lean approach, decreasing stock, improving the processes, decreasing the number of suppliers and the number of the employees dealing with the suppliers.

Summary of Project Specific Case Studies:

Following the company specific case study analysis, the outcome of the two project-specific case studies were presented. The project-specific case studies were based on semi-structured interviews with the project managers and set of structured interviews with the project SC actors. These two analysis presented the overall project information, knowledge resources of the supply chain actors, highlights on the general project issues, information and knowledge methods used in the project, key KM issues, and future expectations of the SC actors. The key findings of each case study were provided at the end of each case study analysis. The case studies revealed that there is standard SCM procedures applied in the upstream aerospace SCs, however the downstream SCs are still in need of development. The downstream supply chains are in need of good information systems for on time knowledge sharing, skilled people who can deal with old and new technology, and reduced employee turnover. Apart from these challenges, there are several the key learning points identified for construction supply chains as follows:

- Long term collaborative relationships helps the SC actors to share their knowledge easily;
- Confidentiality agreements, and partnerships can improve knowledge sharing in the supply chain;
- Early and systematic collaboration and effective knowledge sharing between the client and the SC actors improves the identification of supplier specifications and configuration setup, and brings innovation;
- Early collaboration and effective knowledge sharing with the client improves the understanding of client requirements;
- Standardization and visibility of the project processes help the firms to clarify the knowledge dependencies between SC actors easily;
- Implementation of the lean approach, increased repeatability in design, and standardization of the processes reduces production time and improves project delivery;
- The standard lessons learned practices which are applied to every project can help the SC actors to learn from each other;
- Industry-wide events, trainings, SCM programmes significantly diminish skill deficiencies and improve collaborative relationships;
- Standardised SCM process creates robust SCs.

CHAPTER 9

9 KNOWLEDGE CHAIN FRAMEWORK

9.1 Introduction

This chapter describes the framework developed to enable construction bid managers/project managers plan and manage the project knowledge flow in the supply chain. The literature review and case study analysis chapters provided the background for identification of the key purpose and functions of the framework. The purpose of the framework, the key tasks of the research which provided this background are presented in detail. The output of each task is used to define the main needs of the knowledge chain framework. These needs are linked with the literature review and case studies. The framework addresses these key needs phase by phase in a PFI type project as an example for projects which have integrated (collaborative) procurement route. The framework involves the representation of key tasks, interactions between each supply chain actor, and the information flow during each phase focusing on design.

9.2 The Purpose Of The Framework

The main purpose of the 'knowledge chain framework' is to enable construction bid managers/project managers plan and manage the project knowledge flow in the supply chain and organise activities, meetings and tasks to improve SCM and KM throughout the supply chain in a PFI type project life cycle. The knowledge chain framework is intended to depict the knowledge flow in the construction supply chain specifically, and to offer guidance for specific business processes to transform the supply chains into knowledge chains. The framework will be used by the bid managers and project managers in particular because they plan and manage the whole integrated project delivery from the early beginning to the end. This framework can be used as a practical guide for the systematic and standard implementation of a contractor's supply chain activities to improve the project knowledge flow in the supply chain. It can also assist the contractors in two ways; to inform and encourage the SC actors about the collaborative interactions which have to exist between the SC actors; and the content, type and format of the information and knowledge that needs to flow between these actors. In summary, this framework provides an understanding of how and when information and knowledge is transmitted between supply chain actors, and the main activities needed to be implemented into the business process to improve the effectiveness and efficiency of the information and knowledge flow.

9.3 Background For The Framework

Some tasks of this research provided the information needed to develop the knowledge chain framework. These tasks are defined as follows:

- Investigating the literature on construction and other industry supply chain issues with a focus on their effect on knowledge flow in construction (presented in Chapter Two and Chapter Three)
- investigating the knowledge chain research (presented in Chapter Four);
- identifying each phase of a PFI type project and the supply chain actors which take place in these phases (identified through the case studies, presented in Chapter Six, and Chapter Seven);
- identifying the information and knowledge requirements of key supply chain actors in each phase of a project (identified through the case studies, presented in Appendix E and Appendix F);
- identifying the information and knowledge created by key supply chain actors in each phase of a project (identified through the case studies, presented in Appendix E and Appendix F);
- identifying the information and knowledge dependencies between supply chain actors (identified through the case studies as presented in Chapter Six, Chapter Seven, Appendix E, Appendix F);
- analysing knowledge flows between supply chain actors (presented in Chapter Six, Chapter Seven);
- identifying the main supply chain issues which has direct or indirect effect on the efficiency and effectiveness of the knowledge flow and the creation of knowledge chains (presented in Chapter Six, Chapter Seven and Chapter Eight);
- identifying the necessary tasks which can improve the knowledge flow between supply chain actors and transform the supply chains into knowledge chains (presented in Chapter Six, Chapter Seven and Chapter Eight).

The output of each task is used to define the main needs of the knowledge chain framework. These needs are presented in the following section.

9.4 Needs For The Framework

The literature review and the case studies revealed the key issues which need to be improved in the construction industry such as inadequate experience to adapt and organise for integrated procurement type projects, inadequate SCM integration, a lack of risk sharing partnering, inadequate trust between SC actors, skill deficiencies, inadequate collaboration between the downstream and upstream supply chain, inadequate coordination, lack of interoperability of the design tools, lack of well structured SCM process and lack of well developed KM applications. All these issues negatively affect the knowledge flow process amongst supply chain actors. To improve as an industry, construction industry can learn from automotive and aerospace supply chains in many aspects such as establishing long term SC relationships, early and systematic collaboration and effective knowledge sharing between the client and the SC actors, increased repeatability in design, standardization and visibility of the SC processes, usage of standard lessons learned procedures to learn collaboratively with SC actors and implementation of lean SC practices. Based on these findings, the key issues which needs to be addressed in the framework are identified as follows:

- **Integration of Construction Supply Chain:** The case studies and literature review revealed that there is a need for better integration between supply chain actors with a focus on upstream and downstream SC collaboration in the construction industry. As revealed by the aerospace case studies, the aerospace industry benefits from the factors such as timely engagement of SC actors to the projects, sharing information on future workload with the suppliers, integration of design team with sub-contractors and suppliers, organising relaxed forums, workshops for relationship improvement and knowledge sharing and improving collaboration between the Client and SC actors from the early stages of the projects. These issues are also critical in particular for the integrated procurement type projects where the supply chain actors need to collaborate from the beginning of the project. In the framework, these practices are addressed by planning the collaboration and communication practices between the SC actors from the early beginning. These include providing strategic and operational project briefing on time to the SC actors in collaborative meetings, collaboratively reviewing the scope of service of each SC actor, responsibilities, deliverables, schedule of delivery, the content and schedule of trainings, and the special activities for supplier development and integration.

- **Improved information and knowledge sharing:** There should be more focus on knowledge sharing in the construction supply chain. The input from the design team and specialist consultants in the preparation of supplier and sub-contractor specifications is essential. To improve the information and knowledge sharing between SC actors, the construction industry can benefit from the practices in aerospace industry such as early collaboration with the Client for clear understanding of the client requirements, timely collaboration with the suppliers to identify the knowledge deficiencies of the SC actors, and organising workshops/events to encourage collaborative knowledge sharing. The construction industry needs to provide better clarifications on the knowledge dependencies between SC actors, learn from past projects collaboratively and use this knowledge in the future projects. In the framework, these practices are addressed by planning the KM process within the SC from the early beginning of the project. These include planning of the meetings to assign the people who will be in charge of knowledge sharing process, identification and planning of knowledge sharing mechanisms and IT capabilities expected from the suppliers, identification of the knowledge dependencies of each SC actor in collaborative meetings, providing strategic and operational briefing timely to the SC actors, identification of BIM Strategy for suppliers and effective usage of lessons learned knowledge in each project.

- **The need for structured design and construction process:** As revealed in the literature review and case studies, there is a need for structured and coordinated design and construction process. Construction industry can benefit from the aerospace industries' practices such as the standard and well-known project phases, high visibility of the processes and increased repeatability in design. The construction industry can benefit from factors such as identifying opportunities for offsite and BIM early in the project, better project planning and timely communication of the plans, better design coordination, and usage of real time collaboration tools. In the framework, these practices are addressed by planning for the implementation and effective usage of collaboration tools during design process and on construction site, timely communication of these plans with the SC actors, identification of the BIM and offsite construction opportunities to increase repeatability in design, implementation of standard KM and SCM procedures for improved visibility of the processes, and communicating the plans on time to the relevant SC actors for better coordination.

- **Standardisation of Knowledge Management:** Construction organizations need to implement standard set of KM procedures and tools in their projects. These procedures should be identified in line with the overall company strategy. The procedures should cover standardisation of formats, forms, tools and transfer channels to create and share project knowledge, implementation of ICT tools with associated trainings available to the SC actors, and maintaining the inter-operability of design tools. The procedures should also address the identification of KM unit/people who is in charge of knowledge management, planning of trainings where the SC actors has skill deficiencies, getting the benefit of lessons learned in future projects, and implementation of mechanisms to encourage collaborative knowledge sharing. These issues are addressed through implementation of certain procedures and workshops to standardise the KM process in the framework.

- **Standardisation of Supply Chain Management:** Construction organizations need to implement standard set of SCM procedures in their organizations. These procedures should be identified in line with the overall company strategy. As revealed by the literature review and case studies, the construction industry need to implement certain procedures including the application of consistent supplier selection and evaluation criteria, implementation of development programmes/trainings for the SC actors, usage of supplier performance records in new projects, standard and timely engagement of SC actors to the projects, and getting feedback from the design team and specialist consultants for supplier selection and evaluation. As discussed in Chapter 8, the aerospace industry benefited highly from these standard SCM practices to create long term, lean and sustainable SCs. In the framework, these issues are addressed through implementation of certain procedures and workshops to standardise the SCM process considering all the critical factors identified in the case studies.

- **Need for long term, trust based, mature SC relationships:** One of the key learning from aerospace and automotive supply chains for construction is the establishment for long term, trust based, mature relationships in the SC. As discussed in the literature and case studies, construction supply chains need to change the arm-length relationships and cost oriented approach in SC arrangements. Instead construction supply chain can benefit from past collaborative relationships to improve knowledge sharing, establishing a culture based on trust and collaboration, benefiting from agreements and partnerships to improve confidentiality between SC actors. The procedures in the framework presents a guidance for timely engagement and collaboration of SC actors, highlights the feedback mechanisms of supplier selection and evaluation process, communication of future work plans and SC strategy, organisation of events to improve relationships and the application of the confidentiality and partnership agreements. Apart from this, in the framework, there are certain procedures identified to understand the supplier needs and requirements collaboratively with the SC actor. All of these factors are important elements for the creation of long term, trust based relationships. The consistent application of the procedures in the framework will improve the relationships and increase trust between SC actors.

The needs discussed above are presented in detail in Appendix H, Table 1. The second column of the Table 1 shows the high level needs for the framework. These needs are detailed further in the third column of Table 1. Each of these needs aims to enable the collaborative knowledge creation, sharing and diffusion throughout the supply chain in a construction project life cycle. The sections of the thesis which provides evidence for these detailed needs are presented in the fourth column of Table 1. Finally in the fifth column, the IDEF0 notation of the process in the 'knowledge chain framework' which will address these needs are presented.

9.5 Key Underlying Principles Of The Framework

The 'knowledge chain' framework looks at mapping the business processes that provides clear information and knowledge flow, and suggest ways to reduce or eliminate the key supply chain issues with a focus on knowledge flow.

There are two main levels in the framework. The first level of the framework shows the business processes which have direct and indirect impact on improving the effectiveness of the knowledge flow between the supply chain actors and improving the integration of the supply chain actors. These business processes are identified inline with the main needs for the framework and address these needs specifically (See Table 9.1). The business processes involve specific tasks, meetings, and workshops. The content of each business activity is explained in detail in Section 9.6. The activities presented in the framework feed the Function Management Activities and Knowledge Conversion process of a knowledge chain (KC) as explained in Chapter Three. Knowledge Conversion process is fed by all processes which has direct effect to the effective knowledge flow in the supply chain. These activities address the knowledge discovery, knowledge acquisition and selection internalisation, knowledge generalisation and externalisation of knowledge in the supply chain. Function management activities are fed by the activities which has indirect effect to the knowledge flow. The business processes identified in this framework aims to improve the efficiency and effectiveness of knowledge flow and the integration of the SC actors. The processes which feeds the knowledge chain activities are presented in Table 9-1. The activities presented in Table 9-1 are described in detail in Section 9.6.

Table 9-1 Business Processes which feeds the Knowledge Chain Activities

KNOWLEDGE CONVERSION ACTIVITIES	FUNCTION MANAGEMENT ACTIVITIES
Functional Briefing Workshop (A1-7) Information and Knowledge Dependencies Workshops (A1-9) (A2-4) (A3-2) Project Process Flow Workshop (A1-11) Client Clarifications Workshops (A2-1) Design Coordination Workshop Buildability and Constructability Workshop (A2-5) Design Construction Compatibility Workshop (A3-5) Lessons Learned Workshop A3-7)	Knowledge Management Strategy Identification Meeting (A1-4) Strategic Supply Chain Meeting (A1-5) Strategic Briefing Workshop (A1-6) Supply Chain Organization Workshop (A1-8) Project Information Management Workshop (A1-10) Sub-Contractor Supplier Packages Workshop (A2-3) Supplier Performance Evaluation Workshop (A3-6)

Information and knowledge flow and the business process are inseparable (Poh and Wee, 2004). The second level of the framework focuses on the information flow from the supply chain actors to the main design processes. An integrated supply chain is only possible if there is a common understanding of how this information flows (Wadhwa and Saxena, 2005). To achieve this common understanding, the framework shows the entities (supply chain actors) that provide information and knowledge to the main design tasks. It also presents the content of the information produced by each supply chain actor to the specific design process.

In the framework, IDEF0 notation is selected in particular because it presents a high level of simplicity, a good level of formalism, and provides a well standardised modelling tool to represent the business processes and the knowledge flow (See Section 5.6.4 for further details). This formalism allows the business processes and the knowledge flow to be easily transmitted to different kinds of supply chain actors in a SC. In the next section the knowledge chain framework is presented.

9.6 Knowledge Chain Framework

Figure 9-1 presents the project phases of a PFI type (integrated procurement) project, the SC actors who worked for each phase and the RIBA Design stages achieved in each phase of the project. The Knowledge Chain framework presents the key business activities to transform the construction supply chains to knowledge chains in four main phases of a project life cycle. The details specific to the project life cycle are identified through the case studies held in two large scale contractor's projects. There are four important phases for a PFI type project. These are feasibility and bidding phase, contract close phase, construction phase and operation phase. The RIBA stages which are completed in each phase are shown in the framework.

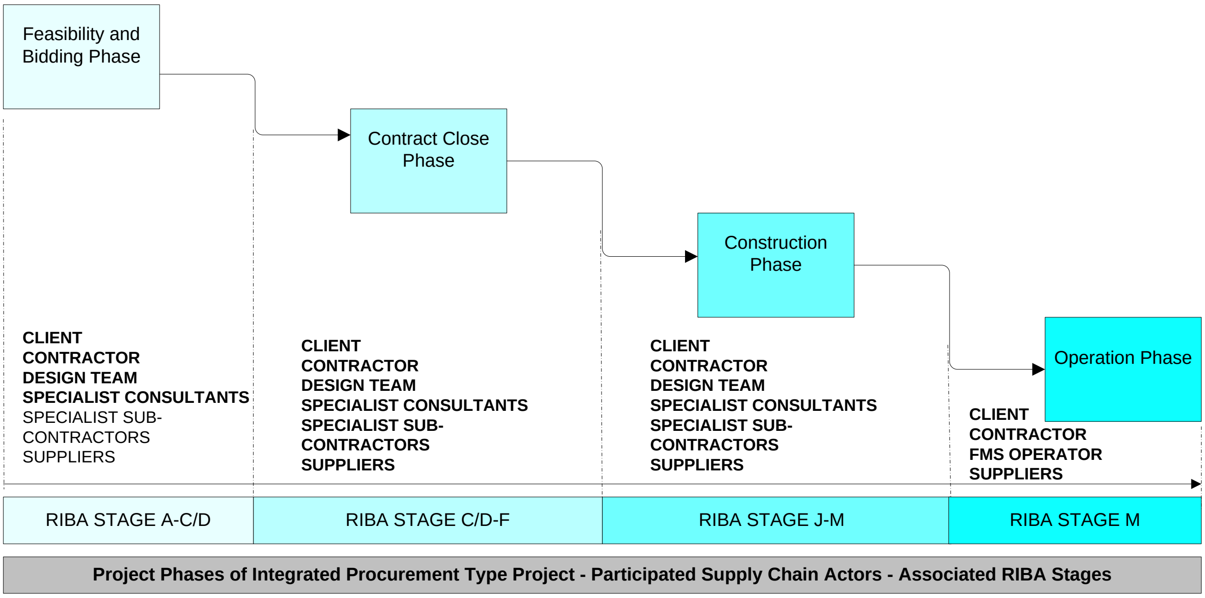

Figure 9-1 Project Phases of an Integrated Procurement Type Project

In the framework the tasks which needs to be delivered in each phase is shown in IDEF0 diagrams. Node index showing overview the diagrams presented as follows:

A0 Plan to Create Knowledge Chain in a PFI Type Project
- A1 Plan for Feasibility and Bidding Phase
  - A11 Review Strategic Business Case
  - A12 Prepare Prequalification Questionnaire
  - A13 Review ITN Package
  - A14 Organise Knowledge management Strategy Meeting
  - A15 Organise Strategic Supply Chain Meeting
  - A16 Organise Strategic Briefing Workshop
  - A17 Organise Operational Briefing Workshop
  - A18 Organise Supply Chain Organisation Workshop
  - A19 Organise Information and Knowledge Dependencies Workshop
  - A110 Organise Project Information Management Workshop
  - A111 Organise Project Process Review Workshop
  - A112 Design
    - A1121 Structural Design
    - A1122 Architectural Design
    - A1123 M&E Design

A113 Submit Final Bidding Documents

A2 Plan for Contract Close Phase

A21 Organise Client Clarifications Workshop

A212 Design

A2121 Structural Design

A2122 Architectural Design

A2123 M&E Design

A23 Organise Sub-Contractor and Supplier Packages Workshop

A24 Organise Information and Knowledge Dependencies and BIM Workshop

A25 Organise Design Coordination Workshop

A26 Organise Buildability and Constructability Workshop

A27 Organise Authority Requirements Meeting

A28 Make Financial Close

A3 Plan for Construction Phase

A31 Mobilise Site

A32 Organise Information and Knowledge Dependencies and BIM Workshop

A33 Issue Coordinated BIM Model and Construction Drawings

A34 Start Construction

A35 Organise Design Construction Compatibility Workshop

A36 Organise Supplier Performance Evaluation Workshop

A37 Organise Lessons Learned Workshop

A38 Handover

A4 Plan for Operational Phase

A4-1 Review Post Occupancy

A4-2 Update BIM for Facility Management

A4-3 Review and Update Operational Plan

A4-4 Report Operational Issues through Life Cycle of the Building

Figure 9-2 presents the top level IDEF0 context diagram which provides the description of the knowledge chain framework. The boxes represent each major function of the knowledge chain framework. These functions are decomposed into more detailed diagrams which show that planning for the knowledge chain framework should be done in each phase of the project as presented in Figure 9-3. These diagrams are followed by a series of child diagrams providing more detail about the steps which should be taken by the project/bid managers in the following figures.

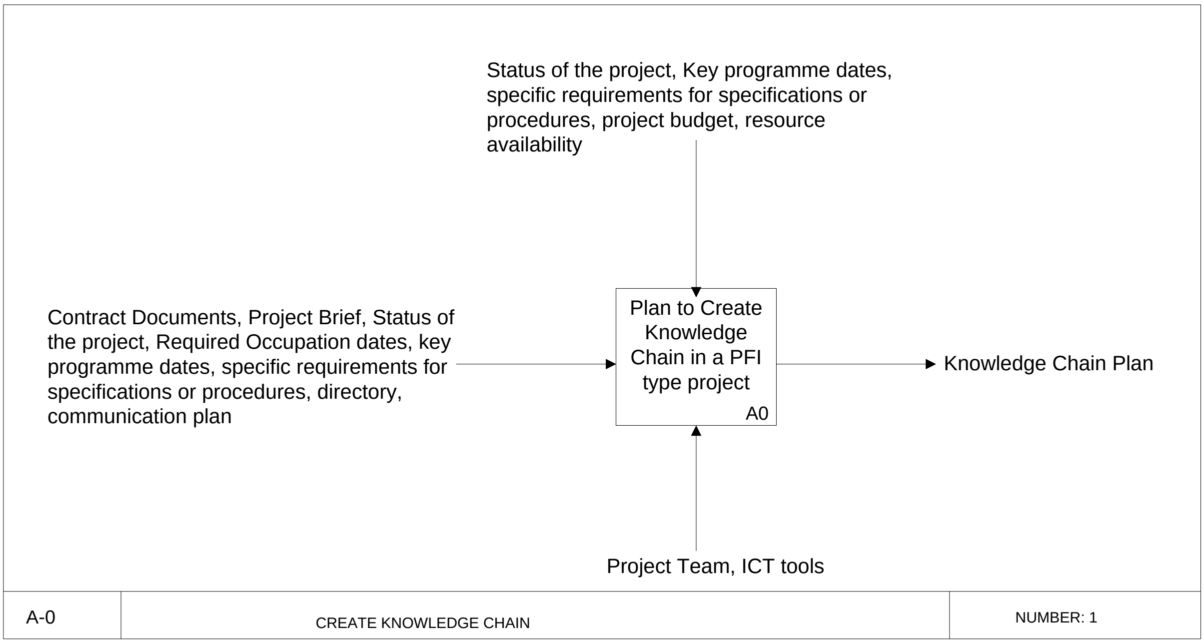

Figure 9-2 'A0 Create Knowledge Chain' Top Level IDEF0 Diagram

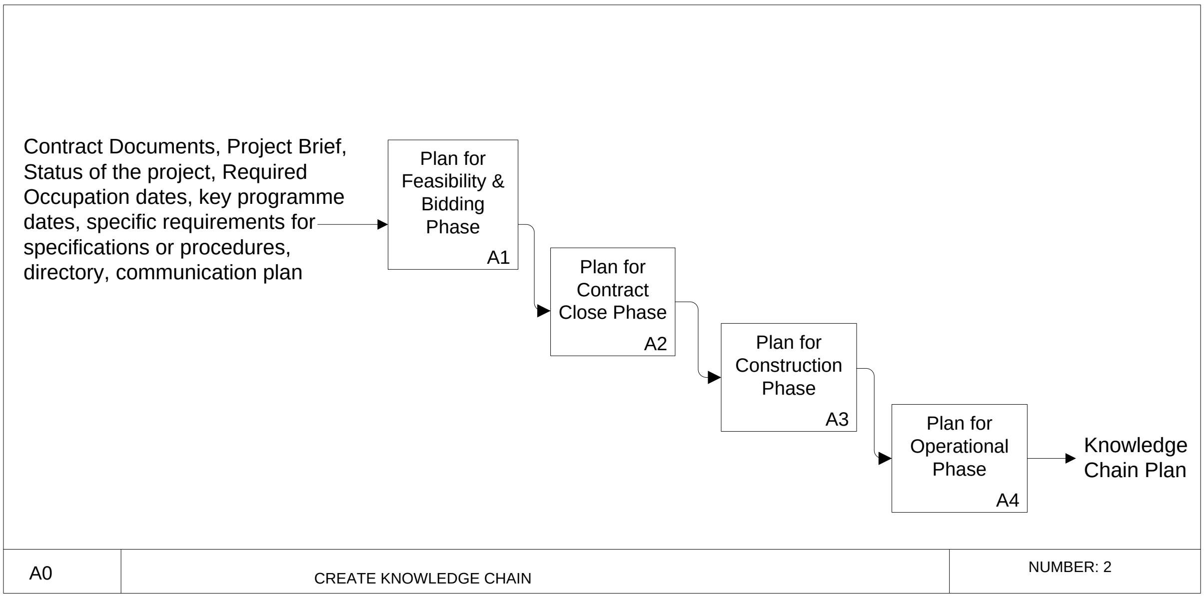

Figure 9-3 'A0 Create Knowledge Chain' Top Level IDEF0 Diagram showing the child diagrams

As presented in Figure 9-1, the first phase in the project is the Feasibility and Bidding phase. Table 9-2 presents the availability of the interactions between SC actors during the Feasibility and Bidding Stage in a matrix form. All project actors which take place in this phase, and the project actors which they interact with are shown in the matrix. Following the

Table 9-2, Figure 9-4 which maps the main activities that are required to be undertaken to achieve the main objectives of the framework is presented. The activities presented in the figure are identified based on the main needs of the construction supply chain and the current business processes in the industry. Following the framework, the detailed explanation for each task is presented.

Table 9-2 Interactions between Project Actors in Feasibility and Bidding Phase

PROJECT ACTORS	Client	End-User	Contractor	Facility Specialist	Architect	Landscape Architect	M&E Consultant	Structural Designer	Fire Consultant	Acoustic Consultant	Surveyor	ICT Supplier	Furniture Supplier	FM Sub-Contractor	Sustainability Consultant	Building Control Specialist	Other Suppliers
Client		√	√	√	√												
End-User	√		√	√	√												
Contractor	√	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√
Facility Specialist	√	√	√		√	√	√					√	√	√			
Architect	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√	√
Landscape Architect			√	√	√		√		√					√	√		√
M&E Consultant			√	√	√	√		√	√	√		√	√		√	√	√
Structural Designer			√		√		√		√		√				√	√	√
Fire Consultant			√		√	√	√	√		√						√	
Acoustic Consultant			√		√		√		√								
Surveyor			√		√			√									
ICT Supplier			√	√	√		√										
Furniture Supplier			√	√	√		√					√					
FM Sub-Contractor			√	√	√	√											
Sustainability Consultant			√		√	√	√	√									
Building Control Specialist			√		√		√	√	√								
Other Suppliers			√		√	√	√	√									

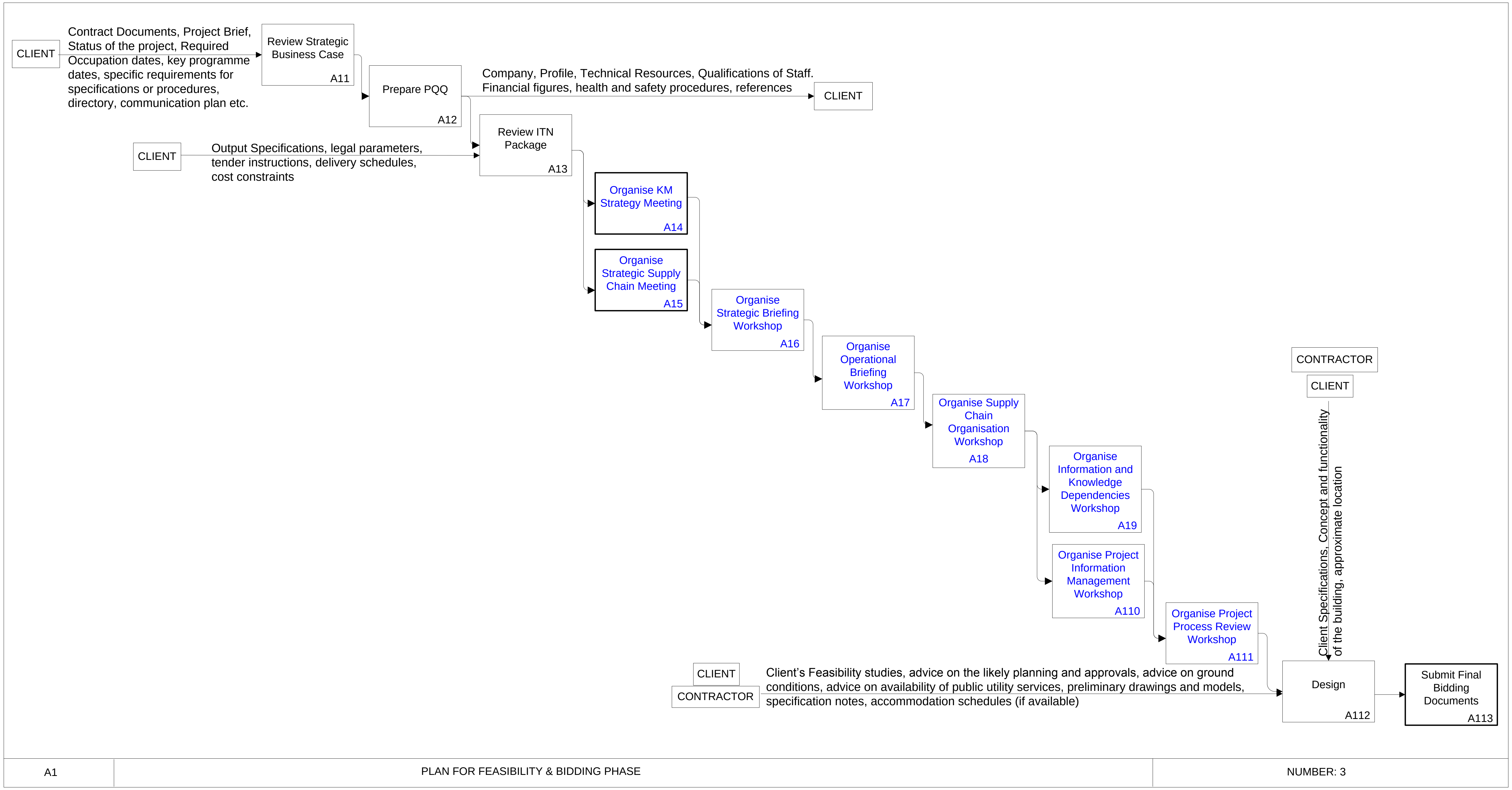

Figure 9-4 Feasibility and Bidding Phase

The Strategic Business Case Review (A11), Prequalification Questionnaire Preparation (PQQ) preparation (A12) and Review of Invitation To Negotiate (ITN) Package A(13) are the generic tasks which are delivered during the projects (See Section 6.6.1.1 for further details). There is a series of new tasks which starts following the review of ITN Package. These tasks are suggested as a standard way of organising the SCM and KM activities to be able to overcome the issues identified in the case studies. The content of each task is explained as follows:

A11 Review Strategic Business Case: Review of the Business Case where the Client set the specifications for the facility, the option appraisal and the chosen procurement route.

A12 Prepare Prequalification Questionnaire: Preparation and submission of the information on the company profile, technical and financial capabilities and references.

A13 Review ITN Package: Review of the ITN documents which involves information on client specifications, legal parameters, description of services, supplies and works, instructions for bidding submissions, delivery schedule etc.

A14 Organise Knowledge Management Strategy Meeting (Internal Meeting): The main objectives of this workshop are:

- assignment of the people who will be in charge of knowledge sharing process;
- planning of the meetings to identify and agree on the knowledge requirements of each SC actor;
- identification and planning of knowledge sharing mechanisms and selection of likely activities (relaxed forums, supply chain events, workshops and social networks) to encourage knowledge sharing;
- identification of IT capabilities expected from the suppliers;
- identification of the information exchange and storage platform and planning the trainings for the identified suppliers, identification of BIM Strategy for suppliers.

Attendees: Contractor’s Bid Manager, Project Manager, Design Manager, Supply Chain Manager and Knowledge/Collaboration manager.

A15 Organise Strategic Supply Chain Meeting (Internal Meeting): The main objectives of this workshop are:

- establishing the expectations from the supply chain in line with the company strategy,
- identification of likely supplier package requirements and interface constraints,
- review of supply chain selection process,
- identification of potential preferred suppliers (Designers, Specialist Consultants, Specialist Sub-Contractors, Material Suppliers) and products,
- identification of special arrangements or agreements for long term collaborative relationships.
- discussion on the potential Design for Manufacturing and Assembly (DfMA)/off-site construction opportunities, lean opportunities, sustainability, innovation encouragement and planning for these.

Attendees: Contractor's Bid Manager, Project Manager, Design Manager, Supply Chain Manager And Knowledge/Collaboration Manager.

A16 Organise Strategic Briefing Workshop: The main aim of this workshop is to gain interdisciplinary understanding of the project scope, procurement strategy, performance criteria and design strategies to be employed by suppliers, lean design and construction strategies, sustainability standards, design standardisation and potential repeatability in design.

Attendees: Contractor's Bid Manager, Project Manager, Design Manager, Supply Chain Manager, Design Team, Specialist Consultants, Collaboration/Knowledge Manager

A17 Organise Operational Briefing Workshop: The main aim of this workshop is review and validate the Client Specifications with the Design Team and the Client. This may involve:

- the discussions and validations on the project aim and objectives,
- identifying operational requirements, environmental and quality standards and performance expectations of the client and the end user,
- introduction of the collaboration platform, programme, milestones,
- scheduling preliminary meetings and workshops,
- reviewing the lessons learned from the previous same type projects and identifying the constraints, priorities and risks.

Attendees: Client, Contractor’s Bid Manager, Project Manager, Design Manager, Design Team, Specialist Consultants, Collaboration/Knowledge Manager.

A18 Organise Supply Chain Organisation Workshop: This workshop aims to collaboratively review the selection criteria of the potential supply chain actors with the Design Team and Specialist Consultants. The scope of service of each supply chain actor, responsibilities, deliverables, and schedule of delivery should be identified. The content and schedule of trainings, and the special activities for supplier development and integration should be planned.
Attendees: Contractor’s Bid Manager, Project Manager, Design Manager, Commercial Manager, Supply Chain Manager, Design Team and Specialist Consultants

A19 Organise Information and Knowledge Dependencies Workshop: The main aim of this workshop is to identify and agree the information and knowledge requirements of SC actors, the interdependencies between the SC actors, and arrange mechanisms for the control of the flow of design in Feasibility & Bidding Phase. The information type, content and format should be agreed. The scope of the design and type of the drawings (design, planning, bidding, fabrication, installation or FM) which will be undertaken by the specialist Sub-Contractors or Suppliers should be agreed. The Designers’ work and Sub-contractors’/Suppliers’ responsibilities should be clarified to prevent duplication or gaps. The work packages schedule and content should be agreed. BIM Protocols should be produced.
Attendees: Contractor’s Bid Manager, Project Manager, Design Manager, Design Team, Specialist Consultants, Collaboration/Knowledge Manager, Sub-contractors, suppliers

A110 Organise Project Information Management Workshop: The main aim of this workshop is to review and agree on the collaborative communication tool, design tools, information and knowledge sharing methods including obtaining information, recording information, reporting, storing, preparation and submission procedures of reports, review and approval procedures. The trainings needs for the use of the ICT tools should be identified. Supplier BIM Compatibility and 3D model capability should be reviewed. Supply Chain BIM involvement should be agreed. BIM Protocols should be detailed and issued.
Attendees: Contractor’s Bid Manager, Project Manager, Design Manager, Design Team, Specialist Consultants, Collaboration/Knowledge Manager, Sub-contractors, and Suppliers

A111 Organise Project Process Review Workshop: This workshop involves review of design tasks, information flow and dependencies, design-supply chain-manufacturing-construction interfaces, key activities, milestones and schedule.

Attendees: Contractor's Project Manager, Design Manager, Design Team, Specialist Consultants, Collaboration/Knowledge Manager, Sub-contractors, suppliers

These workshops are followed by the design process in A112. The design process are divided in to three key schemes as shown in A1121 (structural design), A1122 (architectural design) and A1123 (M&E Design). At the end of the phase, the bidding is submitted to the Client as presented in A113.

Figure 9-5, Figure 9-6, Figure 9-7 presents the information and knowledge flow in key design processes (architectural design, structural design, and M&E design) of the feasibility and bidding phase. The diagram presents the input (information and knowledge) from each supply chain actor, and the output from each supply chain actor, constraints of the process and the tools and mechanisms which can be used for each design activity. Although the content of the knowledge is more applicable to building projects, it has the flexibility to be adapted to any type of project.

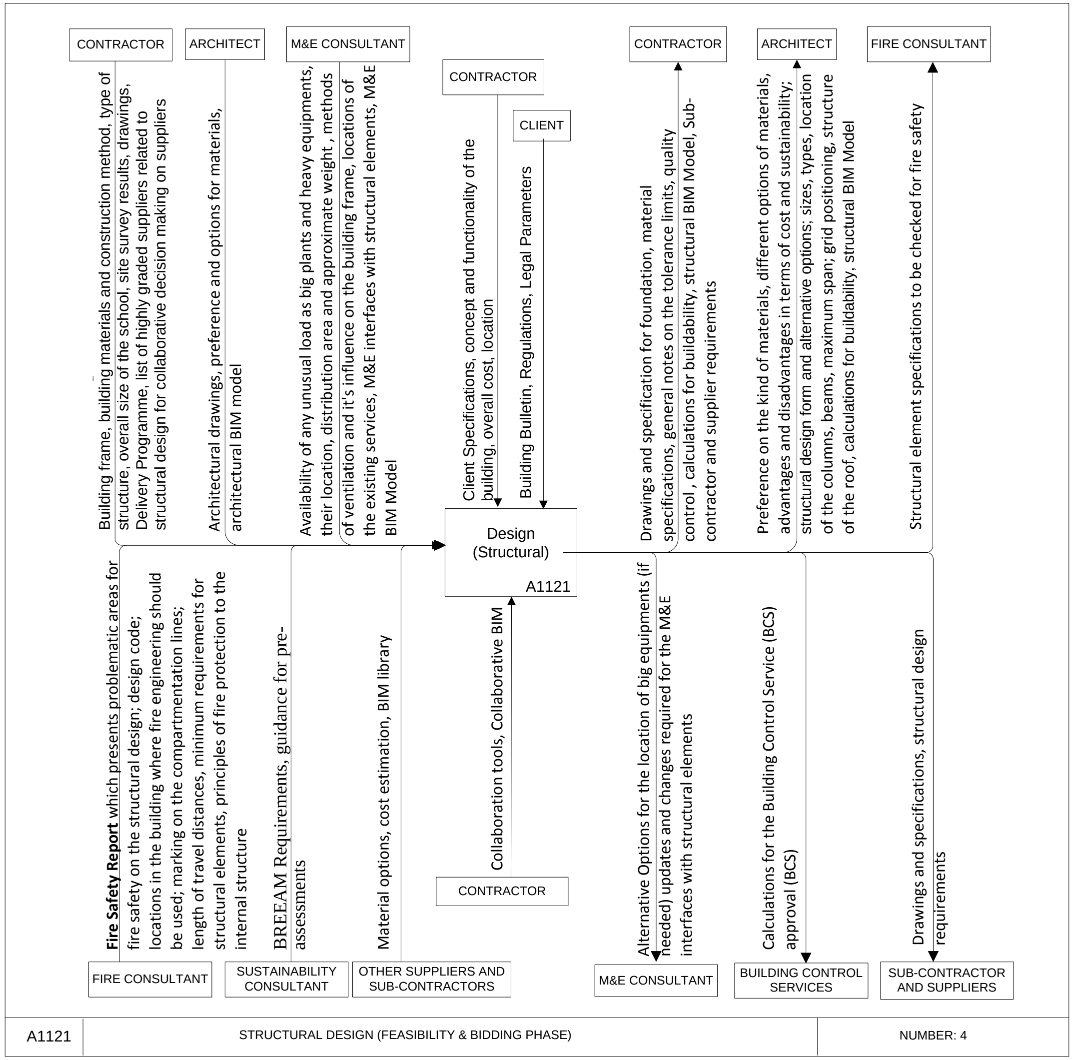

Figure 9-5 Structural Design-Feasibility and Bidding Phase

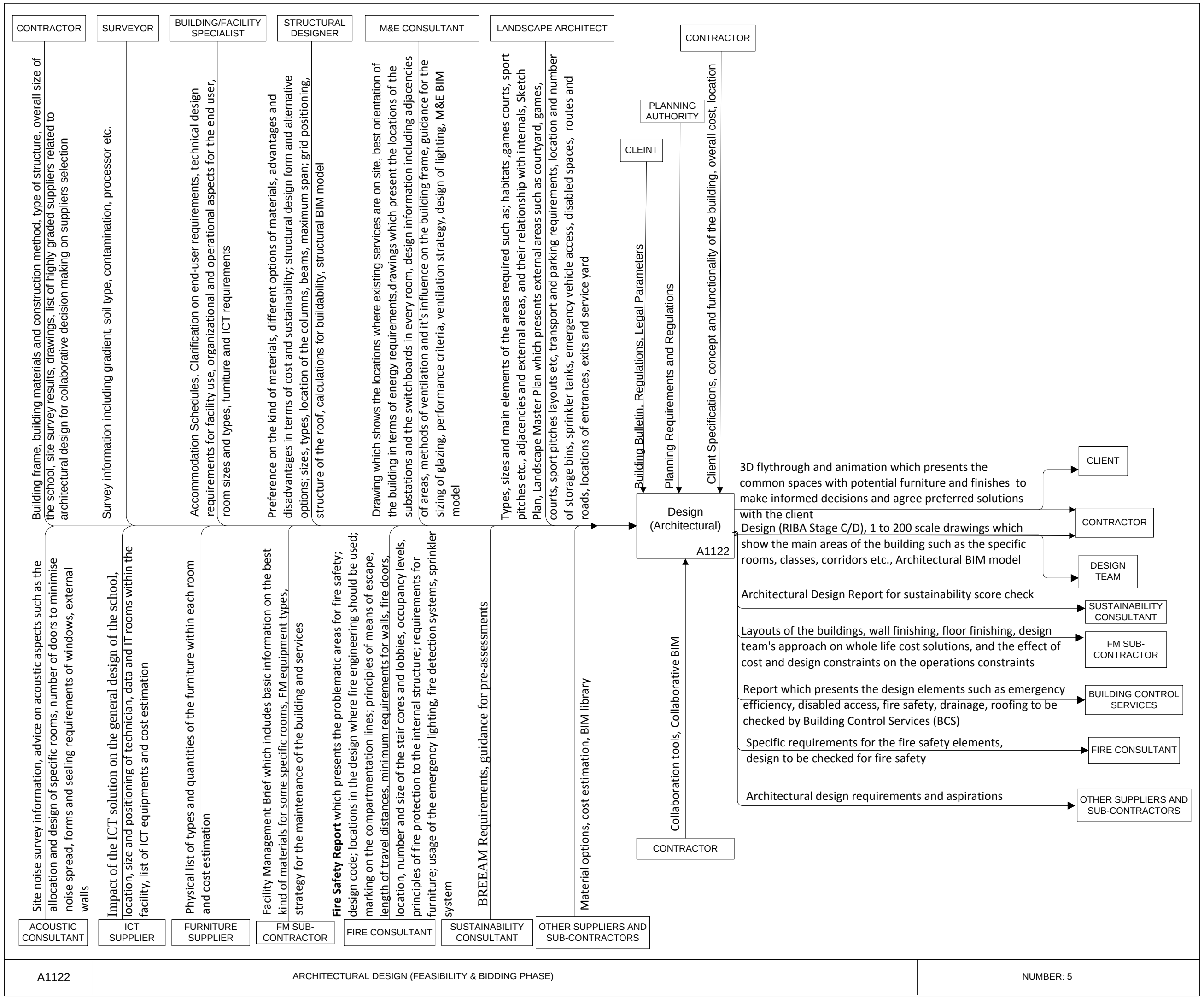

Figure 9-6 Architectural Design-Feasibility and Bidding Phase

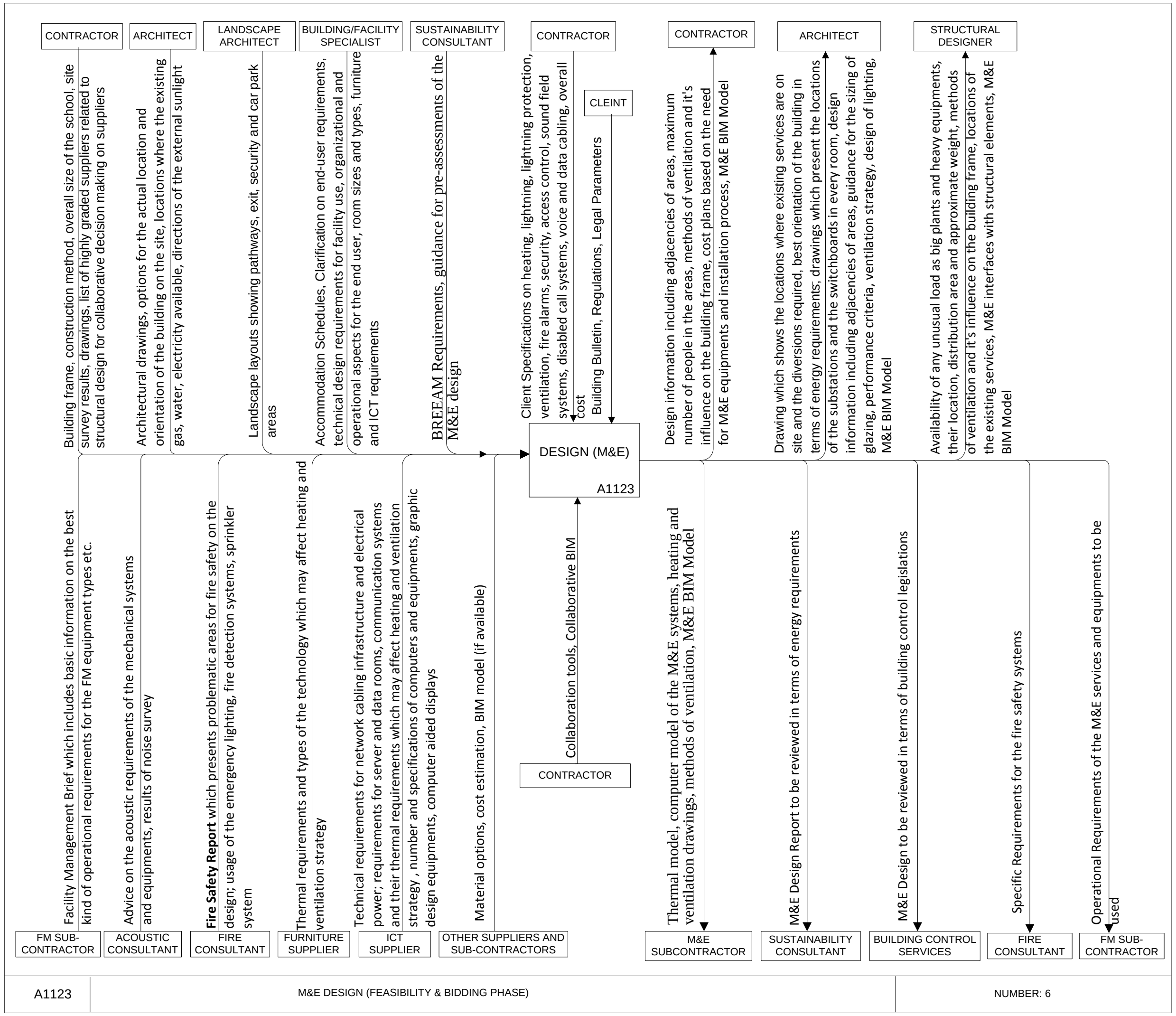

Figure 9-7 M&E Design- Feasibility and Bidding Phase

Contract Close phase follows the Feasibility And Bidding phase as presented in Figure 9-3. Table 9-3 presents the availability of the interactions between SC actors during the Contract Close phase in a matrix form. All project actors which take place in this phase, and the project actors which they interact with are shown in the matrix. Following the Table 9-3, Figure 9-8 which maps the main activities that are required to be undertaken to achieve the main objectives of the framework in the contract close is presented. The activities presented in the figure are identified based on the main needs of the construction supply chain and the current business processes in the industry. Following the framework, the detailed explanation for each task is presented.

Table 9-3 Interactions between Project Actors in Contract Close Phase

	Client	End User	Contractor	Facility Specialist	Architect	Landscape Architect	M&E Consultant	Structural Designer	Fire Consultant	Acoustic Consultant	ICT Supplier	Furniture Supplier	FM Sub-Contractor	Sustainability Consultant	Building Control Services	Other Suppliers
Client		√	√		√									√		
End User	√		√		√											√
Contractor	√	√		√	√	√	√	√	√			√		√		
Facility Specialist	√	√	√		√											
Architect	√		√	√		√	√	√	√	√	√	√		√	√	√
Landscape Architect			√		√									√		√
M&E Consultant			√		√			√	√	√	√	√		√	√	√
Structural Designer			√		√		√		√					√	√	√
Fire Consultant			√		√		√	√								
Acoustic Consultant					√		√							√		
ICT Supplier					√		√									
Furniture Supplier			√		√		√									
FM Sub-Contractor			√		√		√									
Sustainability Consultant	√		√		√	√	√	√		√						
Building Control Services					√		√	√								
Other Suppliers			√		√	√	√	√								

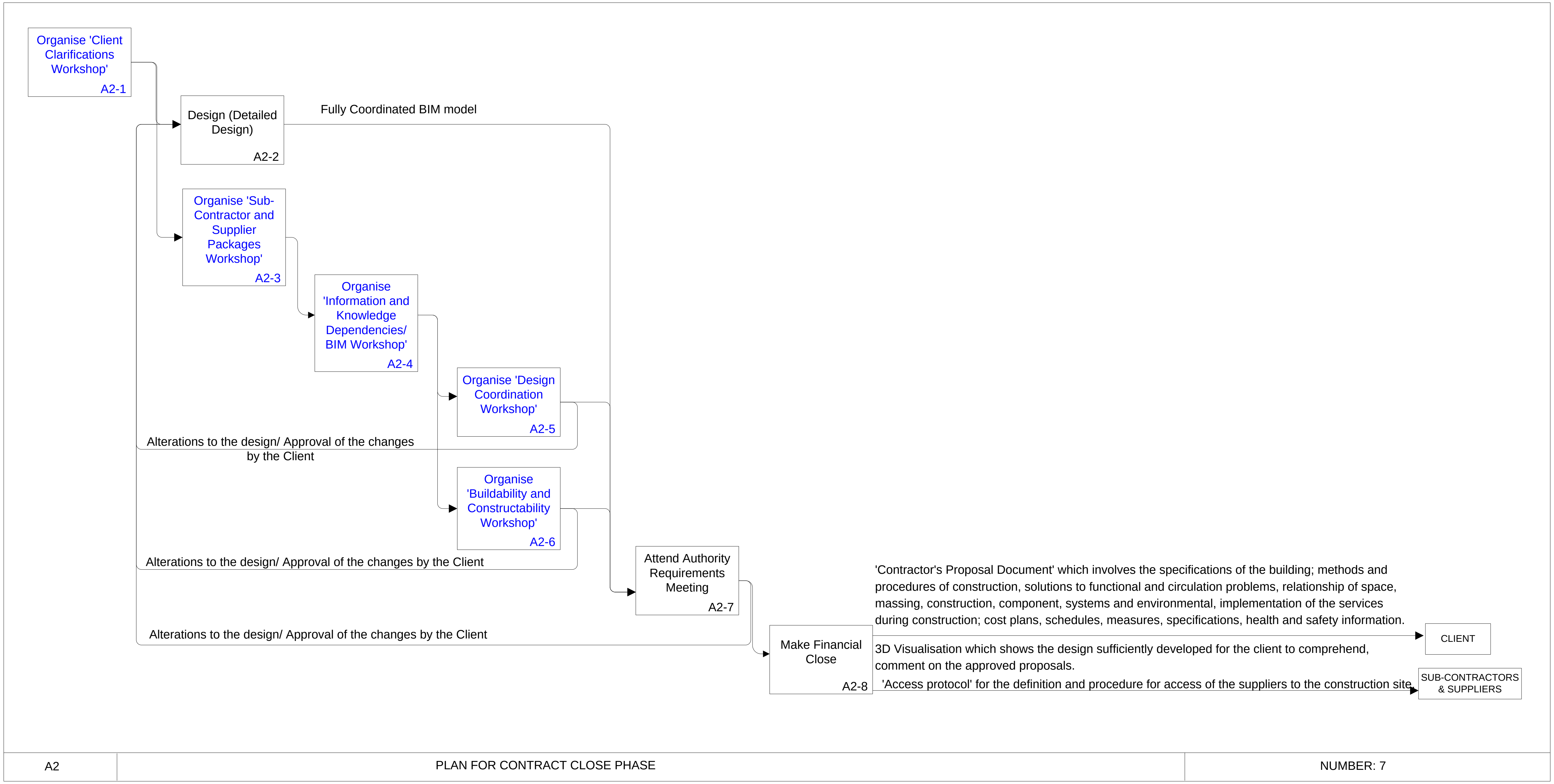

Figure 9-8 Contract Close Phase

As presented in Figure 9-8, the Contract Close phase starts with the Client Clarifications Workshop (A2-1) to clarify the client's view on the design which was delivered at the end of the feasibility and bidding phase. This is followed by the Design Process which will be presented in detail in the next section. During the Contract Close phase, the content of the workshops presented in Figure 9-8 are explained in detail as follows:

A21 Organise Client Clarifications Workshop: The main aim of this workshop is to clarify the design changes required by the Client and make collaborative decisions on these changes with the Client and the Design Team to be able to allocate them on time within the budget. The Client should be advised about any proposals to introduce innovative design or construction ideas or new methods and materials. All these changes should be confirmed with the Client to agree preferred design elements collaboratively and freeze the design. The outcome of the workshop should be shared through the collaboration tool with the supply chain actors.
Attendees: Client, Contractor Bid Manager, Project Manager, Design Manager, Design Team, Specialist Consultants

A23 Organise Sub-Contractor and Supplier Packages Workshop: This workshop aims to identify and develop 2nd Tier Supplier requirements and specifications collaboratively with the Design Team and Special Consultants. These include key interface details for strategic supplier elements, the overall supply chain scope and responsibilities during the Contract Close phase. Individual packages should be examined considering the interfaces, production information, specifications, installation method, building method, site logistics and delivery. The implications of Specialist Consultant proposals on the supplier requirements should be discussed. The decisions should be agreed and transferred to the related supply chain actors through project's collaboration tool following the meeting.
Attendees: Contractor Bid Manager, Project Manager, Design Manager, Supply Chain Manager, Design Team, Specialist Consultants, Sub-contractor and Suppliers

A24 Organise Information and Knowledge Dependencies and BIM Workshop: The main aim of this workshop is to review the issues related to the creation of supplier information in the past phases, to identify and agree on the information and knowledge requirements of SC actors, the interdependencies between the SC actors, and knowledge sharing mechanisms for the control of the flow of design in Contract Close phase. The information type, content, and format should be agreed. The scope of the design and type of the drawings (design, fabrication, installation or FM) which will be undertaken by the specialist Sub-Contractors or Suppliers should be agreed collaboratively with the Design Team. The Designers' work and Sub-contractors'/Suppliers' responsibilities should be clarified to prevent duplication or gaps. 3D CAD Model engagement of suppliers should be encouraged and agreed.

Attendees: Contractor Project Manager, Design Manager, Design Team, Specialist Consultants, Sub-contractor and suppliers, Collaboration/Knowledge/BIM Manager

A25 Organise Design Coordination Workshop: This workshop aims to fully coordinate and integrate Consultants, Suppliers and Specialist Sub-Contractors final production/installation details and drawings in the BIM model. This will avoid clashes, inconsistencies, conflicts and overlaps. The key coordination issues should be clarified. The project can highly benefit from intelligent tools which updates all files (room data sheets, schedules, specifications) automatically when the BIM model changes. The outcome of the workshop should be shared through the collaboration tool with the supply chain actors.

Attendees: Contractor Project Manager, Design Manager, BIM Manager, Design Team**,** Specialist Consultants, Sub-contractor and Suppliers.

A26 Organise Buildability and Constructability Workshop: This workshop aims to review the construction methods and buildability to address key construction and design issues, develop site mobilisation plans, delivery and logistics strategy, and identify any changes which would improve production or installation techniques and durations. The outcome of the workshop should be shared through the collaboration tool with the supply chain actors.

Attendees: Contractor Project Manager, Construction Manager, Design Manager, Design Team**,** Sub-contractor and Suppliers

A27 Organise Authority Requirements Meeting: The Client Requirements and Contactor's Proposals are reviewed and agreed before the financial close.

Attendees: Client, Contractor Project Manager, Bid Manager, Design Manager, Design Team

A28 Make Financial Close: Project is financially closed and the contract which describes the deliverables, cost, schedule, methods and procedures of the delivery is signed.

The design process are detailed further to key design schemes in A221 (structural design), A122 (architectural design) and A123 (M&E Design). Figure 9-9, Figure 9-10, Figure 9-11 presents the information and knowledge flow in key design processes (architectural design, structural design, and M&E design) of the Contract Close phase. The diagram presents the input (information and knowledge) from each supply chain actor, and the output from each supply chain actor, constraints of the process and the tools and mechanisms which can be used for each design activity. Although the content of the knowledge is more applicable to building projects, it has the flexibility to be adapted to any type of project.

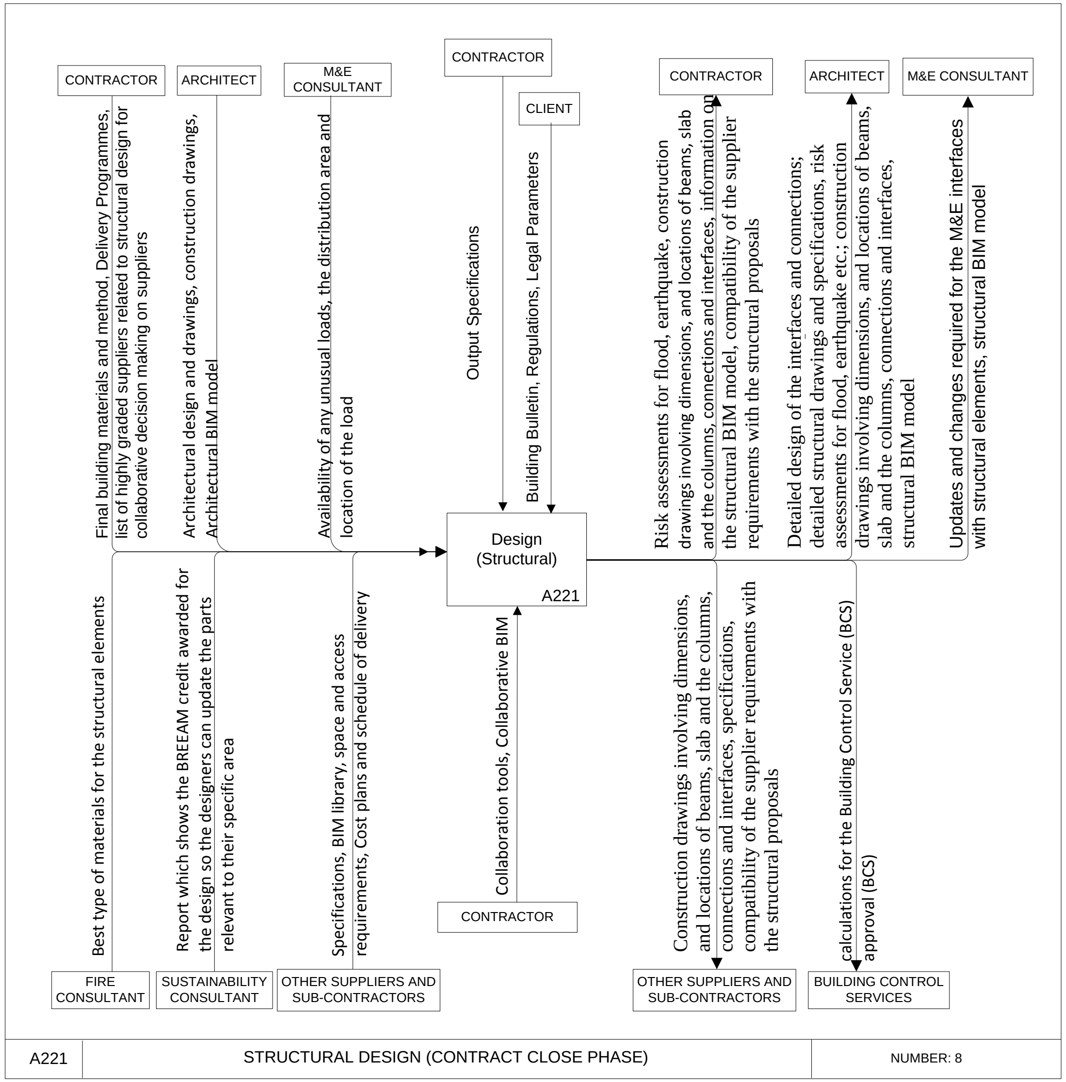

Figure 9-9 Structural Design- Contract Close Phase

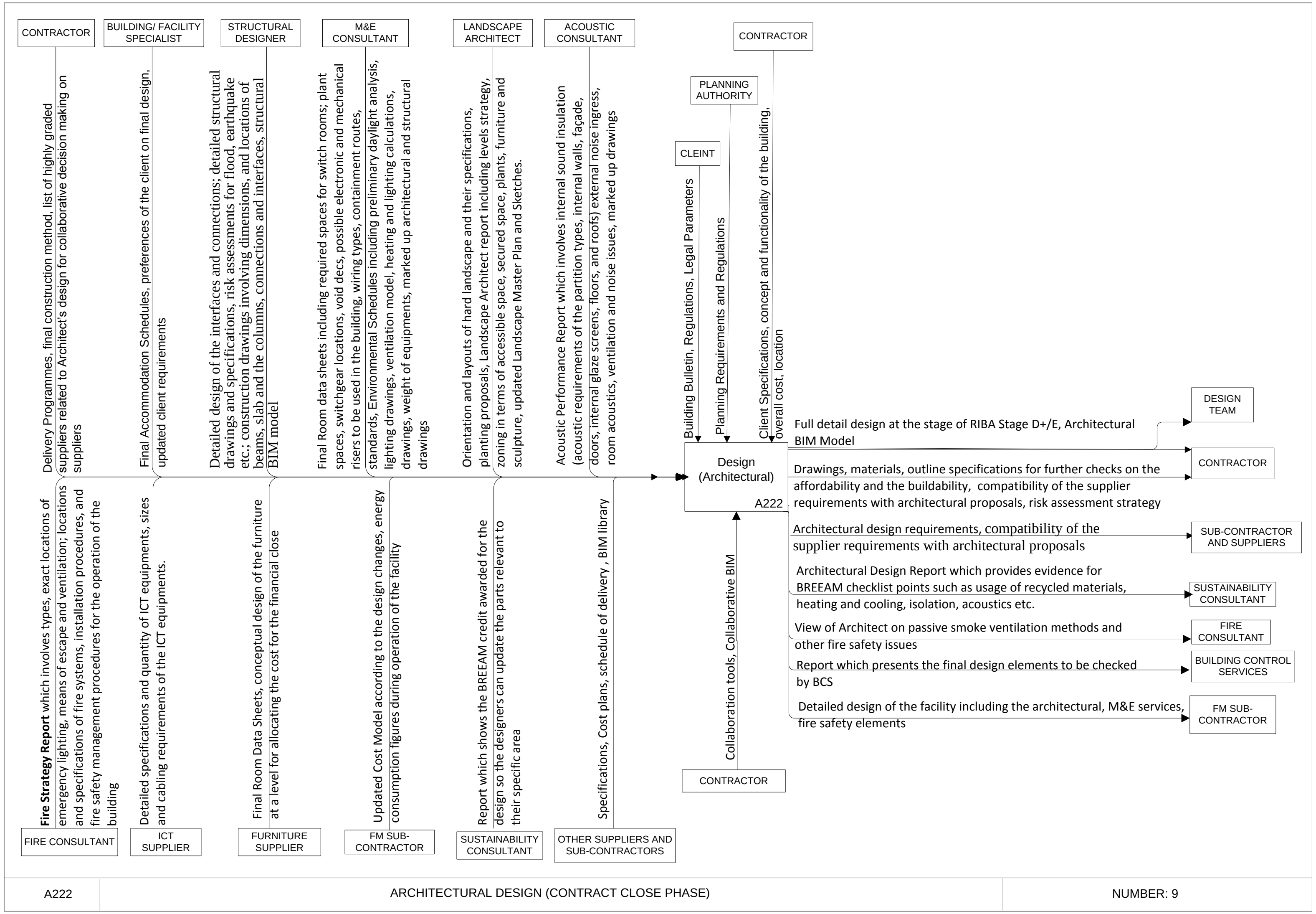

Figure 9-10 Architectural Design-Contract Close

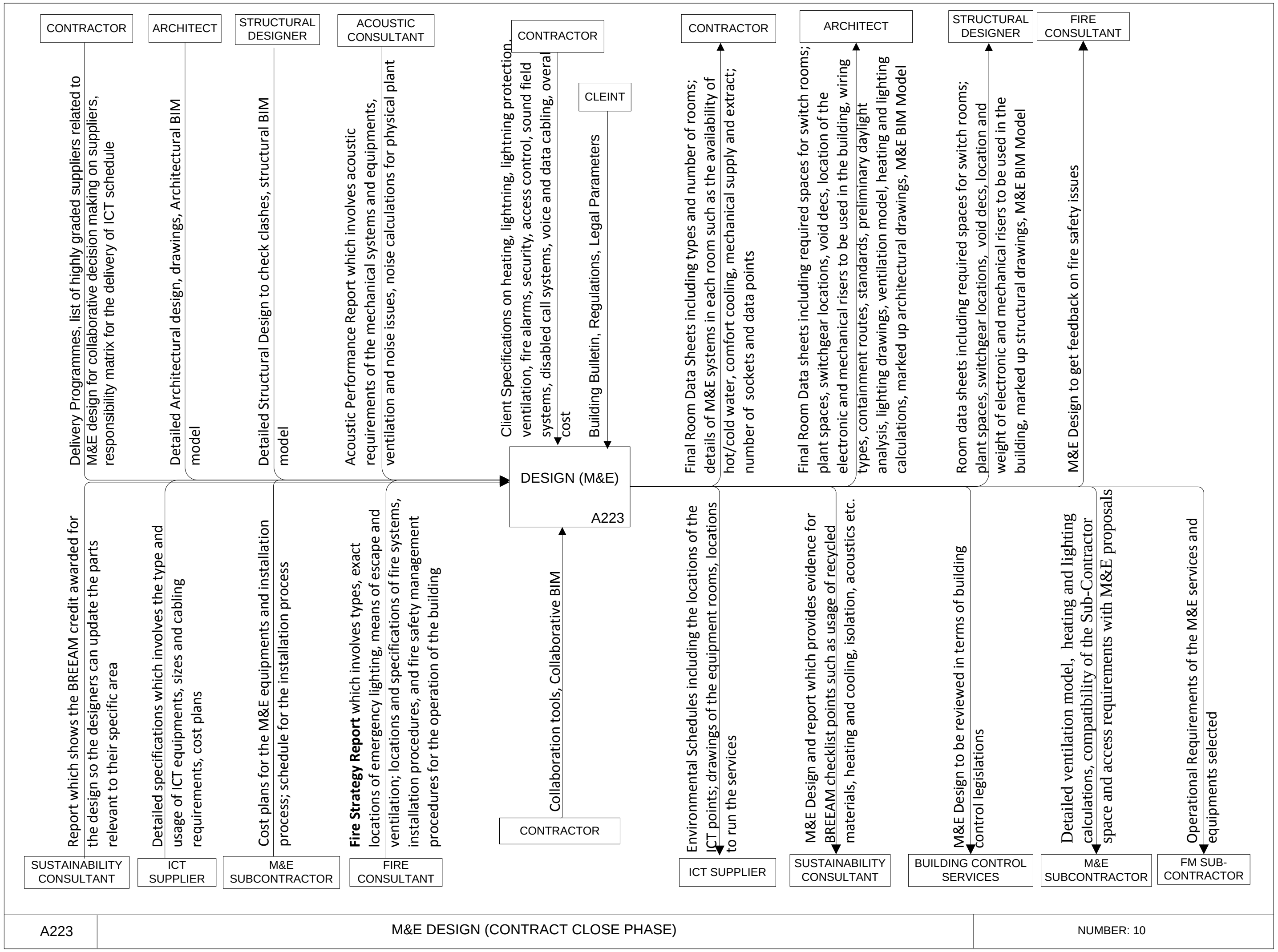

Figure 9-11 M&E Design-Contract Close

As presented in Figure 9-3, the next phase after the contract close phase is the construction phase. Table 9-4 presents the availability of the interactions between SC actors during the Construction phase in a matrix form. All project actors which take place in this phase, and the project actors which they interact with are shown in the matrix. Following the Table 9-4, Figure 9-12 which maps the main activities that are required to be undertaken to achieve the main objectives of the framework in the Construction phase is presented. The activities presented in the figure are identified based on the main needs of the construction supply chain and the current business processes in the industry. Following the framework, the detailed explanation for each task is presented.

Table 9-4 Interactions between Project Actors in Construction Phase

	Client	Contractor	Design Team	Fire Consultant	Acoustic Consultant	ICT Supplier	Furniture Supplier	FM Sub-Contractor	Building Control	Sustainability Consultant	Other Suppliers
Client										√	
Contractor			√			√	√	√	√	√	√
Design Team		√		√	√		√	√		√	√
Fire Consultant			√								√
Acoustic Consultant			√								
ICT Supplier		√									
Furniture Supplier		√	√								
FM Sub-Contractor		√	√								√
Sustainability Consultant	√	√	√								
Building Control S.		√									
Other Suppliers		√	√	√				√			

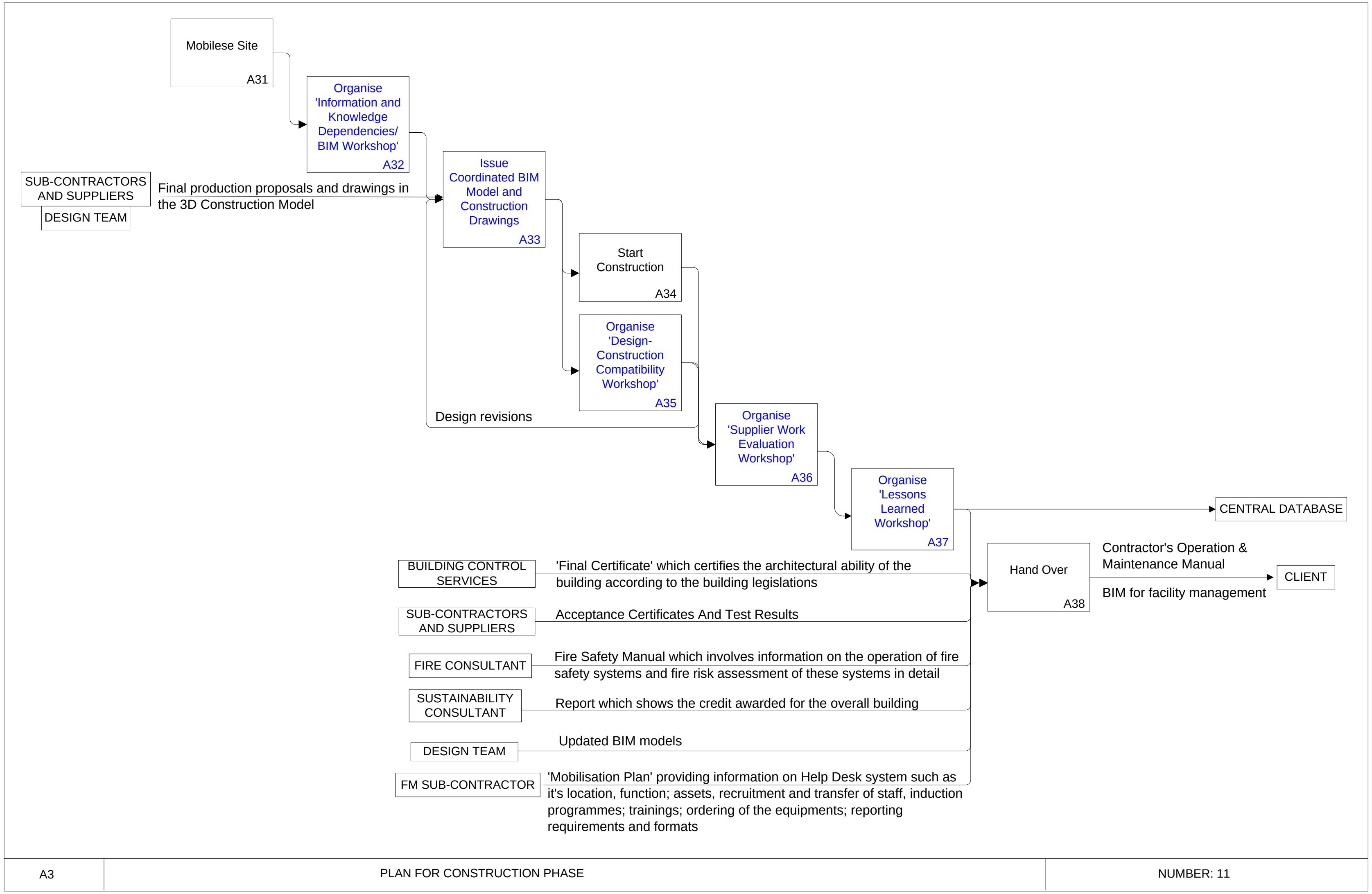

Figure 9-12 Construction Phase

As presented in Figure 9-12, the Construction Phase starts with the contractor's site mobilisation process (A31 Mobilise Site) which involves set up of the general plant, storage areas, office and other facilities required by the contract and regulations. During the phase, the following workshops are suggested to address the needs of the framework:

A32 Organise Information and Knowledge Dependencies and BIM Workshop: The main aim of this workshop is to review the issues related to the creation of supplier information in the past phases, to identify and agree on the information and knowledge requirements of SC actors, and knowledge sharing mechanisms for the control of the flow of design in Construction Phase. The scope of services and the information and knowledge dependencies between the Designers, Subcontractors and Suppliers should be clarified to avoid duplications and gaps. The content, format and delivery schedule of production drawings, builders work and Installation Drawings should be agreed. The Supply Chain 3D BIM Model handover responsibilities should be identified.
Attendees: Contractor's Project Manager, Construction Manager, Design Manager, Collaboration/Knowledge/BIM Manager, Design Team, Sub-contractors and Suppliers

A33 Issue Coordinated BIM Model and Construction Drawings: The aim of this process is to review and agree on the coordinated production information and fabrication details with the Design Team, Suppliers and Specialist Sub-Contractors, agree on the full and final details, schedule and specifications.
Attendees: Contractor Project Manager, Construction/Site Manager, Design Manager, BIM Manager, Design Team, Suppliers, Subcontractors

A34 Start Construction: The construction phase starts.

A35 Organise Design Construction Compatibility Workshop: The aim of this workshop is to review design versus actual production and installation on construction site. The construction methodology and buildability should be reviewed and necessary changes considering the associated technical and commercial constraints should be agreed. The changes should be reflected to the coordinated BIM model. All these changes should be reported to the Client for approval.

Attendees: Contractor Project Manager, Construction/Site Manager, Design Manager, Design Team

A36 Organise Supplier Performance Evaluation Workshop: The aim of this workshop is to discuss on the results of the Contractor's standard supplier performance evaluation at the end of the project. The discussion should cover the areas such as performance, quality, on time delivery, cost, availability of lean approach and innovative techniques, willingness to collaborate and knowledge sharing, relationships. The main issues and reasons which lowered the performance of the suppliers and the Contractor, and the processes which improved the performance of the Contractor/suppliers should be discussed. The requirements of the suppliers and the Contractor for future projects should be discussed. The actions which can improve both the performance of Contractor and the suppliers should be identified. Besides performance, actions should be identified to improve the knowledge sharing, relationship, cultural and leadership commitment capabilities of the suppliers. Using the result of this workshop, the supplier performance expectations and criteria with the needs of Contractor should be aligned.
Attendees: Contractor Project Manager, Construction/Site Manager, Design Manager, Design Team, Specialist Consultants

A37 Organise Lessons Learned Workshop: The aim of this workshop is to capture what did or didn't go well on the project, how to replicate success, and what to do differently in the future. The workshop should be organised within a week at the end of a project to ensure the feedback of the supply chain actors isn't lost as team members may move to the next project.
Attendees: Contractor Project Manager, Construction Manager, Design Manager, Design Team, Specialist Consultants, Supplier and Sub-contractors

A38 Handover: The final preparations for the submission of the Contractor's Operation & Maintenance Manual and BIM model for facility management.

The Construction phase is completed at the end of the hand over process. The next phase presented in the framework is the operational phase.

As presented in Figure 9-3, the next phase after the construction phase is the Operational phase. Table 9-5 presents the availability of the interactions between SC actors during the Operational phase in a matrix form. All project actors which take place in this phase, and the project actors which they interact with are shown in the matrix. Following the Table 9-5, Figure 9-13 which maps the main activities that are required to be undertaken to achieve the main objectives of the framework in the Construction phase is presented. The activities presented in the figure are identified based on the main needs of the construction supply chain and the current business processes in the industry. Following the framework, the detailed explanation for each task is presented.

Table 9-5 Interactions between Project Actors in Operational Phase

	End-User	Client	Contractor	Facility Specialist	FM Sub-Contractor	Design Team
End-User		√	√		√	
Client	√		√	√	√	
Contractor	√	√		√	√	√
Facility Specialist	√	√	√			
FM Sub-Contractor	√	√	√			√
Design Team			√		√	

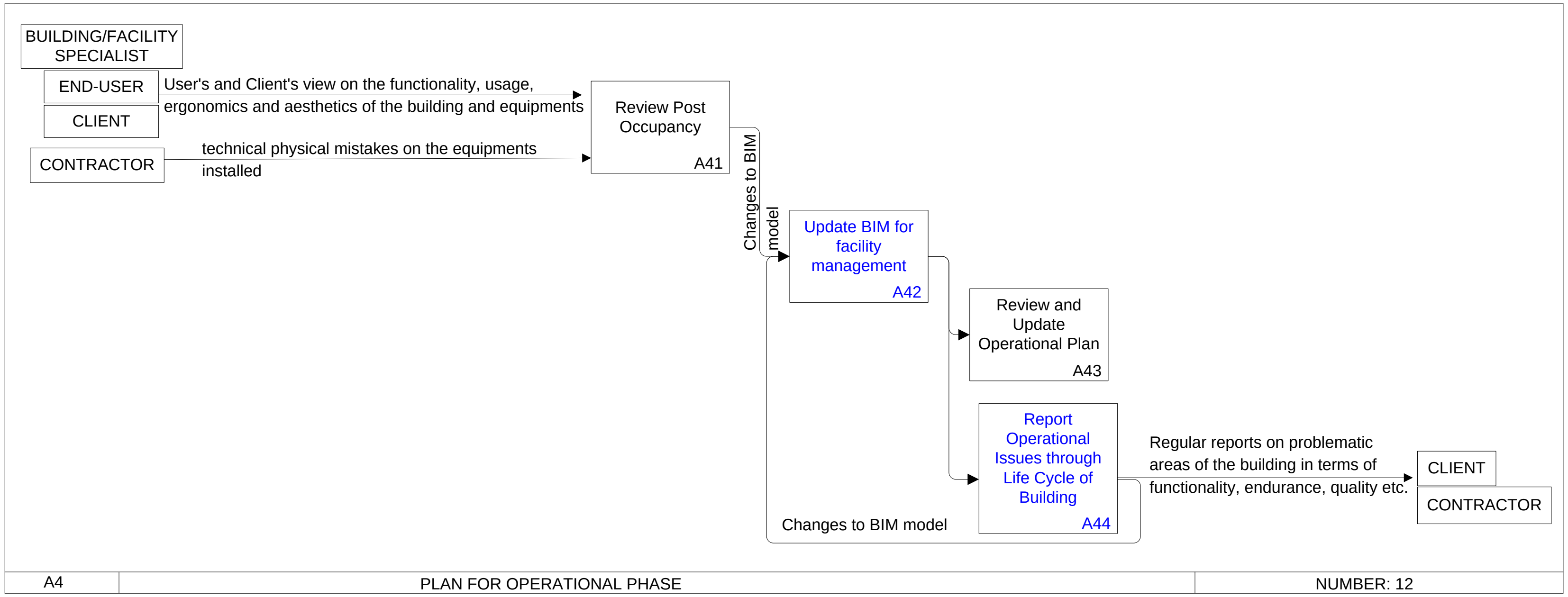

Figure 9-13 Operational Phase

Figure 9-13 presents the Operational Phase and the main tasks which are required to be undertaken to achieve the main objectives of the framework. During the Operational Phase, the following procedures should be followed to contribute to creation of the 'Knowledge Chain'.

A4-1 Review Post Occupancy: The client's and end-user's view on the building and the technical mistakes on the equipments installed are reviewed.
Attendees: Client, FM Sub-contractor, End-user, Contractor, Facility Specialist

A4-2 Update BIM for Facility Management: Update of BIM for Facility Management aims to provide digital health and safety file which is integrated with the BIM model of the building to the client. This will enable the client to access to consistent coordinated building information in a virtual platform throughout building life cycle.
Responsible Actors: Design Manager, BIM Manager, Construction Manager, FM Manager

A4-3 Review and Update Operational Plan: Review and Update of the Operational Plan according to the needs of the end-user. The updates should be reported to the Client regularly.
Responsible Actors: FM Sub-contractor, End-user, Client

A4-4 Report Operational Issues through Life Cycle of the Building: During the operation life cycle, the issues on design and quality of the building should be regularly reported to the Client by the Facility Management Sub-Contractor. This information should also be reported to the Contractor as an input to the Lessons Learned File of the project.
Responsible Actors: FM Sub-contractor, Client, Contractor

9.7 Framework Evaluation

The proposed framework is not without its limits. Although the needs of the framework are based on the detailed case studies held in the construction supply chains, this framework must be tested by the practitioners from the construction industry to understand the weaknesses and strengths or potential development areas for future research. The evaluation process and results are explained in detail in Chapter Ten.

9.8 Chapter Summary

In this chapter, the framework which is developed to enable construction bid managers/project managers plan and manage the project knowledge flow in the supply chain, organise activities, meetings and tasks to manage knowledge effectively in the supply chain was presented. To make a clear understanding on the needs of the framework, the key findings from the case studies were highlighted. The sections of the case study chapters which discuss these key findings were reminded to show the link between the case study the findings and the framework functions. Within the Knowledge Chain framework the key business activities to transform the construction supply chain to knowledge chain in four main phases of a project life cycle, and the knowledge flow during the design processes were presented. In the next chapter, the results of the framework evaluation is presented.

CHAPTER 10

10 EVALUATION

10.1 Introduction

Evaluation is the process by which the researcher provides an account of the findings and the recommendations to participants and checks the agreement or disagreement of the account by these participants. (Bryman and Bell, 2003). It is essential to evaluate how the framework has met the key research findings, and also, how it met the goals and objectives of the research (Bryman and Bell, 2003 and Yin, 2003b). It is also important to acknowledge the significance of the research findings and framework to the construction industry. Therefore this chapter focuses on evaluation of the framework which will into the conclusions of this research.

10.2 Evaluation Aim And Objective

The aim of the evaluation is to determine the account of the case study findings, and usability of the Knowledge Chain framework by construction professionals. The evaluation process focuses on identifying the benefits and shortcomings of the knowledge chain framework in addressing the needs for the framework. It also focuses on collecting information which can be used to develop the research findings for future research.

To achieve the main aim of the project, the specific objectives of the evaluation are identified as follows:

1. To evaluate if the framework can help to improve the integration of supply chain actors;
2. To evaluate if the framework can help to improve the knowledge sharing between the supply chain actors;
3. To evaluate if the framework can help to standardise Supply Chain Management practices in an integrated procurement type project;
4. To evaluate if the framework can help to standardise Knowledge Management practices in an integrated procurement type project;
4. To evaluate if the framework can well integrate the different components of SCM and KM;
7. To obtain feedback for further improvement of the framework and to highlight any improvement areas.

8. To obtain recommendations that would provide future directions of research.

10.3 The Evaluation Methodology

The overall goal of selecting a evaluation method is to obtain the most useful information to prove that the research work has achieved its targets in the most user effective and realistic fashion (Riley and Rosanske, 1996). General Evaluation methods are presented in Table 10-1 (Carter, 2008).

Table 10-1 General Evaluation Methods

METHOD	PURPOSE	ADVANTAGES	DISADVANTAGES
Questionnaires Surveys Checklists	To get lots of information from people quickly and easily.	▪ can complete anonymously ▪ inexpensive to administer ▪ easy to compare and analyze ▪ can get lots of data ▪ many sample questionnaires exist	▪ might not get careful feedback ▪ wording can bias participant's responses ▪ may need sampling expert ▪ doesn't get full story
Interviews	To fully understand someone's impressions or experiences, or learn more about their answers to questionnaires	▪ get full range and depth of information ▪ develops relationship with participant ▪ can be flexible with participant	▪ can take much time ▪ can be hard to analyze and compare ▪ can be costly- ▪ interviewer can bias participant's responses
Workshops	To generate much information quickly with a group of people.	▪ can generate much information quickly ▪ quickly and reliably get common impressions	▪ need good facilitator for safety and closure ▪ can be hard to analyze responses ▪ difficult to schedule people
Focus Groups	To explore a topic in depth through group discussion, e.g., about reactions to an experience or, common complaints	▪ quickly and reliably get common impressions ▪ can generate much information quickly	▪ need good facilitator for safety and closure ▪ can be hard to analyze responses ▪ difficult to schedule 6-8 people together
Case Studies	To fully understand or depict participants' experiences, and	▪ fully depicts participant's experience, process and results ▪ powerful means to portray	▪ usually time consuming to collect, organize and describe ▪ represents depth of

	conduct comprehensive examination through cross comparison of cases	the issues to outsiders	information, rather than breadth
Documentation Review	To get impression of how program/project operates without interrupting; can be accessed through review of applications, finances, memos, minutes	▪ get comprehensive and historical information ▪ doesn't interrupt participant's routine information already exists ▪ few biases about information	▪ often takes much time ▪ info may be incomplete ▪ need to be quite clear about what looking for ▪ data restricted to what already exists
Observation	to gather accurate information about how a program/project actually operates, particularly about processes	▪ view operations of a program/project as they are actually occurring ▪ can adapt to events as they occur	▪ can be difficult to interpret seen behaviours ▪ can be complex to categorize observations ▪ can influence behaviours of participants ▪ can be expensive

According to the description of the evaluation method above, this research is validated through a combination of workshop and questionnaire methods. This combination is selected in particular to overcome the disadvantages of the questionnaire methods such as not being able to get the full story, or the disadvantage of the workshops such as the difficulties to analyze responses. By this way, good amount of information could be generated quickly and reliably in a structured way.

10.4 Evaluation Approach

To have a different view on the research and the framework, it was decided to use 'non-participants' in the research study to evaluate the framework and the research findings. Workshop sessions were organised with industry practitioners who have expertise in project management, bid management, design management, supply chain management or knowledge/collaboration management, and integrated procurement type projects. The details of the 14 evaluators are presented in Table 10-2.

Table 10-2 Details of Evaluators

Company of the Evaluator	Role/Position	Area of experience	Experience within construction industry
Contractor 1 (C1)	Head of Design Management	Project Management/ Bid Management	30
	Project Manager	Project Management/ Bid Management	25
	Bid Manager	Design Management/ Project Management	12
	Supply Chain Manager	Supply Chain Management	24
Contractor 2 (C2)	Senior Design Manager	Design Management	22
	Head of Procurement	Supply Chain Management	27
	Senior Project/ Bid Manager	Project Management	22
Contractor 3 (C3)	Principal Consultant	Collaboration / Bid Management	22
	Bid Manager	Design Management/ FM	6
Contractor 4 (C4)	Group Innovation/ Knowledge Manager	Collaboration/ Innovation Management	12
Contractor 5 (C5)	BIM/Project Manager	Project Management	10
Consultancy 1 (Cs1)	Former Head of Collaboration	Collaboration / Knowledge Management	26
	Project Manager	Collaboration/ Information Management	9
Consultancy 2 (Cs2)	Project Management Consultant	Project Management	10

In the first part of the workshop, background of the research objectives and the key research findings were presented. Following this, the framework was introduced to the participants. During the presentation, participants were encouraged to give their feedback on the framework and the research work. Finally, to obtain a structured feedback and to generalise the user perception on the framework, participants were asked to complete a questionnaire on the evaluation of the knowledge chain framework. The details of the questionnaire are presented in the next section.

10.5 Questionnaire Design & Workshop

The questionnaire provided at the end of the workshop was based upon the aim and objectives of the evaluation in Section 10-2. The questionnaire covered all the major aspects of the research work that need to be validated and it was useful for obtaining essential feedback from the evaluators. The questionnaire contained 26 questions which was divided in to seven main sections. These sections are identified in line with the needs and the functions of the framework as follows:

- Supply chain integration
- Information and Knowledge Sharing
- Structured Design and Construction Process
- Standardisation of KM
- Standardisation of SCM
- Format and Feasibility
- General

Each section includes several questions which asks the evaluator to rate the framework from ‘poor’ to ‘excellent’ in a scale of 1 to 5. Each question aims to rate the ability of the framework to the deliver the main needs for the framework identified in Section 8.4. The questions and the evaluation results are presented in the following section.

10.6 Evaluation Results

Table 10-3 presents the framework evaluation results. The first column of the Table presents the questions asked for each section. The second column which is divided into 5 sub-columns shows the level of agreement in a scale of 1 to 5. The number of people who selected each level and associated percentage is presented in these five sub-columns. The last column presents the average score for each question. The results are discussed in the next section.

Table 10-3 Evaluation Results

Questions	Level of Agreement					Average Score
	1	2	3	4	5	
SC Integration						
1. How well do the processes in the framework address the communication between the Client, Contractor and SC actors?	(0p)	(0p)	(0p)	(9p)	(5p)	4.4
2. How well do the processes in the framework address the improvement of collaborative relationships between the Client, Contractor and SC actors?	(0p)	(0p)	(1p)	(8p)	(5p)	4.3
3. How well do the processes in the framework address the integration between the upstream and downstream supply chain?	(0p)	(0p)	(1p)	(5p)	(8p)	4.5
4. How well do the processes in the framework address the timely engagement of SC actors to the project?	(0p)	(0p)	(2p)	(5p)	(4p)	4.1
Information and Knowledge Sharing						
5. How well do the processes in the framework address the identification of knowledge requirements of the SC Actors?	(0p)	(0p)	(0p)	(10p)	(4p)	4.3
6. How well do the processes in the framework address the clarification of knowledge dependencies between the Client, Contractor and SC Actors?	(0p)	(0p)	(3p)	(7p)	(4p)	4.1
7. How well do the processes in the framework address the content of the knowledge flow between the SC actors in each phase of the project?	(0p)	(0p)	(3p)	(7p)	(4p)	4.1
8. How well do the processes in the framework encourage the SC actors to share their knowledge?	(0p)	(1p)	(2p)	(10p)	(1p)	3.8
Structured Design and Construction Process						
9. How well do the processes in the framework address the identification of the opportunities for the usage of DFMA solutions?	(0p)	(0p)	(5p)	(8p)	(1p)	3.7
10. How well do the processes in the framework address the identification of the opportunities for the usage of fully coordinated BIM modelling?	(0p)	(0p)	(1p)	(7p)	(6p)	4.4
11. How well do the processes in the framework address effective design coordination?	(0p)	(0p)	(0p)	(11p)	(3p)	4.2
12. How well do the processes in the framework address the integration between the design and construction teams?	(0p)	(0p)	(1p)	(7p)	(6p)	4.1

Standardisation of KM						
13. How well do the processes in the framework address the planning of the KM process?	**(0p)**	**(0p)**	**(1p)**	**(7p)**	**(6p)**	4.4
14. How well do the processes in the framework address the interoperability of design tools?	**(0p)**	**(0p)**	**(1p)**	**(10p)**	**(3p)**	4.1
15. How well do the processes in the framework address the implementation and usage of a collaboration tool for the SC actors?	**(0p)**	**(0p)**	**(2p)**	**(9p)**	**(3p)**	4.1
16. How well do the processes in the framework address the capture and use of lessons learned knowledge?	**(0p)**	**(0p)**	**(1p)**	**(9p)**	**(4p)**	4.1
Standardisation of SCM						
17. How well do the processes in the framework address the feedback from the design team and the consultants on the supplier selection, and evaluation ?	**(0p)**	**(0p)**	**(0p)**	**(10p)**	**(4p)**	4.3
18. How well do the processes in the framework address the implementation of trainings/events in skill deficiency areas of SC actors?	**(0p)**	**(0p)**	**(3p)**	**(8p)**	**(3p)**	4.0
19. How well do the processes in the framework address the implementation of strategic SC objectives in the project SC?	**(0p)**	**(0p)**	**(3p)**	**(8p)**	**(3p)**	4.0
Format and Feasibility						
20. How easy is the application of the workshops into the overall project lifecycle?	**(0p)**	**(2p)**	**(2p)**	**(4p)**	**(6p)**	4.0
21. How well presented is the flow of knowledge in the framework?	**(0p)**	**(0p)**	**(1p)**	**(5p)**	**(6p)**	4.2
22. How well integrated are the different components of knowledge management and supply chain management in the overall framework?	**(0p)**	**(0p)**	**(3p)**	**(4p)**	**(8p)**	4.3
23. How well do the processes add value to the culture of construction industry in terms trust and relationships between SC actors?	**(0p)**	**(0p)**	**(2p)**	**(8p)**	**(4p)**	4.1
24. How well do the framework improve the knowledge flow amongst SC actors?	**(0p)**	**(0p)**	**(4p)**	**(6p)**	**(3p)**	4.0
25. How convinced are you that construction industry professionals will accept the use of this framework as a guideline in their projects?	**(0p)**	**(0p)**	**(6p)**	**(7p)**	**(1p)**	3.6
General						
26. What is your overall rating of the knowledge chain framework?	**(0p)**	**(0p)**	**(1p)**	**(9p)**	**(4p)**	4.2

10.7 Discussion On The Results

The outcome from the evaluation of the research is discussed under the seven main sections as follows.

10.7.1 Supply Chain Integration

In terms of the supply chain integration, the evaluators were asked about the benefits of the framework in terms of communication and collaboration improvement between SC actors, timely engagement of SC actors to the projects, and integration of downstream and upstream SC. The evaluators informed that the framework clearly informs the processes which the project/bid managers need to follow to improve the communication and collaboration between different actors of the supply chain. The clarity on the usage of the ICT tools and the workshops are found as beneficial methods for better collaboration and communication amongst SC actors. The ratings for this section ranged between ‘satisfactory’ to ‘excellent’ with and average between [4.1-4.5]. In summary, the ability of the framework for SC integration is rated between ‘good’ to ‘excellent’ by the evaluators.

10.7.2 Information and Knowledge Sharing

For this section the evaluators were asked about the benefits of the framework in terms of addressing the identification of knowledge requirements of the SC Actors, the clarification of knowledge dependencies between the Client, Contractor and SC Actors, content of the knowledge flow between the SC actors in each phase of the project, encouragement of knowledge sharing between SC actors. The evaluators informed that identification of the KM strategy before the project starts would be very helpful. The evaluators also found the content of the information and knowledge dependencies workshops in very detailed level and agreed on the importance of these workshops on the overall project lifecycle. The information flow charts which are presented as an example for building school projects are found to be in a good level of detail. It is agreed that this can be used as a checklist by the design managers to control and check the knowledge flow in each phase of the project The ratings for this section ranged between ‘fair’ to ‘excellent’ with and average between [3.8-4.3]. In summary, the ability of the framework for ‘information and knowledge sharing’ is rated as ‘good’ by the majority of the evaluators.

10.7.3 Structured Design and Construction Process

In terms of the structured design and construction process, the evaluators were asked about the benefits of the framework in terms of the identification of the opportunities for the usage of DFMA solutions, fully coordinated BIM, design coordination and integration of the design and construction teams. The evaluators agreed that the discussions and identification on the offsite opportunities and BIM coordination early in the process can enhance the opportunities for design repeatability, better design coordination, reduced clashes, and reduces mistakes on site. Majority of the evaluators agreed that framework address these issues in a 'good' level. The ability of the framework in addressing the design coordination and integration between the design and construction teams are agreed as 'good' level by the evaluators. The ratings for this section ranged between 'satisfactory' to 'excellent' with and average between [3.7-4.1]. In summary, the ability of the framework for ;structured design and construction process' is rated as 'good' by the majority of the evaluators.

10.7.4 Standardisation of KM

In terms of the standardisation of KM process, the evaluators were asked about the benefits of the framework in terms of the planning of the KM process, the interoperability of design tools, usage of a collaboration tool by the SC actors, and the capture and use of lessons learned knowledge. The evaluators agreed that the planning of the KM practices early in the project such as the identification of KM strategy, identification of responsible bodies for KM control, clarifications on the knowledge dependencies, introduction of the ICT and design tools to the SC actors, identification of trainings, usage and storage of lessons learned knowledge and standardisation of all these activities in a project lifecycle can significantly reduce the complexity and improve project delivery. The ratings for this section ranged between 'satisfactory' to 'excellent' with and average between [4.1-4.4]. In summary, the ability of the framework for 'KM standardisation' is rated as 'good' by the majority of the evaluators.

10.7.5 Standardisation of SCM

In terms of the standardisation of SCM process, the evaluators were asked about the benefits of the framework in terms of effective usage of the feedback from the design team and the consultants on the supplier selection and evaluation process, implementation of trainings/events in skill deficiency areas of SC actors, implementation of strategic SC objectives in the project SC, and timely engagement of SC actors to the projects. The evaluators agreed that the planning of the SCM practices early in the project such as the identification of SCM strategy, clarifications of supplier packages, interfaces and constraints, identification of trainings for SC actors, getting benefit of the design team's knowledge on the sub-contractor and supplier packages timely in the project and engagement of downstream and upstream suppliers with a standard set of procedures will significantly improve the supply chain. The ratings for this section ranged between 'satisfactory' to 'excellent' with and average between [4.0-4.3]. In summary, the ability of the framework for 'SCM standardisation' is rated as 'good' by the majority of the evaluators.

10.7.6 Format and Feasibility

In terms of the feasibility, the evaluators were asked about the easiness of the application of the workshops into the overall project lifecycle, level of integration of SCM and KM practices in the framework, framework's effect on cultural aspects as collaborative relationships and trust, framework's effect on the overall improvement for knowledge flow and the acceptance of the framework by the construction practitioners. The ratings for this section ranged between 'fair' to 'excellent' with and average between [3.6-4.3]. Majority of the evaluators rated the 'easiness of the implementation of the framework to business processes' and the 'integration of SCM and KM practices in the framework' as 'excellent'. Majority of the evaluators rated the effect of the framework on cultural aspects as collaborative relationships and trust, and the framework's effect on the overall improvement for knowledge flow as 'good'. Majority of the evaluators rated the acceptance of the framework by the construction practitioners between 'satisfactory' to 'good'. The evaluators informed that to improve the acceptance of the framework, there may need some additional planning to overcome resistance to change. In terms of the format, majority of the evaluators rated the framework as 'excellent'.

10.7.7 General

In this section, the evaluators were asked to rate the overall framework. The ratings for this section ranged between 'satisfactory' to 'excellent' with and average between [4.2]. Majority of the evaluators rated the framework as 'good'. The evaluators informed that the framework brings good level of standardisation and consistency to the business process and integrates significant areas as SCM and KM in an excellent level of detail. Also, the necessity of such a guidance was highlighted.

10.8 Advantages

Through the evaluation, the respondents identified several practical benefits of the framework which are summarised as follows:

- The research study and the framework has been found to be executed and produced in an extraordinary level of detail and understanding of the process [C1-Bid Manager] It is based on an extensive research background and it provides very good knowledge of the processes, issues and requirements [Cs1-Collaboration Manager].
- There is not a tool available in the industry which shows the project life cycle in such a detail. All stages from feasibility and bidding to operational phase is very well considered [C1-Design Manager]. It provides the 'big picture' to the managers as well as containing high level of detail. It provides a good management tool focused on SCM and KM for project and bid managers [C2-Design Manager].
- The framework can highly improve the successful delivery of strategic projects in the industry [C5-BIM Manager; Cs1-Collaboration Manager].
- The framework addresses one of the biggest gap in the industry! It covers all the recent trends in the construction industry like off site construction and BIM where all supply chain management and knowledge management should take place [C5-BIM Manager].
- The framework's greatest strength lies in its integration of supply chain process optimisation and knowledge sharing within a single framework. This makes it much more likely to be adopted, usable and effective [Cs1-Project Manager].
- The framework is presented very clearly with useful mapping of the process [Cs1-Collaboration Manager].
- The framework presents the detailed list of what is required, however in reality the agendas of projects meetings are mixed, and there is huge amount of complexity. The most important benefit of the framework is its potential to bring standardisation to the project life cycle with its focus on the most strategic areas as KM and SCM [C1_Bid Manager]. Currently, the content of the meetings and workshops suggested in the framework is discussed in the project lunch meetings or design team meetings. However, the depth of the content relies on the capability and experience of the individuals,

therefore there is no consistency in the knowledge created and shared. This framework provides consistency in the content of the knowledge which needs to be shared [C1-Design Manager]. It is a good guidance for the project/bid and design managers and can be used as a checklist during the projects [C3-Principal Consultant].

- The framework brings visibility of the processes, if it is implemented to the business processes, project actors will know what will happen in the next stage of the project by reviewing the standard set of procedures [C1-Project Manager].
- Many contractors do not link the supplier performance information to their selection process. They also do not store or use the lessons learned knowledge during the projects. This framework provides integration between strategic issues of supply chain and knowledge sharing [C2-Head of Procurement].

10.9 Limitations

Through the evaluation, the evaluators identified some limitations of the framework which are summarised as follows:

- Although content is applicable to any type of project, it would be helpful to see the versions applicable to traditional contracts [C4-Innovation and Knowledge Manager].
- The framework involves a variety of client interactions. however, it is more focused on intelligent clients. Unfortunately not every client in the industry has a collaborative working environment and procedures in place [C3-Bid Manager]. Construction industry professionals will accept the use of this framework as a guideline if the clients take the lead. However, based on their experiences, the Client behaviour is changing in a positive manner and the Client has better understanding of the collaboration in recent years. The PFI type projects create awareness on the importance of collaboration in the industry [C3-Principal Consultant].
- This framework shows the SC design review and input from the design team and specialist consultants very clearly. However, this is only achievable when SC actors are confident of financial reimbursement [C2-Project Manager]. Translating the theory of supply chain management into real projects is very difficult due to commercial pressures in construction industry [C1-Supply Chain Management]. The construction industry is still very cost oriented which affects the implementation of supply chain processes effectively [C3-Principal Consultant].

- There are lots of knowledge sharing and feedback mechanism in the framework however the construction industry practitioners are not inclined to give feedback to prevent competitors from gaining commercial advantage. This can decrease the applicability of the framework [C1-Supply Chain Management].
- The framework can be implemented by more rigidly structured contractors rather than small scale contractors [C2-Project Manager].
- Although the content of the processes are common with the contractors, the implementation of the framework requires 'buy in' from all parties and contributors. There may be some resistance to change [C1-Design Manager].

10.10 Suggestion For Improvement

The suggestions made by the evaluators for improvements to the research work are summarised as follows:

- The framework can be converted to a toolkit for piloting in real projects and further research should be based on piloting in real projects for benchmarking the improvement received through the use of proposed framework [C5-BIM Manager].
- The interaction matrix can be linked to the knowledge flow presented in the design process. This can also be linked to the project timeframe [C3-Bid Manager]. A typical example project to give a feel for timeline may be helpful to appreciate the overall commitment required by all parties to the contract. [C1-Design Manager].
- If the framework can be converted to a tool kit, it should be also linked to live platforms to provide instant knowledge sharing.
- The framework should be communicated with the UK organizations like dBIS, BRE, BuildOffsite, Bulding Smart for wide industry engagement. [C5-BIM Manager]
- Although the content of the processes are common with the contractors, for easier implementation there needs some more focus on change management planning [C1-Design Manager].

10.11 Chapter Summary

The chapter presented the evaluation of the framework with it's advantages, limitations, and potential improvement areas . The evaluation approach adopted helped to test all aspects of the framework identified in the objectives. At the beginning of this chapter, the objectives of the evaluation process were presented. The justification for evaluation method and description of participants in the evaluation of the research was made. The questionnaire and workshop methods were selected for evaluation. The questionnaire covered all major aspects of the research work that needed to be evaluated. The workshop was useful for obtaining feedback from evaluators. The main outcomes of the evaluation are discussed in detail considering the benefits, limitations and future development areas of the research. The overall feedback on the research work done is positive. The feedback drew conclusions on the necessity of a knowledge chain tool which can be used in projects as a guidance and checklist for project/bid and design managers.

CHAPTER 11

11 CONCLUSIONS AND RECOMMENDATIONS

11.1 Introduction

This chapter presents an overall summary of the research, reviews the aim and objectives and discusses how each of them was achieved. Conclusions drawn from the research are also presented along with the limitations and recommendations for further research in this domain.

11.2 Research Review

The main aim of this research was to investigate supply chain management practices within construction industry with a particular focus on developing a systematic approach that fosters collaborative knowledge creation, sharing and diffusion throughout the construction project life cycle. The research objectives were as follows:

Objective 1: Review state of the art of issues and practices in SCM and KM in construction and across a range of industry sectors to learn and establish opportunities for improvement in construction industry.

The research work began with the review of Supply Chain Management field (Chapter Two). SCM was investigated in terms of its historical development, definition, and its theoretical background. It is revealed that scholars use a variety of theories to explain their aspects of SCM studies. Investigating the development of SCM as a field, the most important issue is found to be the lack of a unique definition, inadequate theory development and lack of theory validation. It is revealed that there is a remarkable gap in the theoretical work and the industry practice.

To have a better understanding on the current SCM trends, improvements and failures which can be useful to identify best practices for the construction industry, other capital and technology intensive industries were investigated (Chapter Three). The automotive and aerospace industries are selected because both have engineering design, production and maintenance phases similar to construction industry. The review was able to highlight the key issues in construction supply chains as recent industrial changes in procurement strategy, lack of SCM integration, a lack of risk sharing partnering, inadequate trust, skill deficiencies, lack of innovative thinking and lack of well developed knowledge management applications. On the other hand, the automotive industry has very mature SCM applications and is subjected to continuous improvement in SCM with various applications as JIT, JIS, lean, agile, flexibility, modularisation. The global challenges including satisfying the needs of different customers and markets under varying market conditions and demand growth, balancing the outsourcing and local procurement, balancing lean and agile applications in the supply chain improved the automotive SCs. The review also revealed that aerospace supply chains are conservative and slow to adapt new challenges compared to the automotive industry. However, aerospace supply chains benefited from the improvements in the automotive industry such as JIT and JIS production, lean applications, and trend to move to agile SCs. Due to a high level of standardization, the industry has defined procedures to create and share design knowledge. Both aerospace and automotive industries have mature relationships and high level of R&D investment. This enables these industries to implement new technologies and processes faster than the construction industry.

Another aim of the review highlighted different aspects of KM concepts and KM lifecycle (Chapter Four). It is revealed that, similar to SCM, KM has a lack of consensus on a unique definition and theoretical background; however this was accepted as evidence of the richness of the concept. The review also revealed that the integration of KM practices in construction supply chains by considering both the social and technical perspectives can be very helpful to bring innovation, to improve performance and project delivery, to avoid repeating past mistakes, to become agile, and to minimize risks in the supply chain. This supported the key premise of this research; the transformation of supply chains to knowledge chains will help to overcome the identified issues in the construction industry.

Finally the review highlighted the knowledge chain activities which involve knowledge conversion activities such as knowledge discovery, acquisition, generation, and supporting activities such as HRM, strategy management, technology implementation. To enable the transfer of construction supply chains to knowledge chains, these activities and practices are decided to be investigated further in practice.

Objective 2: Investigate SCM practices with a particular focus on KM within construction and other industries (automotive and aerospace), to establish best practices and opportunities for improvement in construction industry.

In order to investigate the SCM practices company-specific case studies were completed. These case studies were based on structured interviews held in large scale construction and aerospace organizations. Within these interviews, information on the SC organization, main SC priorities, selection criteria for the suppliers, maturity of the relationships, availability of supply chain development programmes, availability of the collaboration tools, key knowledge exchange and collaboration issues, and the future SCM agenda of the organizations were collected. According to the review, it is revealed that the SCM applications in construction organizations are not as mature and structured as the aerospace organizations. The main SC priorities for construction organizations identified as sales, client satisfaction, driving productivity, reducing labour and material on site, leanness and agility throughout the SC. Although these priorities are identified in the SC strategy of the organizations, cost and client satisfaction are the most addressed ones for construction industry. For aerospace organizations client satisfaction, increasing quality, improving delivery, reducing working capital, and cost are identified as major priorities. The main criteria for aerospace companies to keep a supply chain actor in the supply chain is identified as performance, delivery, quality and cost by all case study companies. This is a standardized approach to supplier selection in aerospace organisations whereas construction is still mainly cost oriented. The relationships in aerospace supply chains are more mature and longer term compared to the construction industry. The aerospace industry benefited significantly from industry wide programmes to standardise the supply chain practices as supplier selection, evaluation, trainings, sharing common values and aims with suppliers whereas in construction there is lack of structured industry wide programmes. Globalisation challenged the aerospace supply chains and this brings the lean concept to their work schemes earlier than construction industry. Both industries have different issues on knowledge exchange practices. Aerospace industry has a very conservative culture, and there is too much competition amongst employees, this hinders knowledge sharing process. The project durations are very long and there is always danger of losing knowledge and key skills. However, availability of standard and well structured processes, and closer collaboration with the clients and suppliers at early stages of the projects improve the knowledge flow across the supply chain and bring innovation to the industry. Barriers for knowledge sharing in construction is defined as the lack of diffusion of knowledge from the SC to other parts of business, inadequate collaboration between client, contractor, design team and suppliers, and inadequate usage of lessons learned. The future agenda for aerospace supply chains are identified as maintaining long term relationships, having leaner processes, sharing future workload with the suppliers earlier, better positioning, creating knowledge sharing culture, implementing live knowledge exchange platforms and getting more benefit from industry wide programmes. The future agenda for construction supply chains are defined as collaborative working between stakeholders starting from early phases of the projects, implementation of effective knowledge sharing process and tools, leaner supply chain, certain budget for innovation, exploring the global markets, and waste minimization.

Objective 3: Identify the knowledge requirements of different sectors of the construction supply chain, the interdependencies across the supply chain, and the key issues related to the knowledge flow leading to the development of a knowledge chain in the construction industry.

In order to identify the knowledge requirements of different supply chain actors and the interdependencies across the supply chain, project-specific case studies were completed in construction and aerospace industries as presented in Chapter Six, Seven and Eight. These case studies were based on two different steps. In the first step, the project managers of a recently completed project were interviewed. These interviews provided an insight into the general project management approach, and access to the supply chain actors of a real project. The project managers briefly explained the phases of the project in chronological order and provided information on the main suppliers in each phase. Following this, structured interviews were conducted with supply chain actors. These provided insight on how the project knowledge was created, transferred and stored throughout the whole project lifecycle in the supply chain. This involved the investigation of the knowledge flow and associated KM issues in detail. It also provided future expectations of supply chain actors. The detailed knowledge requirements of each supply chain actor, and the knowledge created by each supply chain actor were presented in Appendices E, F and G. These case studies revealed the following key issues:

- There is a need for better integration between supply chain actors with a focus on upstream and downstream SC collaboration (engagement of SC actors timely to the projects, making collaborative decisions with SC actors, integration of design team with sub-contractors and suppliers, benefiting from relaxed forums, workshops for relationship improvement, sharing information on future workload with the suppliers);

- improved information and knowledge sharing (clear understanding of the client requirements, improved information and knowledge flow, better clarifications on the knowledge dependencies between SC actors, establishing the link between Facility Management to design and construction specifications, learning from past projects, planning to improve the knowledge deficiencies of SC actors, organising workshops to encourage collaborative knowledge sharing);
- the need for structured design and construction process (identifying opportunities for offsite and BIM early in the project, better planning and design coordination, usage of real time collaboration tools);
- standardisation of Knowledge Management (standardisation of formats, forms, tools and transfer channels to create and share project knowledge, interoperability between design tools, starting BIM process early, usage of standard collaboration tool with well defined procedures, identifying people responsible for KM);
- standardisation of Supply Chain Management process (planning according to strategic supply chain issues, standardising the supplier selection and evaluation process, and benefiting from records for the supplier selection, getting feedback from the design team and specialist consultants for supplier selection and evaluation, standardisation for the timely engagement of suppliers);
- need for long term, trust based, mature sc relationships (benefiting from past collaborative relationships to improve knowledge sharing, establishing a culture based on trust and collaboration, benefiting from agreements and partnerships to improve confidentiality between parties).

Objective 4: Develop and evaluate a framework for transforming the construction supply chain into a knowledge chain, taking full cognisance of both the technical and social aspects of KM.

Based on the review of the state-of-the-art, investigation of key supply chain issues, identification of the knowledge requirements of different disciplines of the construction supply chain, the interdependencies across the supply chain, and the key knowledge flow issues, the ‘knowledge chain’ framework was developed. The ‘knowledge chain’ framework aimed to enable the project/bid managers to plan and manage the construction project knowledge flow in the supply chain and organise activities, meetings and tasks to improve SCM and KM throughout the supply chain of an integrated procurement type project life cycle.

As discussed in Chapter Nine, the framework presented the whole phases of project life cycle which includes several processes such as strategic SCM and KM planning process; the tasks to clarify the knowledge dependencies amongst SC actors; key engagement meetings with SC actors and the content of the knowledge to be shared; the planning of the mechanisms and tools to be used for effective knowledge transfer; engagement of the Client into collaborative decision making process; implementation of effective design coordination; planning for improved buildability and constructability; and effective usage of lessons learned knowledge. It also presents the availability of interactions between each project actor, and the information flow during design process. The processes in the framework aimed to standardise the knowledge conversion and function management activities of a knowledge chain which are discussed in Chapter Four.

The Framework was evaluated by industry experts and practitioners through presentations and demonstrations in a workshop. Evaluators were able to provide comments as necessary in different relevant areas including the framework's ability to address the identified needs for the framework, format, feasibility and areas for further improvement. Questionnaires were used to capture their comments which was analysed in (Section 9.7) of the thesis.

11.3 Conclusions

The research reported in this Thesis examined the supply chain management practices within construction industry with a particular focus to transform the supply chains into 'knowledge chains'. Subsequent to the conduct of the research, the following conclusions are formulated:

- Investigating the development of SCM as a field, the most important issue is found to be the lack of a unique definition. There is a remarkable gap in the theoretical work and the industry practice for SCM. The research in the field of KM has also sought to look into different aspects of organization and management of knowledge in different conditions and in different contexts. Similar to SCM, KM has a lack of consensus on a unique KM definition and theoretical background; however this can be accepted as an evidence of the richness of these concepts. Both KM and SCM can be considered as multidisciplinary areas. The conventional demarcations in traditional subject areas are not comprehensive enough to establish the theoretical background of KM.

- Based on a detailed literature review and case studies, recent changes in procurement strategy, lack of SCM integration, a lack of risk sharing partnering, inadequate trust, skill deficiencies, lack of innovative thinking, inadequate collaboration between the downstream and upstream supply chain, lack of interoperability of the design tools, lack of well structured SCM process and lack of well developed knowledge management applications are considered as the main issues that needs detailed investigation for SCM in construction industry.
- Compared to construction industry, the automotive and aerospace industries has much more mature SCM applications. The automotive industry developed and implemented various innovative approaches such as JIT, JIS, lean, agile, flexibility, modularisation in their SCM processes. Although the aerospace supply chains are conservative and slow to adapt new challenges compared to automotive industry, aerospace supply chains also benefited from these improvements. Moreover, the aerospace industry significantly improved by the help of the nation-wide SC development programmes. These programmes helped the aerospace firms to develop common SCM priorities, supplier evaluation and selection criterion, and awareness on SC collaboration. Both aerospace and automotive industries have mature relationships and a high level of R&D investment. This makes these industries quicker to implement new technologies and processes than the construction industry.
- Construction industry can learn from automotive and aerospace supply chains in many aspects such as implementation of lean SC practices, improving collaboration between project actors to improve knowledge sharing, improving relationship development between the SC actors, standardisation of SCM processes.
- There is a need for a mind change in the construction industry, the cost oriented approach of the industry hinders the improvement of it's supply chain.
- Construction organizations need to implement standard set of SCM procedures in their organizations. These procedures should be identified in line with the overall company strategy. The procedures should cover application of consistent supplier selection and evaluation criteria, implementation of development programmes/trainings for the SC actors, usage of supplier performance records in new projects, standard and timely engagement of SC actors to the projects, and integration of design team and specialist consultants to the downstream suppliers.

- Construction organizations need to implement standard set of KM procedures and tools in their projects. These procedures should be identified in line with the overall company strategy. The procedures should cover identification of KM unit/people who is in charge of knowledge management, implementation of ICT tools with associated trainings available to the SC actors, maintaining the inter-operability of design tools, planning of trainings where the SC actors has skill deficiencies, getting the benefit of lessons learned in future projects, and implementation of mechanisms to encourage collaborative knowledge sharing.
- Construction organizations should improve the collaboration with the Client from the early stages of the projects. There is a need for early collaboration between the Client, contractor, design team and specialist consultants. Early collaboration between the SC actors is identified as the main driver for innovation.
- There should be more focus on knowledge sharing between the upstream and downstream supply chain. The input from the design team and specialist consultants in the preparation of supplier and sub-contractor specifications is essential.
- The integration of KM practices by considering both the social and technical perspectives can be very helpful to produce high quality, lower costs, and just in time knowledge sharing within construction supply chains. KM can facilitate the transfer of knowledge across a variety of project interfaces, bring increased intellectual capital and innovation, improve performance and project delivery, help firms to avoid repeating past mistakes, retain tacit knowledge, become agile, and minimize risks. Therefore KM based Construction SCM will change the problematic nature of current construction SCM.
- The 'knowledge chain' framework is a potential management tool for the project/bid managers to plan and manage project knowledge flow and in the supply chain and organise activities, meetings and tasks to improve SCM and KM throughout the supply chain of an integrated procurement type project life cycle. The framework brings consistency, visibility and standardisation to the project life cycle whilst considering all the recent trends in the construction industry like off site construction and BIM coordination where all SCM and KM should take place. It has the potential to significantly improve the successful delivery of strategic projects in the industry.

- A firm's KC shows the effectiveness of the management of its knowledge resources, the ability of the organization's to cope with its business environment, it's cognitive power for action, its capacity for recognizing, and acting on market changes and developments. The creation of KCs not only enhances the final product but also can affect the whole business nature in a positive way. Because of this, transformation of the supply chains to knowledge chains is critical in terms of diminishing the issues of construction supply chain.

11.4 Contributions Of The Research

The research reported in this Thesis has made significant number of contributions to knowledge in terms of outcomes on:

- A comparative analysis of the SCM practices in different industry sectors, a better demonstration of the maturity level and critical factors of the SCM within the construction industry and identification of best practices for construction supply chains;
- Introduction of knowledge chain concept for construction supply chains taking full cognisance of both the technical and social aspects of KM which needs to be implemented in construction supply chains;
- Demonstration of knowledge requirements for different sectors of the construction supply chain and their interdependencies;
- Identification of key knowledge flow issues in the existing construction and aerospace supply chains, best practices and improvement approaches for construction supply chains;
- The development of a framework that enables construction supply chains to transform themselves into Knowledge Chains that add value to all stages of the project delivery process;
- Integration of supply chain process and knowledge sharing within a single framework which covers all the recent trends in the construction industry like collaborative procurement, applications like off site construction and BIM where all supply chain management and knowledge management should take place; and
- Creating awareness in construction organisations about 'knowledge' as a value in supply chain activities during the case studies and evaluation workshops;

11.5 Limitations Of The Research

In any research, despite the brilliant work and results achieved, there will be limitations of some sort. This research identified the following limitations:

- The framework focused on the PFI type projects. Although the content of the framework is applicable to the collaborative procurement type projects, this can limit the generalisation of the results for all procurement type projects.
- The framework developed is focused on design/technical knowledge flow and does not include financial or other project knowledge.
- The construction case studies were based on two large scale contractors, and the supply chains on their particular projects. Although the depth of the knowledge collected in these case studies was high, it could have been much more useful if the number of case studies could be increased.
- The design knowledge flow presented in the framework is a detailed example for building projects. However, it could be generalised for other type of projects.
- The research is more focused on large scale contractors and their needs and do not include small to medium scale contractors and their supply chains.

11.6 Recommendations for Construction Industry

The following recommendations are formulated for the construction industry:

- Construction organizations need to implement a standard set of SCM procedures in their organizations. These procedures should be identified in line with the overall company strategy. The procedures should cover application of consistent supplier selection and evaluation criteria, implementation of development programmes/trainings for the SC actors, usage of supplier performance records in new projects, standard and timely engagement of SC actors to the projects, and integration of design team and specialist consultants to the downstream suppliers.
- Construction organizations need to implement a standard set of KM procedures and tools in their projects. These procedures should be identified in line with the overall company strategy. The procedures should cover identification of KM unit/people who is in charge of knowledge management, implementation of ICT tools with associated trainings available to the SC actors, maintaining the inter-operability of design tools, planning of

trainings where the SC actors has skill deficiencies, getting the benefit of lessons learned in future projects, and implementation of mechanisms to encourage collaborative knowledge sharing.

- Large scale contractors and non-profit construction organizations can lead standardisation of the SC practices industry-wide. There is a need for collaboration between these organizations to lead change as aerospace industry achieved through programmes such as SC21.
- There is a need for a mind change in the construction industry, construction organizations should focus on performance, delivery and quality as well as cost.
- Construction organizations should improve the collaboration with the Client, Design Team, and Specialist Consultants from the early stages of the projects. The Design Team should benefit from the material Suppliers' and Specialist Contractors' knowledge during the design stage.
- There should be more focus on knowledge sharing between the upstream and downstream supply chain. The input from the Design Team and Specialist Consultants in the preparation of Supplier And Sub-Contractor Specifications is essential.
- Contractors should link the supplier performance information to their supplier selection process. They also should store or use the lessons learned knowledge during the projects.

11.7 Personal Learning Outcomes Of The PhD Study

Despite the limitations of the research, some critical learning outcomes are identified as follows:

- The research provided a methodical understanding of the process of conducting research from the idea development; critical literature review; identification of key issues and gaps; identification of aim and objectives, formulation of research questions to the process of research design. Ethical considerations of conducting research such as confidentiality, bias, validity and accuracy of the data was learnt and applied in the research.
- During the research design general body of knowledge on epistemological and philosophical underpinnings of research approaches and methods; data collection, analysis and evaluation methods were gained.

- During the research, an understanding on the importance of time management, effective communication and networking skills were achieved. Presentation skills and reporting skills has been improved.

11.8 Future Work

This research has identified a number of key areas that requires further research. These are as follows:

- Six company specific and four project specific case studies are conducted in total during the research. The content and depth of the information collected during these studies are very detailed. The framework also reflects this detail and it needs to be simplified and tailored according to the business processes.
- Extend the research by incorporating focus on organizational change management in order to further study the methods for overcoming resistance to change in construction supply chains;
- Extend the research by incorporating focus on the current BIM applications and in the construction supply chains and implementation of standardized Building Knowledge Model (BKM).
- Extend the research by incorporating focus on the 'culture' (such as trust, collaboration, etc.) and change management to make comprehensive planning for the implementation of the framework in construction supply chains;
- To establish the link between the interaction tables Table 8-3, Table 8-4, Table 8-5, Table 8-6), the information flow diagrams (Figure 8-3, Figure 8-4, Figure 8-5, Figure 8-7, Figure 8-8, Figure 8-9) and the project time frame in order to develop it as a tool which can help the end-user (project/bid manager) to follow the information to be created and shared during the project life cycle.
- The framework can be converted to a toolkit for piloting in real projects and further research should be based on piloting in real projects for benchmarking the improvement received through the use of proposed framework
- To investigate the applicability of the framework in a different context compared to one developed in this research. This would address the limitation relating to the standardization of the framework and guidelines.

- To research how to implement the framework within the current tools and applications of project management to provide more 'practical' applications and to improve the ease of deployment of the framework.

11.9 Closing Remarks

This research made significant contributions to the SCM and KM area as identified in Section 11.4. This research's greatest strength lies in its integration of supply chain management and knowledge management research and optimization of these two broad areas in a single 'knowledge chain' framework. These contributions and achievements are the corroborations that the objectives set out in Section 1.3 of this Thesis have been achieved. A methodological research approach was designed and appropriately applied in order to conduct the research. As a result, the research required to conduct industrial investigation to establish the need for a solution. This research's other key strength lies in it's systematic and rich data collection process to provide a solid background for the framework development. This data collection covered an in-depth review of construction, aerospace and automotive industries' supply chain issues. Consequently, six company-specific case studies and four detailed project-specific case studies in construction and aerospace industries were conducted. During the case studies in total 42 in-depth interviews (structured and semi-structured) were made. The results of these case studies coupled with the literature contributed to identifying inefficiencies and ineffectiveness, which also helped shape the development of the 'knowledge chain' framework. The framework was evaluated by 14 industry practitioners with expertise on SCM, KM, collaboration and project management. As a result of this, significant benefits of the Framework to the construction industry were identified. It is expected that when adopted and implemented in the construction business process, knowledge chain framework which specifies a better approach to SCM and KM practices in construction project lifecycle, will help construction supply chains to better integrate and collaborate, to share information and knowledge effectively, to increase the consistency and visibility of the business processes, to diminish complexity, to improve the relationships whilst increasing performance, delivery, and innovation.

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APPENDICES

APPENDIX A
COMPANY SPECIFIC CASE STUDY INTERVIEW QUESTIONS

1.BACKGROUND QUESTIONS

1. Organisational Details:

- Approximate number of people employed
- Annual Turnover of organisation
- Country
- Core Business Activity: (for example architecture, contracting, supplier, engineering consultancy)

2. Personal Details:

- Specify role carried out or position held (for example project manager, design consultant, engineer)
- Area of experience (for example civil engineering, building etc.)
- Experience in/with construction industry (years)
- Experience in/with the organization (years)
- E-mail

2. GENERAL SUPPLY CHAIN MANAGEMENT ISSUES

1. How many supply chain partners do you have in each sector of your supply chain?
2. How often are the lists of supply chain members reviewed?
3. What is the selection criteria for the supply chain partners?
4. What are the criteria for keeping a supply chain member?
5. What are the supply chain management priority from your point of view?

(Increased customer satisfaction, reduce supply chain costs, reduce working capital, increase sales, extract more value from existing customers, reduce direct labor and material, transform fixed costs to variable costs.)

6. Are they generally old relationships, or is there a tendency to work with new actors? If there is, which supply chain sector or sectors are mainly looked for mostly?
7. What are the problematic areas in your relationships with your supply chain actors, can you please tell these problems for each sector specifically?
8. Do you develop special programmes to improve your relationships with these partners?
9. Which collaboration tools are you using in your supply chain (for collaborative decision making.)
10. What are the methods that you use for knowledge exchange with your suppliers?
11. To what extent is the transfer of knowledge a key issue for maintaining a supply chain member?
12. Are there any contractual requirements to encourage supply chain members to share their knowledge?
13. What mechanisms are there to encourage the transfer of knowledge - both through formal and informal channels?
14. Have there been any particular cases where knowledge transfer has created either a positive or negative impact on other supply chain members or the project?
15. What do you think about lean supply chain management, are there any actions taken to achieve leaner supply chains?
16. What do you think about sustainability, and its effect to supply chains?
17. What do you think about innovation and the ways for improving innovation through the whole supply chain activities?
18. How do you assess the visibility of your company in the supply chain?
19. How do you define the supply chain flexibility of your company and what are the steps that have to be taken to improve the supply chain flexibility of your company? (as there is a tendency to demand driven supply chains rather than forecasting demand chains)
20. In which does your company spend supply chain improvement budget mostly? (Operational improvement, operational excellence, operational innovation)
21. What are the effects (as large structural shifts, new challenges to manage) of globalization in your company supply chain?
22. What do you think about the changes and the steps needed to be taken for your supply chain in future?

APPENDIX B

PROJECT SPECIFIC CASE STUDY INTERVIEW QUESTIONS

1.BACKGROUND QUESTIONS

1. Organisational Details:

- Approximate number of people employed
- Annual Turnover of organisation
- Country
- Core Business Activity:

2. Personal Details:

- Specify role carried out or position held (for example project manager, design consultant, engineer)
- Area of experience
- Experience in/with aerospace industry (years)
- Experience in/with the organization (years)
- E-mail

2. KNOWLEDGE MANAGEMENT

2.1.Knowledge Flow

These questions will be replied for each phases of the project separately.

1. What knowledge do you need to do your job in this phase of this project?
2. From which supply chain actor do you obtain the required knowledge?
3. What knowledge do you share with the other supply chain actors?
4. Which supply chain members do you share knowledge in this phase of project?
5. Are knowledge requests dependencies clear for all partners?
6. What methods and tools are used to share knowledge?
7. Do you go outside the supply chain to satisfy your knowledge requirement?
    a. Formal Source
    b. Informal Source

8. What knowledge do you produce at the end of this phase?
9. What happens to this knowledge?

2.2.KM Issues

1. What mechanisms are there to encourage the transfer of knowledge - both through formal and informal channels?
2. How would you describe knowledge sharing across the supply chain upstream and downstream?
    a. Strong / Adequate / Week
3. What are the possible problems that you encounter through the KM cycle (knowledge creation/dissemination/ storing) in your organization?
4. What are the possible problems that you encounter through the KM cycle (knowledge creation/dissemination/ storing etc.) in your supply chain?
5. What are the issues do supply chain actors have to share their knowledge freely in your supply chain?
6. What are the possible actions that can be taken to diminish these problems?
7. To what extent does Knowledge sharing enhance the value of collaborative relationships within SC?
8. How often do SC partners provide insolicited knowledge that has proved highly valuable to you?
9. Have there been any particular cases where knowledge transfer has created either a positive or negative impact on other supply chain members or the project?
10. What do you think about the changes and the steps needed to be taken for better knowledge sharing in your supply chain in future?

APPENDIX C

COMPANY A SUPPLIER DATABASE REGISTRATION QUESTIONNAIRE and PREQUALIFICATION QUESTIOANNAIRES

DATABASE REGISTRATION QUESTIONNAIRE

? Help

Enter Email address to whom invitation to complete this form was sent * email@address.com

N.B. fields marked * are Mandatory

1. Subcontractor (selected) Supplier Both — Pin No. * 192837
2. Company Name (not Trading Name): Interserve Project Services Limited
3. Trading Name (if applicable):
4. Address Line 1 *: 395 George Road
   Address Line 2 *: Erdington
   Address Line 3: Birmingham
   Address Line 4:
   County *: West Midlands — Post Code *: B23 7RZ

Is the above address to receive all enquiries? Yes (selected) No

If No, please provide the relevant address to which enquiries are to be sent.

Address Line 1 *:
Address Line 2 *:
Address Line 3:
Address Line 4:
County *: — Post Code *:

5. What is the main scope of your Company's activities: text here
6. Company Registration No.: 123456789
7. Year of Registration or Formation: 2000
8. Telephone No. (incl STD): 0121 344 4888
9. Fax No. (incl STD): 0121 344 4801
10. E-mail address:
11. Web Site Address: www.interserve.com
12. State maximum value of work for which you wish to be considered. £ 1,000,000.00
13. State minimum value of work for which you wish to be considered. £ 10,000.00
14. What is the largest project undertaken to date. £
15. Turnover Status for past 3 years

Year	2001	2002	2003
Turnover	5,000,000.00	5,500,000.00	5,800,000.00

16. Please provide details of any associated companies and branches: text here
17. Are you CITB registered Yes (selected) No — Reg. No: 987654321
18. Of which Trade Organisation or Federations are you a member: text here

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DATABASE REGISTRATION QUESTIONNAIRE

19. Please provide details of the main points of contact within your organisation.

	Name	Position	Contact Number
1.	a n other	Director	0121 344 4888
2.	a body	Managing Director	0121 121 1212
3.	s one	Company Secretary	0121 121 1213

20. Do you have in-house design capabilities to support your services? Yes (•) No ( )

21. Are you actively seeking CSCS certification for your workforce? Yes (•) No ( )

22. By which year end do you expect to have completed CSCS certification? 2004

Health & Safety Information

23. **Safety Policy**
Do you employ more than four people? Yes (•) No ( )
If **Yes**, do you have a current Health & Safety Policy and Company Management Structure? Yes (•) No ( )

24. **Training**
Do you have a standard that establishes minimum safety training / competence for persons under your control? Yes (•) No ( )

25. **Competent Safety Advice**
Do you employ a Safety Professional / external Consultancy / Other? Yes (•) No ( )

26. **Sub Let Works**
Do you sub-let any works? Yes (•) No ( )
If **Yes**, how do you evaluate the competency of subcontractors? (i.e. do you use a questionnaire)

text

27. Are you prepared to operate to our Business Systems for
(view each policy by clicking on the buttons below before making your selection).

	Yes	No
Safety	(•)	( )
Quality	(•)	( )
Environmental	(•)	( )

28. You will be presented with a set of choices indicating the geographic areas in which you are willing to work.

Internationally * Yes ( ) No (•)

	Anywhere	Only in certain parts	Not at all
England *	( )	(•)	( )
Scotland *	( )	( )	(•)
Wales *	( )	(•)	( )

Please indicate in which parts you are prepared to work.

	Anywhere	Only in certain parts	Not at all
Northern England	( )	( )	(•)
Central England	(•)	( )	( )
Southern England	( )	(•)	( )
Highlands & Islands	( )	( )	( )
Southern Scotland	( )	( )	( )
North Wales	( )	(•)	( )
South Wales	( )	(•)	( )

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PREQUALIFICATION QUESTIONNAIRE

In order that we can assess your Health, Safety, Quality and Environmental competence, please complete and return this questionnaire. Supporting information should be included with your response when returned to enable us to make a fair assessment.

Company Details

Company Name	Interserve Project Services Limited	Telephone	0121 344 4888
Address	395 George Road	Fax	0121 344 4801
	Erdington	E-Mail	hazel.ullah@interserveprojects.com
	Birmingham	Acc Code	INTERS601
		PIN No	123456
Post Code	B23 7RZ		
Completed By	Hazel Ullah	Date Completed	02/12/2005
Job Title	Business Systems Administrator		

1. Safety Policy

	Yes	No
Do you employ more than four people?	●	○
Does your Company have a Safety Policy?	●	○
If yes, please provide a copy of your current Policy and Company Management Structure		
Does your Policy contain, Statement of Intent, Organisation and Arrangements	●	○
Is the Statement of Intent signed by a senior member of the organisation	●	○
Does your Policy state the person ultimately responsible for safety	●	○
Does your Policy make clear the responsibilities of persons (either by name or job title)	●	○
Has your Policy been updated in the last two years	●	○

2. Safety Training

Do you have a standard that establishes minimum safety training / competence levels for persons under your control? ● ○ If yes, please give details below:

Off-Site Management — Yes ● No ○

Text

On-site Management and Supervisors — Yes ● No ○

text

Tradesman & Operatives — Yes ● No ○

text

CSCS cards of all above — Yes ● No ○

text

Note: Copies of certificates / cards will be required to be submitted prior to, and periodically during any works you undertake for us.

	Yes	No
Are operatives given method statements, risk, COSHH, noise and manual handling training / briefings?	●	○
Do you undertake toolbox talks?	●	○

3. Safety Advice

Do you employ a Safety Professional / external Consultancy / other for Competent Safety Advice? ● ○

If Yes, please indicate below

- ● Non Safety Specialist (line Manager) with no additional training
- ○ Non Safety Specialist (line Manager) with additional training
- ○ External Consultant with formal NEBOSH Qualifications or equivalent
- ○ In house Safety Adviser with no formal NEBOSH Qualifications or equivalent
- ○ In house Safety Adviser with formal NEBOSH Qualifications or equivalent

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PREQUALIFICATION QUESTIONNAIRE

Please provide a copy of the Safety Professional's Curriculum Vitae and qualifications

What is the frequency of your Safety Professionals/External Consultants/Others visits to site?

Weekly (•) Monthly ( ) Greater than monthly ( )

4. Health Arrangements

Please indicate below health hazards that pose a risk to your employees

None [ ] Noise [✓] Vibration [ ] Manual Handling [ ] Lead [ ] Asbestos [ ]

Other Chemical * [ ] Other * [ ] * detail below

	Yes	No
Do you have arrangements in place for managing health issues for your employees, e.g. competent health advice, pre-employment medicals, health surveillance, rehabilitation scheme? If yes, please describe below	(•)	( )

text

5. Sub-Let Works

	Yes	No
Do you sub-let works?	(•)	( )
Do you evaluate the competence of your sub-contractors	(•)	( )
Is your evaluation of your subcontractors based on experience ONLY?	( )	(•)
Is your evaluation of your subcontractors based on a pre-qualification questionnaire?	( )	(•)

If yes please provide a copy

What minimum criteria do you require from subcontractors to whom you sub-let works to satisfy you of their competence with regards to:

- Health & Safety Policy

text

- Health & Safety Advice

text

- Health & Safety Training

text

- Health Arrangements

text

- Sub-sub-let-works

text

- Safety Management

text

- Quality Management

text

- Environmental Management

text

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PREQUALIFICATION QUESTIONNAIRE

6. Supervision

You will be required to have competent and trained management and supervision to plan, supervise and monitor the works under your control at all times and to provide a single point of contact for all issues on site.
What is your policy with regards to adequate supervision?

text

Please confirm – ratio of Gangers 1 to Operatives 5
Please confirm – ratio of Managers 1 to Supervisors of Gangs (Gangers) 6

7. Design (inc. Design Development and Temporary Works) Yes No

Do you undertake any design for the work package?
If yes, do you have processes in place to ensure / undertake and record:

- Competence of those undertaking design
- Design Risk Assessments to avoid / reduce risks / environmental impacts during construction and maintenance
- Provide information regarding Health & Safety and environmental impacts with the design
- Co-operate with the Planning Supervisor and other Designers

Do you sub-contract any design work?

8 Incident Statistics: Reportable Under RIDDOR

Accidents for previous 3 years	Last Year		Year Before		Year Before	
	Employees	Subcontractor	Employees	Subcontractor	Employees	Subcontractor
Average Employed	523	65	562	70	585	77
Fatalities	0	0	0	0	0	0
Major Injuries	2	0	1	1	1	0
Over 3-Day Injury	5	1	5	0	4	0
A.I.R.	13.61		11.08		7.55	
Dangerous Occurrences	2	0	1	0	0	0
Diseases	1	0	0	0	0	0

Please supply details of initiatives / action taken to address significant incidents or improve performance generally.

text

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PREQUALIFICATION QUESTIONNAIRE

9 Enforcement Action

	Yes	No
Has your company been served with Prohibition Notices concerning unsafe conditions in the last 5 years?	○	●
Has your company been prosecuted for breach(es) of the Health & Safety Legislation in the last 5 years?	○	●
Has your company been prosecuted for breach(es) of Environmental Legislation in the last 5 years?	○	●

10 Safety, Quality & Environmental Management Systems

For each of the following questions please answer for	Safety OHSAS 18001		Quality ISO 9001		Environmental ISO 14001/EMAS	
	Yes	No	Yes	No	Yes	No
Are any of your management systems registered with a third party assessor?	●	○	●	○	●	○

(If yes, either attach certificate copy or attach in a word file, details of Registration Body, Certificate Number and Scope details)

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PREQUALIFICATION QUESTIONNAIRE

11 References

Please detail companies we can use as references, preferably current projects of similar size

Project	A Supermarket High Street Birmingham	Project	A Warehouse
Value £	1450000.00	Value £	1200000.00
Principal Contractor	Contractors UK	Principal Contractor	Builders UK
Contact Name	A N Other	Contact Name	A Body
Contact Number	0121 565 7196	Contact Number	0121 412 2898
Contact's Position	Managing Director	Contact's Position	Managing Director

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PREQUALIFICATION QUESTIONNAIRE FOR PRINCIPAL CONTRACTORS

In order to establish your competency relating to Health & Safety Please complete and return this questionnaire. If you have done this within the past 12 month, please specify the contract your completed it for.

For which contract is this form being completed?

Contractor :

Address :

Date :

IPSL Ref :

Nature of Business :

1. Safety Policy

1.1 Please attach a copy of your latest Health and Safety Policy ☐

2. Safety Advice

2.1 Do you have a person who provides you with safety advice Yes ☐ No ☐

If **Yes** Job Title

3 Subcontractors

3.1 Do you employ subcontractors? (including labour only) Yes ☐ No ☐

3.2 How are the selected?

3.3 How do you evaluate their health and safety competency?

4 Safety Training

4.1 Do you provide any of the following safety training

	Employees		Subcontractors		
	Yes	**No**	**Yes**	**No**	**N/A**
Induction Training	☐	☐	☐	☐	☐
Management supervisors	☐	☐	☐	☐	☐
Task Specific	☐	☐	☐	☐	☐

5 Risk Assessment

5.1 The Management of Health & Safety at Work Regulations 1999 require *every employer to make a suitable and sufficient assessment of health and safety associated with their work.*

How do you meet this legal requirement?

5.2 Attach an example of a Construction H&S Plan ☐

5.3 How is information about H&S conveyed to operatives/subcontractors?

APPENDIX D

COMPANY B OBJECTIVE PERFORMANCE MANAGEMENT CRITERIA

ASSESSMENT	Score
Unacceptable/poor	(-1)
Adequate/ satisfactory	(0)
Good	(1)
Very Good	(2)

EVALUATION CRITERIA OF SC ACTOR	Score
Management (Category):	
Understanding the brief: Ability to interpret Client brief/ Employer (LOR) brief	
Sustainability: Degree to which sustainability is embedded in design process, procedures for identifying opportunities and eliminating key risks/impacts.	
Safety in Design: Degree to which safety approach embedded in design process, procedures for identification/elimination of key and residual risks. Completion of risk assessments and compliance with Construction Design and Management (CDM)	
Ability to plan and manage: Quality of design programmes, resource plans and management of peaks and troughs in workload.	
Design Delivery: Ability to meet design delivery requirements	
Management of external statutory approvals: Approach to managing the planning approval process, Building control etc., expertise and adeptness at closing out residual matters/ attached conditions.	
Resources: Expertise, competence, calibre and availability of staff, use of Sub-Consultants	
Documentation and QA: Production and quality of documentation, adherence to QMS	
Quality:	
Presentation of Information: Clarity, accuracy if drawings, specifications, and schedules (including checking, sign off procedure), completeness and compliance. Ability to provide package information to suit procurement approach	
Response to Technical Queries: General approach, quantity and quality of response	
Buildability: Contractor awareness, willingness to rework design	
Record Information: Quality of information and its timely production for Operation and Maintenance Manual/ Health & Safety File	
Commercial:	

Design to Cost: Ability to design to budget. Awareness of cost, input to cost and value engineering processes.	
Changes/ variations: Ability to deal with and manage change, including reworking design.	
Behavioural:	
Commitment: Business approach to dealing with LOR	
Commerciality: Management of account, fee accuracy, dealing with valuations and final account settlement	
Responsive/ Proactive: Ability to drive solutions rather than react to them, positive contributions to the challenges in designing to cost, quality and programme.	
Innovation/Off Site/ MMC: Ability to embrace modern technology processes and systems, and integrate these into design. Balanced approach to risk/rigour/robustness.	

APPENDIX E

COMPANY A KNOWLEDGE FLOW ELEMENTS

E.1. Feasibility and Bidding Phase

Table 1 Information and Knowledge Flow Elements in Feasibility & Bidding Phase ITN Stage-Contractor

Phase	Information and Knowledge Required	Information and Knowledge Created
PIN&SHORTSTING	• Strategic Business Case (specifications for the school, option appraisal and chosen procurement route) (Client); • Prequalification Questionnaires (PQQ) (company profile, technical and financial capabilities, and past work as a proof of delivery) (Client).	• Company profile; technical resources such as size of business, work categories, skills and qualifications of staff; financial figures such as turnover and profit, taxation and insurance cover; health and safety procedures; references etc. (Client)
ITN	• background information (Client). • legal parameters (Client). • Output Specifications (building life expectancy, service life, main requirements on the structure, external and internal walls, doors and windows, functions, sizes and number of the rooms required, and the delivery time scale (Client). • Instructions for Tender Submission • Pricing and Delivery Schedule (Client). • Form of Tender (Client).	• Legal documentation, project schedule, specifications, design, drawings with a collaborative effort of supply chain actors (Client)

Table 2 Knowledge Flow Elements in Feasibility & Bidding Phase-Educational Specialist

Information and Knowledge Required	Information and Knowledge Created
• aspirations for the end product (Client, School); • end-user requirements for the facility (Client, School); • detailed scope for educational and common spaces (Client, School); • contractor's concerns on the affordability and constraints around project (Contractor); • education trends in the next 25 years	• detailed brief including schedule of accommodation describing the number of each room types, room sizes, basic Furniture and ICT requirements (Architect-M&E Services-Furniture Supplier-ICT Provider); • technical design requirements for facility use, organizational and operational aspects for the end user (Architect).

(Literature); • latest trends at design development (Architect).	

Table 3 Knowledge Flow Elements in Feasibility & Bidding Phase-Architect (Due to high capacity of knowledge created and shared, Architect's knowledge is presented in two sections as Stages 1 &2 according to the chronological order.)

Information and Knowledge Required	Information and Knowledge Created
Stage 1	
• Output Specifications (Contractor); • legislation for schools, building bulletins related to schools (Literature); • construction method (Contractor); • location, overall size of the school (Client, Contractor); • accommodation Schedules (Educational Specialist); • functionality and requirements of the building (Educational Specialist, Client, School); • site survey results (Surveyor).	• Positioning of the building according to daylight, energy efficiency and sustainability requirements (M&EServices, Contractor); • architectural design options (M&E Services, Structure Engineer, Contractor).
Stage 2	
• grid positioning, structural design form and alternatives, (Structural designer); • advice on fire safety which may affect the cost and layout of the building such as the location, size and number of the staircases, lobbies, exits (Fire Consultant was hired through the end of the this phase; thus architect made assumptions); • advice on acoustic aspects, noise minimisation requirements (Acoustic Consultant was hired through the end of this phase, thus architect made assumptions).	• detailed design produced as 1 to 200 scale drawings which show the main areas of the building such as the specific rooms, classes, corridors etc. (M&E Services, Structure Eng., Contractor); • 3D flythrough and animation which presents the common spaces with potential furniture and finishes (Contractor, Client).

Table 4 Knowledge Flow Elements in Feasibility & Bidding Phase-Landscape Architect

Information and Knowledge Required	Information and Knowledge Created
Stage 1	
• Schematic design of the architect (Architect); • initial sizes, and orientation of the building	• Types, sizes and main elements of the areas required such as; habitats ,games courts, sport pitches etc. (Architect);

(Architect); • educational requirements for external learning (Education Specialist).	• adjacencies and external areas, and their relationship with internals (Architect);
Stage 2	
• detailed design (Architect); • window cleaning strategy (Architect) • fire strategy (Fire Consultant was hired through the end of this phase; thus Landscape architect made assumptions) • Sport England requirements (Supposed to be given by Sports England but not received on time); • requirements and standards on parking numbers, routes and the roads, availability of need for additional entrances, exits and a service yard, number of coaches, (transportation consultant and highways engineers).	• Sketch Plan (Architect); • **Landscape Master Plan** which presents information on external areas such as courtyard, games, courts, sport pitches layouts etc (Architect); • location and number of storage bins, sprinkler tanks (Facility Manager, Architect, M&E Subcontractor); • transport and parking requirements, emergency vehicle access, number of cars and disabled spaces, optimizing parking provisions, routes and roads, locations of entrances, exits and service yard, number of coaches (Facility Manager, Architect, M&E Subcontractor).

Table 5 Knowledge Flow Elements in Feasibility & Bidding Phase-Structural Designer

Information and Knowledge Required	Information and Knowledge Created
• Detailed design (Architect); • M&E Interfaces (M&E Services Subcontractor); • Codes & Regulations (Literature); • Method of Construction (Contractor).	• Structural Drawings, Grid Layouts (Architect, Contractor); • Calculations for Buildability (Architect, Contractor).

Table 6 Knowledge Flow Elements in Feasibility & Bidding Phase- M&E Services Subcontractor

Information and Knowledge Required	Information and Knowledge Created
Stage 1	
• Output Specification (Client); • Accommodation Schedules (Educational Specialist); • functionality of the building, preferences (Educational Specialist, Client, School); • location, overall size of the school and the main aim of the school (Client); • options for the actual location and orientation of the building on the site to limit things such	• Best Orientation of the building (collaborative decision made with Architect, Structural designer); • Draft drawing which shows where the existing services are on the site (Architect, Landscape Architect, Structural designer).

as glare from the sun and heat gain (Architect); • locations where the existing gas, water, electricity available and diversions that may be required (Architect).	
Stage 2	
• updated Accommodation Schedules (Education Specialist); • detailed design (Architect); • directions of the external sunlight to make an optimised design which balances the sunlight and ventilation (Architect); • layout showing pathways, exit, security and car park areas (L. Architect); • number and specifications of computers, graphic design equipments, computer aided display functions, systems for telephony, conferencing, presentation, fire protection. (ICT Provider).	• detailed drawing which presents the locations of the substations, the switchboards in every room and the locations where the existing services are on the site (Architect); • availability of heavy equipment, it's location and approximate weight (Structure Engineer); • design of the lighting in the building (Architect); • cost plans based on the need for M&E equipments and installation process (Contractor)

Table 7 Knowledge Flow Elements in Feasibility & Bidding Phase-M&E Services Consultant

Information and Knowledge Required	Information and Knowledge Created
• Detailed design (Architect) • requirements on heating, lightning, lightning protection, ventilation, fire alarms, security, access control, sound field systems, disabled call systems, voice and data cabling (M&E Services, ICT Provider, Contractor).	• Thermal model (M&E Services Subcontractor); • computer model of the M&E systems (M&E Services Subcontractor); • heating and ventilation drawings considering the occupancy of each room (M&E Services Subcontractor); • adjacencies of areas, number of people in the areas, methods of ventilation and it's influence on the building structure (M&E Services Subcontractor).

Table 8 Knowledge Flow Elements in Feasibility & Bidding Phase-Acoustic Consultant

Information and Knowledge Required	Information and Knowledge Created
• Detailed design (Architect); • detailed design (M&E Subcontractor) • ventilation methods in each room (Architect, M&E Services Subcontractor); • M&E equipment in each room and their specifications (M&E Services	• forms of construction, forms and sealing requirements of windows, external walls (Contractor, Architect); • advices on the allocation and design of specific rooms such as music rooms etc. (Architect);

Subcontractor).	• advices on the design and number of doors and fire doors to minimise the noise spread (Architect, Fire Consultant).

Table 9 Knowledge Flow Elements in Feasibility & Bidding Phase-Fire Consultant

Information and Knowledge Required	Information and Knowledge Created
• size and location of the school, and the value of the project (Architect); • detailed design (Architect); • Fire Safety and Building Regulations which provides information on means of escape, means of warning, internal fire spread, external fire spread, fire fighter access and facilities for fire service. (Governmental Literature).	• **Fire Safety Report** which presents problematic areas for fire safety on the design; design code; locations in the building where fire engineering should be used; marking on the compartmentation lines; principles of means of escape, length of travel distances, minimum requirements for walls, fire doors, place and widths of the stair cores, occupancy levels; principles of fire protection to the internal structure; requirements for furniture; usage of the emergency lighting, fire detection systems, sprinkler system (Architect, M&E Consultant).

Table 10 Knowledge Flow Elements in Feasibility & Bidding Phase-ICT Provider

Information and Knowledge Required	Information and Knowledge Created
• Output Specifications (Client); • Accommodation Schedules (Educational Specialist); • Schematic design of the architect (Architect). • project programme (Contractor);	• impact of the ICT solution on the general design of the school, (Architect); • location, size and positioning of technician, data and IT rooms within the facility (Architect); • technical requirements for network cabling infrastructure and electrical power; requirements for server and data rooms (M&E Subcontractor); • transformational spaces with IT infrastructure, integrated ICT equipment with Furniture (Furniture Supplier); • number and specifications of computers, graphic design equipments, computer aided displays, communication systems and their thermal requirements which may affect heating and ventilation strategy (M&E Subcontractor); • cost plans (Contractor).

Table 11 Knowledge Flow Elements in Feasibility & Bidding Phase-Furniture Supplier

Information and Knowledge Required	Information and Knowledge Created
• Output Specification (Contractor); • Accommodation Schedule (Contractor); • standards of furniture the client would like to have, British Standards they need to cover, Building Bulletins (Contractor, Governmental Literature); • Client or school specific requirements (Architect); • project programme (Contractor); • schematic design of the architect (Architect).	• physical list of types and quantities of the furniture within each room (Architect, Contractor); • availability of cable ports in the furniture (ICT Provider); • cost plans based on each furniture and the installation process (Contractor); • thermal requirements and types of the technology equipments which may affect heating and ventilation strategy (M&E Subcontractor).

Table 12 Knowledge Flow Elements in Feasibility & Bidding Phase-Sustainability Consultant

Information and Knowledge Required	Information and Knowledge Created
• Client requirements on sustainability rating (Contractor) • architectural & M&E design and reports (Contractor)	• Assessment on the design and evaluation of that sustainability rating (Contractor).

Table 13 Knowledge Flow Elements in Feasibility & Bidding Phase-Facility Management Services (FMS)

Information and Knowledge Required	Information and Knowledge Created
• Output Specifications (Contractor); • layouts of the buildings, wall finishing, floor finishing (Architect); • number of staff for the maintenance (Client, School); • design team's approach on whole life cost solutions, and the effect of cost and design constraints on the operations constraints (Design Team); • detailed design (Architect).	• Facility Management Brief which includes basic information on the best kind of materials for some specific rooms, FM equipment types . (Contractor, Architect, Furniture Supplier) • Contingency plans for risk mitigation during the building lifecycle, failing output specifications throughout the delivery and it's a financial implications (Contractor). • Facilities Management Submission including service delivery plans, abilities; financial cost model per year to operate; organizational structure charts (Contractor, Client).

Table 14 Knowledge Flow Elements in Feasibility & Bidding Phase-Building Control Services (BCS)

Information and Knowledge Required	Information and Knowledge Created
• Output Specifications (Contractor);	• Building Control Report providing

• Building Regulations Standards (Government Literature); • detailed design (Design Team); • design elements such as emergency efficiency, disabled access, fire safety, drainage, roofing (Architect, Fire Consultant)	information on the compliance of the design with Building Regulations Standard (Contractor) • Guidance documents for the necessary changes to Architect, Structure Engineer and M&E Services Subcontractor.

E.2 Contract Close

Table 15 Knowledge Flow Elements in Contract Close Phase-Contractor (Bid Team)

Information and Knowledge Required	Information and Knowledge Created
• List of highly graded specialist companies (Contractor's SCM Team); • methods and ways of delivery of services or products; maintenance and project's whole life costing (Subcontractors-Suppliers); • cost plans and schedule of delivery (Subcontractors-Suppliers); • future solutions and ideas for the next 10 years market (Subcontractors-Suppliers);	• List of best suppliers for the project with selection reasons such as cost, performance, willingness to interact for bidding; and list of reasons for rejection of other suppliers (Project Manager); • design control, and cost control information, so that project team planned to give orders to the suppliers through the end of this phase (Project Manager)

Table 16 Knowledge Flow Elements in Contract Close Phase-Educational Specialist

Information and Knowledge Required	Information and Knowledge Created
• Preference of client; aspects that the client liked about phase one design or the changes needed (Contractor, Architect); • requirement validation from the client for the changes (Contractor).	• Updated client requirements particularly on the usage of the building, or having certain faculties in certain locations (Architect, and other Specialist Consultants via Architect)

Table 17 Knowledge Flow Elements in Contract Close Phase-Architect

Information and Knowledge Required	Information and Knowledge Created
• Environmental Schedules(M&E Services) • orientation and layouts of hard landscape and their specifications (Landscape architect) • final Accommodation Schedules (Education Specialist) • Room Data Sheets (Furniture supplier-ME Subcontractor) • delivery programmes (Contractor)	• Full detail design at the stage of RIBA Stage D+-RIBA Stage E (Contractor); • drawings, materials, outline specifications to the contractor, for further checks on the affordability and the buildability (Contractor);

Table 18 Knowledge Flow Elements in Contract Close Phase-Landscape Architect

Information and Knowledge Required	Information and Knowledge Created
• Detailed design (Architect) • suitability of design to the transportation of the children in certain times of the day (Transportation consultant) • Sports England requirements and view on the design and planning permission requirements (Sports England) • BREAM Education 2008 Requirements (BREAM website)	• Detailed landscape architectural layouts, (one overall and two large scale drawings) (Architect) • Landscape Master Plan (Architect) • orientation and layouts of hard landscape (paving, curb, edging, walls, external structures, fences, boundaries.), and their specifications (Architect) • typical planting proposals (Contractor)

Table 19 Knowledge Flow Elements in Contract Close Phase-Structural Designer

Information and Knowledge Required	Information and Knowledge Created
• detailed drawings (Architect); • final construction method (Contractor) • specifications from material suppliers (Material Suppliers)	• detailed design of the interfaces (Contractor, Architect, M&E services) • detailed structural drawings and specifications (Contractor, Architect)

Table 20 Knowledge Flow Elements in Contract Close Phase- M& E Services Subcontractor

Information and Knowledge Required	Information and Knowledge Created
• Detailed ventilation model, heating and lighting calculations (M&E Consultant); • detailed specifications which involved the type and usage of ICT equipments, sizes and cabling requirements (ICT Provider). • detailed Architectural Design (Architect) • detailed Structural Design to check clashes (Structural designer) • responsibility matrix for the Delivery of ICT schedule (Contractor)	• Room data sheets including types and number of rooms; details of M&E systems in each room such as the availability of hot/cold water, comfort cooling, mechanical supply and extract; number of sockets and data points (Contractor). • Environmental Schedules including the locations of the ICT points; drawings of the equipment rooms, locations to run the services (ICT provider).

Table 21 Knowledge Flow Elements in Contract Close Phase-Fire Consultant

Information and Knowledge Required	Information and Knowledge Created
• detailed design and drawings (Architect) • view of Architect on passive smoke ventilation methods (Architect) • Room Data Sheets in order to provide fire safety for ICT and ME equipments	• detailed design of the fire safety systems (Contractor); • calculations to prove the fire safety systems defined in the feasibility and bidding phase will be working as planned;

(Contractor)	• exact locations of emergency lighting, means of escape and ventilation; information on signage; specifications of fire alarm system; • Fire Strategy Report which involves types, locations and specifications of fire systems, installation procedures, and fire safety management procedures for the operation of the building (Contractor)

Table 22 Knowledge Flow Elements in Contract Close Phase-Acoustic Consultant

Information and Knowledge Required	Information and Knowledge Created
• M&E strategy drawing (M&E Consultant); • detailed design (Architect)	• Acoustic Strategy Report which involves acoustic requirements of the partition types, internal walls, doors, internal glaze screens, floors, and roofs (Architect); acoustic requirements of the mechanical systems and equipments (M&E Consultant); ventilating and noise issues in the detailed design (Architect).

Table 23 Knowledge Flow Elements in Contract Close Phase-ICT Provider

Information and Knowledge Required	Information and Knowledge Created
• environmental schedules (M&E Services) • the architectural layouts (Architect) • room data sheets (Contractor) • responsibility matrix for the Delivery of ICT schedule (Contractor)	• detailed specifications involving the types of ICT equipments, sizes and cabling requirements of the ICT equipments. (M&E Services, Architect)

Table 24 Knowledge Flow Elements in Contract Close Phase-Furniture Supplier

Information and Knowledge Required	Information and Knowledge Created
• sections of the architectural layouts to provide options for furniture for flexible teaching (Architect); • Environmental Schedules (locations of the floor outlet boxes, sockets, lights, and the services (M&E Services). • responsibility matrix for the Delivery of ICT schedule (Contractor)	• Room data sheets which presents exact number and type of furniture in each room (Contractor); • conceptual design of the furniture at a level for allocating the cost for the financial close rather than actual design of the furniture) (Contractor-Architect)

Table 25 Knowledge Flow Elements in Contract Close Phase-Facility Management Services (FMS)

Information and Knowledge Required	Information and Knowledge Created
• detailed design of the facility including the architectural, M&E services, fire safety elements (Architect, M&E Services Subcontractor)	• updated Cost Model according to the design changes (Contractor); • energy consumption figures during operation of the facility (Contractor); • employment procedures such as pension schemes, number of employees (Contractor).

Table 26 Knowledge Flow Elements in Contract Close Phase- Building Control Services (BCS)

Information and Knowledge Required	Information and Knowledge Created
• Fire Safety Report (Fire Consultant); • detailed design (Architect); • Landscape Architectural Layouts (Landscape Architect).	• issues which affects the compliance of the design with the Building Regulations Standard. (Contractor, Design Team via Contractor)

Table 27 Knowledge Flow Elements in Contract Close Phase- Contractor (Project Team)

Information and Knowledge Required	Information and Knowledge Created
• frozen Design to put in the Contractor's Proposal Document (Design Team)	• 'Contractor's Proposal Document' which involves the specifications of the building; methods and procedures of construction, implementation of the services during construction (Client). • cost plans, schedules, design knowledge, measures, specifications, health and safety information (Client, Construction team). • 'Access protocol' for the definition and procedure for access of the suppliers to the construction site such as ICT, Furniture Suppliers (Subcontractors &Suppliers).

E.3 Construction Phase

Table 28 Knowledge Flow Elements in Construction Phase- Architect

Information and Knowledge Required	Information and Knowledge Created
• Subcontractor's Packages (Contractor) • Final revisions on design issued by client (Client, Contractor)	• set of record for construction drawings (Contractor) • construction design drawings (Outsourced the construction drawing production to a Company in South Africa due to low cost and limited time allocations)

Table 29 Knowledge Flow Elements in Construction Phase- M&E Services Subcontractor

Information and Knowledge Required	Information and Knowledge Created
• detailed drawings that electricians, plumbers use to physically install the M&E systems (M&E Consultant); • factory drawings for the specific units which were delivered from the suppliers (M&E Subcontractor's Supply Chain); • information about new products which can improve the performance of the design or installation process (M&E Subcontractor's Supply Chain); • CIBSE recommendations which provides detailed lifecycle requirements and guidance notes for M&E services; • Fire officer's view on the installation of the M&E Services (Fire Officer).	• final drawings with containment, steelwork, builders work hole details in order to actually physically install the M&E Services (Contractor, Architect); • maintenance specifications of the equipments during the lifecycle of the building (Contractor, FMS via Contractor).

Table 30 Knowledge Flow Elements in Construction Phase- Furniture Supplier

Information and Knowledge Required	Information and Knowledge Created
• detailed room layouts (Architect)	• architectural drawings (2D) where the furniture symbols are shown (Architect, Contractor); • updated Room Data Sheets (Architect, Contractor); • detailed furniture design (Architect, Contractor); • production drawings (Factory Team); • Purchasing Order Information which involves numbers, models, requirements for the parts and materials (Suppliers)

Table 31 Knowledge Flow Elements in Construction Phase- ICT Supplier

Information and Knowledge Required	Information and Knowledge Created
• final requirements for the supply and installation of ICT equipment (Contractor).	• Room Data Sheets (RDS) which involves makes, models and installation procedures of ICT equipment (Furniture Supplier, M&E Subcontractor and the contractor); • Purchasing Order Information which involves numbers, makes, models and exact requirements of ICT equipments (Suppliers);

	• Acceptance Certificates And Test Results regarding the operation of ICT equipment within the facility.

Table 32 Knowledge Flow Elements in Construction Phase- Fire Consultant

Information and Knowledge Required	Information and Knowledge Created
• detailed Architectural design (Architect); • detailed M&E Services drawings (M&E Subcontractor); • inspection reports (Site Visits).	• Fire Safety Manual which involves information on the operation of fire safety systems and fire risk assessment of these systems in detail (Contractor); • Advices on mistakes

Table 33 Knowledge Flow Elements in Construction Phase- Acoustic Consultant

Information and Knowledge Required	Information and Knowledge Created
• snagging and inspection reports (Site Visits).	• Advices on mistakes

Table 34 Knowledge Flow Elements in Construction Phase- Facility Management Services (FMS)

Information and Knowledge Required	Information and Knowledge Created
• specifications of the equipments, the mechanical, electronic drawings, sewage drawings, layouts (M&E Subcontractor, ICT Provider, FMS Subcontractors and Suppliers)	• 'Mobilisation Plan' providing information on Help Desk system such as it's location, function; assets, recruitment and transfer of staff, induction programmes; trainings; ordering of the equipments; reporting requirements and formats (Contractor) • list of suppliers to be used for FMS and equipments (selected according to the Contractor's SCM criteria) • make and model of the equipments to be used in the Contractor's Operation & Maintenance Manual. (Contractor)

Table 35 Knowledge Flow Elements in Construction Phase- Building Control Services (BCS)

Information and Knowledge Required	Information and Knowledge Created
• last versions of the construction drawings (Contractor) • snagging and inspection reports on the foundations, drainage, and fire elements (Site Visit)	• main issues regarding the compliance of the project with Building Regulations particularly fire doors, means of escape, access for disabled people (Contractor); • 'Final Certificate' which certifies the architectural ability of the building according to the building legislations (Contractor).

E.4 Operational Phase

Table 36 Knowledge Flow Elements in Operational Phase- Facility Management Services (FMS)

Information and Knowledge Required	Information and Knowledge Created
• technical physical mistakes on the equipments installed (during Post Occupancy Support Review with Education Specialist, Contractor) • user's and Client's view on the functionality, usage, ergonomics and aesthetics of the building and equipments (Through Customer satisfaction surveys).	• condition of equipments in the building to ensure that the building and equipments will operate as intended to work (Contractor, Client, School); • 1-3-5 years Operational Plan (Contractor, Client, School); • Help Desk reports (Damage and fault reports may affect the design in the future projects. This knowledge can be linked in to the FM Design Brief (Contractor);

APPENDIX F

COMPANY B KNOWLEDGE FLOW ELEMENTS

F.1. Feasibility and Bidding Phase

Table 1 Knowledge Flow Elements in Feasibility & Bidding Phase-Architect

Information and Knowledge Required	Information and Knowledge Created
RIBA Stage A-B	
• Output Specifications (Contractor); • legislation for schools, building bulletins related to schools (Literature); • building frame, materials and method, type of structure, general cost of the building (Contractor); • location, overall size of the school (Client, Contractor); • Accommodation Schedules (Educational Specialist); • functionality and requirements of the building (Educational Specialist, Client, School); • Design Brief (Stage 0 Report) (Consultant of Client, Architect Company) • Survey information regarding the processor, soil, gradient, contamination etc (Contractor-Surveyor) • Educational Brief (Educational Specialist) • Schedule of Adjacencies, design and technology located near the break out area and ICT (School, Client) • Architectural plans of the Refurbishment Block (Consultant of Client) • Strategy for the maintenance of the building and services, guidance for the sizing of glazing, performance criteria, ventilation strategy (M&E Consultant)	• update of Output Specifications according to the discussions on the clients requirements with the Client, school, and Education Specialist (Contractor, Client); • RIBA STAGE A-B Report including the actual location and orientation of the building on the, options of area schedule presented as artistic sketches, Understanding of the school requirements (M&E Services, Structure Engineer, Contractor).
Stage 2	
• updated Accommodation Schedules (Educational Specialist); • grid positioning, basic form of structures, sizes, types, location of the columns, beams, maximum span, structure of the roof	• detailed design produced as 1 to 200 scale drawings which show the main areas of the building such as the specific rooms, classes, corridors (M&E Services, Structure Eng., Contractor);

(Structural designer); • Fire Strategy report which involves advice on fire safety which may affect the cost and layout of the building such as the location, size and number of the staircases, lobbies, exits (Fire Consultant); • advice on acoustic aspects, noise minimisation requirements, deafness provision for students with hearing problems (Acoustic Consultant). • M&E Services design and reports (M&E Consultant) this information could not be provided due to having no M&E Consultant at this stage.	• visualised material which shows the entrance ways with people, models and some soft furniture in 3-D format (Contractor, Client) • Master Planning and presentation, brief on functionality of site Drawings (Landscape Architect) • Architectural Stage C Report (preplanning application)

Table 2 Knowledge Flow Elements in Feasibility & Bidding Phase-Landscape Architect

Information and Knowledge Required	**Information and Knowledge Created**
Stage 1	
• Schematic design of the architect (Architect); • initial sizes, and orientation of the building (Architect); • educational requirements for external learning (Education Specialist) • schedules, objectives of Local Authority, budget and programme (Contractor)	• preliminary design proposals, site layouts, ideas (Architect)
Stage 2	
• tree survey information (Arboriculture Consultant); • fire strategy (Fire Consultant) • Sport England requirements • requirements and standards on parking numbers, routes and the roads, availability of need for additional entrances, exits and a service yard, number of coaches, (transportation consultant and highways engineers). • Local Planning Policy, planning requirements (Local Authority)	• **Landscape Master Plan** which presents information on external areas such as courtyard, games, courts, sport pitches layouts etc (Architect); • transport and parking requirements, emergency vehicle access, number of cars and disabled spaces, optimizing parking provisions, routes and roads, locations of entrances, exits and service yard, number of coaches (Facility Manager, Architect, M&E Subcontractor). • 1:500 1:250 drawings (Architect) • Sizes and location of the items, the roads between the building, garden, courtyard, and sport pitches, transport and parking requirements (Facility Manager)

Table 3 Knowledge Flow Elements in Feasibility & Bidding Phase-Structural Designer

Information and Knowledge Required	Information and Knowledge Created
• Set of drawings, preference and options for materials (Architect); • Codes & Regulations (Literature); • Method of Construction (Contractor). • Cost estimation (Quantity Surveyor) • Cost options (Subcontractors) • Potential availability of any unusual load as big plants, the distribution area and the location of the load (M&E Services)	• Preference on the kind of materials, different options of materials, advantages and disadvantages in terms of cost, sustainability (Architect, Contractor) • Size, grid positioning, maximum span, basic form of structures, types, location of the columns, beams, span, structure of the roof (Architect, Contractor); • Calculations for Buildability (Architect, Contractor). • Drawings and specification for foundation, materials, pre-cast concrete, general notes on the tolerance limits, quality control (Contractor)

Table 4 Knowledge Flow Elements in Feasibility & Bidding Phase-M&E Services Consultant

Information and Knowledge Required	Information and Knowledge Created
• Client requirements on heating, lightning, lightning protection, ventilation, fire alarms, security, access control, sound field systems, disabled call systems, voice and data cabling (Contractor).	• RIBA STAGE A/B design information including adjacencies of areas, number of people in the areas, methods of ventilation and it's influence on the building structure (Contractor). The contractor changed the consultancy, and did not assign anyone until the RIBA Stage E.

Table 5 Knowledge Flow Elements in Feasibility & Bidding Phase-Acoustic Consultant

Information and Knowledge Required	Information and Knowledge Created
• RIBA Stage A/B ideas, general proposals and arrangements (Architect) • Client requirement on noise emissions (Client) • Building Bulletin 93 Acoustic Requirements for schools (Governmental literature)	• List of questions for guidance to the contractor to be answered and presented to the client by the contractor, brief proposal which explains how they control external and internal noise (Contractor) • Preliminary noise survey information (They had to make a comprehensive noise survey however, they had to make a brief one due to cost constraints)

Table 6 Knowledge Flow Elements in Feasibility & Bidding Phase-Fire Consultant

Information and Knowledge Required	Information and Knowledge Created
• size and location of the school, and the value of the project (Architect); • detailed design (Architect); • Fire Safety and Building Regulations which provides information on means of escape, means of warning, internal fire spread, external fire spread, fire fighter access and facilities for fire service. (Governmental Literature).	• **Fire Safety Report** which presents problematic areas for fire safety on the design; design code; locations in the building where fire engineering should be used; marking on the compartmentation lines; principles of means of escape, length of travel distances, minimum requirements for walls, fire doors, place and widths of the stair cores, occupancy levels; principles of fire protection to the internal structure; requirements for furniture; usage of the emergency lighting, fire detection systems, sprinkler system (Architect, M&E Consultant).

Table 7 Knowledge Flow Elements in Feasibility & Bidding Phase-ICT Provider

Information and Knowledge Required	Information and Knowledge Created
• Output Specifications (Client); • Accommodation Schedules (Educational Specialist); • Schematic design of the architect (Architect). • project programme (Contractor);	• impact of the ICT solution on the general design of the school, (Architect); • location, size and positioning of technician, data and IT rooms within the facility (Architect); • technical requirements for network cabling infrastructure and electrical power; requirements for server and data rooms (M&E Subcontractor); • transformational spaces with IT infrastructure, integrated ICT equipment with Furniture (Furniture Supplier); • number and specifications of computers, graphic design equipments, computer aided displays, communication systems and their thermal requirements which may affect heating and ventilation strategy (M&E Subcontractor); • cost plans (Contractor).

Table 8 Knowledge Flow Elements in Feasibility & Bidding Phase-Furniture Supplier

Information and Knowledge Required	Information and Knowledge Created
• Output Specification (Contractor); • Accommodation Schedule (Contractor);	• physical list of types and quantities of the furniture within each room (Architect,

• standards of furniture the client would like to have, British Standards they need to cover, Building Bulletins (Contractor, Governmental Literature); • Client or school specific requirements (Architect); • project programme (Contractor); • schematic design of the architect (Architect).	Contractor); • availability of cable ports in the furniture (ICT Provider); • cost plans based on each furniture and the installation process (Contractor); • thermal requirements and types of the technology equipments which may affect heating and ventilation strategy (M&E Subcontractor).

Table 9 Knowledge Flow Elements in Feasibility & Bidding Phase-Sustainability Consultant

Information and Knowledge Required	Information and Knowledge Created
• Client requirements on sustainability rating (Contractor) • Pre-assessments (Previous Sustainability Consultant) • architectural & M&E design and reports which provides evidence for BREAM checklist such as usage of recycled materials, heating and cooling, isolation (Contractor)	• Could not produce the report because the designers did not provide evidence

F.2 Contract Close

Table 10 Knowledge Flow Elements in Contract Close Phase-Contractor (Bid Team)

Information and Knowledge Required	Information and Knowledge Created
• List of highly graded specialist companies (Contractor's SCM Team); • methods and ways of delivery of services or products; maintenance and project's whole life costing (Subcontractors-Suppliers); • cost plans and schedule of delivery (Subcontractors-Suppliers); • future solutions and ideas for the next 10 years market (Subcontractors-Suppliers);	• List of best suppliers for the project with selection reasons such as cost, performance, willingness to interact for bidding; and list of reasons for rejection of other suppliers (Project Manager); • design control, and cost control information, so that project team planned to give orders to the suppliers through the end of this phase (Project Manager)

Table 11 Knowledge Flow Elements in Contract Close Phase-Architect

Information and Knowledge Required	Information and Knowledge Created
• Environmental Schedules(M&E Services) • orientation and layouts of hard landscape and their specifications (Landscape architect)	• Full detail design at the stage of RIBA Stage D+-RIBA Stage E (Contractor); • drawings, materials, outline specifications to

• final Accommodation Schedules (Education Specialist) • Room Data Sheets (Furniture supplier) • delivery programmes (Contractor) • Structural Drawings showing every construction element, connections and calculations (Structural engineer) • Landscape Architect report including levels strategy, zoning in terms of accessible space, secured space, plants, furniture and sculpture (Landscape Architect)	the contractor, for further checks on the affordability and the buildability (Contractor); • Risk Assessment Strategy (Architect) • Contractual Proposals (Contractor)

Table 12 Knowledge Flow Elements in Contract Close Phase-Landscape Architect

Information and Knowledge Required	Information and Knowledge Created
• Detailed design (Architect) • suitability of design to the transportation of the children in certain times of the day (Transportation consultant) • Sports England requirements and view on the design and planning permission requirements (Sports England) • BREAM Education 2008 Requirements (BREAM website)	• Detailed landscape architectural layouts, (Architect) • Landscape Master Plan (Architect) • orientation and layouts of hard landscape (paving, curb, edging, walls, external structures, fences, boundaries.), and their specifications (Architect) • typical planting proposals (Contractor)

Table 13 Knowledge Flow Elements in Construction Phase- Sustainability Consultant

Information and Knowledge Required	Information and Knowledge Created
• architectural & M&E design and reports which provides evidence for BREAM checklist such as usage of recycled materials, heating and cooling, isolation, acoustics (Contractor, M&E Subcontractor, Architect, L.Architect Acoustic Consultant, Client)	• Could not produce the report because the designers did not provide evidence. This needed to be done by RIBA Stage E latest.

Table 14 Knowledge Flow Elements in Contract Close Phase-Structural Designer

Information and Knowledge Required	Information and Knowledge Created
• detailed drawings (Architect); • final construction method (Contractor) • specifications from material suppliers (Material Suppliers) • construction drawings (Architect)	• detailed design of the interfaces (Contractor, Architect, M&E services) • detailed structural drawings and specifications (Contractor, Architect) • risk assessments for flood, earthquake • calculations for the Building Control Service

	(BCS) approval (BCS) RIBA STAGE F • Construction drawings involving dimensions, and locations of beams, slab and the columns, connections and interfaces (Architect, Contractor, Subcontractors, Steel Work & Connections Subcontractor, Pre-cast Subcontractor etc)

Table 15 Knowledge Flow Elements in Contract Close Phase- M& E Services Consultant (The consultant was assigned during the RIBA Stage E.

Information and Knowledge Required	Information and Knowledge Created
• RIBA Stage A/B M&E Report (Previous Consultant) • RIBA Stage D+ Design (Architect & Structural Engineer) • Fire Strategy Report (Fire Consultant) • Acoustic Report (Acoustic Consultant) • Cost of equipments (M&E Subcontractor) • Noise calculations for physical plant and optimum locations (Acoustic consultant)	• Stage C Report including room data sheets including required spaces for switch rooms; plant spaces, switchgear locations, void decs, possible electronic and mechanical risers to be used in the building, wiring types, containment routes, standards, preliminary daylight analysis, lighting drawings, ventilation model, heating and lighting calculations, drawings, weight of equipments, marked up architectural and structural drawings (Contractor, Structural Engineer, Architect).

Table 16 Knowledge Flow Elements in Contract Close Phase- M&E Services Subcontractor

Information and Knowledge Required	Information and Knowledge Created
Stage 1	
• Output Specification including location, overall size of the school and the main aim of the school (Client); • Stage C M&E Design showing the locations where the existing gas, water, electricity available and diversions that may be required (M&E Consultant).	• Initial Costing (M&E Consultant & Contractor)

Table 17 Knowledge Flow Elements in Contract Close Phase-Fire Consultant

Information and Knowledge Required	Information and Knowledge Created
• detailed design and drawings (Architect) • view of Architect on passive smoke ventilation methods (Architect) • Room Data Sheets in order to provide fire safety for ICT and ME equipments	• detailed design of the fire safety systems (Contractor); • calculations to prove the fire safety systems defined in the feasibility and bidding phase will be working as planned;

(Contractor)	• exact locations of emergency lighting, means of escape and ventilation; information on signage; specifications of fire alarm system; • Fire Strategy Report which involves types, locations and specifications of fire systems, installation procedures, and fire safety management procedures for the operation of the building (Contractor)

Table 18 Knowledge Flow Elements in Contract Close Phase-Acoustic Consultant

Information and Knowledge Required	Information and Knowledge Created
• M&E strategy drawing, ventilation strategy, external plants (M&E Consultant); • detailed design (Architect) • thickness of floor slabs, floor construction types, type of façade construction (Structure Engineering) • Room schedule (Architect) • External Layouts (Landscape Architect)	• Acoustic Performance Report which involves internal sound insulation (acoustic requirements of the partition types, internal walls, façade, doors, internal glaze screens, floors, and roofs) external noise ingress, room acoustics, ventilation and noise issues, marked up drawings (Architect); acoustic requirements of the mechanical systems and equipments (M&E Consultant)

Table 19 Knowledge Flow Elements in Contract Close Phase-Furniture Supplier

Information and Knowledge Required	Information and Knowledge Created
• sections of the architectural layouts to provide options for furniture for flexible teaching (Architect); • Environmental Schedules (locations of the floor outlet boxes, sockets, lights, and the services (M&E Services). • responsibility matrix for the Delivery of ICT schedule (Contractor)	• Room data sheets which presents exact number and type of furniture in each room (Contractor); • conceptual design of the furniture at a level for allocating the cost for the financial close rather than actual design of the furniture) (Contractor-Architect)

Table 20 Knowledge Flow Elements in Contract Close Phase- Contractor (Project Team)

Information and Knowledge Required	Information and Knowledge Created
• frozen Design to put in the Contractor's Proposal Document (Design Team)	• 'Contractor's Proposal Document' which involves the specifications of the building; methods and procedures of construction, implementation of the services during construction (Client). • cost plans, schedules, design knowledge,

	measures, specifications, health and safety information (Client, Construction team). • 'Access protocol' for the definition and procedure for access of the suppliers to the construction site such as ICT, Furniture Suppliers (Subcontractors &Suppliers).

Table 21 Knowledge Flow Elements in Contract Close Phase- Architectural Metalwork Package Sub-Contractor

Information and Knowledge Required	Information and Knowledge Created
• Design drawings and specifications (Structure Engineer, Architect) • Actual beam size (Structure eng.)	• Pricing for agora staircases, balustrades, AHU (Air handling Units) bases • Connection design including main feature staircases, protection around atrium, balustrades to the concrete staircases, AHU support bases • Subcontractor requirements for AHU design (Subcontractor) Selection is made on cost basis.

Table 22 Knowledge Flow Elements in Contract Close Phase- Cladding &Plasterboard Subcontractor (Externals as lightweight steel walling, brick tie channels, installation of windows, trespa cladding, kingspan cladding, insulation, rock wool, fixings and internal plasterboard)

Information and Knowledge Required	Information and Knowledge Created
• Design drawings (elevation, floor plans and specifications (Contractor) • Fire Strategy drawings (Contractor) • External Access Strategy (Contractor)	• Pricing (Contractor) • List of materials and installation suppliers, sub materials, cost and colour scheme and selection of lightweight steel structures subcontractor (Contractor) Materials supplier selection is made from the contractor's list and installation suppliers were made from the subcontractors list. Selection is made on KPIs as qualifications, tools, location, cost, delivery. • Schedule of delivery and installation

F.3 Construction Phase

Table 23 Knowledge Flow Elements in Construction Phase- Architect

Information and Knowledge Required	Information and Knowledge Created
• Subcontractor's Packages (Contractor) • Final revisions on design issued by client and	• RIBA Stage F full construction drawings (Contractor)

school (Client, School, Contractor) • M&E design updates (M&E Consultant who was appointed by the end of Stage E)	• As Built drawings, record drawings, specifications (Contractor)

Table 24 Knowledge Flow Elements in Construction Phase- Landscape Architect

Information and Knowledge Required	Information and Knowledge Created
• Construction programme, materials to be used, elevations (Contractor) • Doorway design (Architect) • Drainage requirements (Drainage Consultant) • Requirements on planting, landscape management plan (Ecologist Consultant. Normally this consultant has to advice in earlier stages, but their role was not known and noone was aware that BREEAM has a requirement on this)	• set of record for construction drawings including paving, hard works, soft wors, furniture, fencing drawing (Contractor) • Specifications • Redesign of planting plans • As Built drawings, record drawings (Contractor)

Table 25 Knowledge Flow Elements in Construction Phase- Structure Engineer

Information and Knowledge Required	Information and Knowledge Created
• Construction programme, materials to be used, elevations (Contractor) • Subcontractor drawings for approval	• As-Built drawings, record drawings (Contractor)

Table 26 Knowledge Flow Elements in Construction Phase- Sustainability Consultant

Information and Knowledge Required	Information and Knowledge Created
• architectural & M&E design and reports which provides evidence for BREAM checklist such as usage of recycled materials, heating and cooling, isolation, acoustic (Contractor, M&E Subcontractor, Architect, L.Architect Acoustic Consultant, Client)	• Report which shows the credit awarded for the design with a colour code as red/amber/green so the designers can update the parts relevant to their specific area, as material specifications, leak detection for water meters

Table 27 Knowledge Flow Elements in Construction Phase- M&E Services Contractor

Information and Knowledge Required	Information and Knowledge Created
• RIBA Stage E M&E design that shows the locations of the equipments, radiators, heat specification for value engineering purposes (M&E Consultant) • Architects 3-D design (Architect)	• The areas where lower standards may be applicable, cheaper equipments, smaller boilers, pumps, pipes to reduce cost • RIBA Stage F M&E design where fully coordinated 3-D drawings are shown with

• Supplier list recommended and the prices the suppliers offer (M&E Consultant & Contractor) • Updates and changes in terms of BREAM requirements (M&E Consultant, Sustainability Consultant) • List of ICT equipments in each room, their types, data requirements, size and location (ICT Consultant)	exact locations of all equipments, cables, lights, distribution board, void ceilings, height, builders work hole details in order to actually physically install the M&E Services (Contractor, Architect, Subcontractors) • Final list of suppliers and subcontractors and schedule of installation (Contractor, Architect) • Detailed installation information, health and safety strategy (Subcontractors); • maintenance specifications of the equipments during the lifecycle of the building (Contractor, FMS via Contractor). •

Table 28 Knowledge Flow Elements in Construction Phase- M&E Services Consultant

Information and Knowledge Required	Information and Knowledge Created
• RIBA Stage D+ Design (Architect, Landscape Architect, Structural Engineer) • Light fittings (Lighting Supplier) • No interaction with Fire Consultant and limited interaction with M&E Subcontractor although it was essential.	• Stage E M&E Services Design and information including types of pipe works, specifications of pumps, performance specifications of sprinklers, ventilation drawing, chilled water, heating, schedules of equipment, specifications of manufacturers, electronic model for daylight analysis)

Table 29 Knowledge Flow Elements in Construction Phase- Furniture Supplier

Information and Knowledge Required	Information and Knowledge Created
• detailed room layouts (Architect)	• architectural drawings (2D) where the furniture symbols are shown (Architect, Contractor); • updated Room Data Sheets (Architect, Contractor); • detailed furniture design (Architect, Contractor); • production drawings (Factory Team); • Purchasing Order Information which involves numbers, models, requirements for the parts and materials (Suppliers)

Table 30 Knowledge Flow Elements in Construction Phase- Fire Consultant

Information and Knowledge Required	Information and Knowledge Created
• detailed Architectural design (Architect); • detailed M&E Services drawings (M&E Subcontractor); • visual inspection of any mistake (Site Visits).	• Fire Strategy drawings which is a part of health and safety file and building manual. • Fire Risk Assessment information (for this project they did not produce this information)

Table 31 Knowledge Flow Elements in Construction Phase- Acoustic Consultant

Information and Knowledge Required	Information and Knowledge Created
• Subcontractor specification (Architect, Contractor) • visual inspection of any mistake (Site Visits).	• Advices on the acoustic specifications of the manufacturers selected (Contractor) • Testing information (Contractor)

Table 32 Knowledge Flow Elements in Construction Phase- Architectural Metalwork Package Subcontractor

Information and Knowledge Required	Information and Knowledge Created
• AHU detailed design (Subcontractor) • Comments and advices on the design drawings (Structure Engineer, Architect) • Construction drawings (Subcontractor) • List of steel suppliers (Their own database)	• Construction issue drawings for the whole materials package (Structure Engineer, Architect) • Manufacturing drawings (2-D) (Production team) • Installation drawings (Their Site team) • Materials List including stock bars, laser profiles, rubber separators, screws, bolts (Suppliers) • As Built Drawings (Contractor)

Table 33 Knowledge Flow Elements in Construction Phase- Cladding &Plasterboard Subcontractor

Information and Knowledge Required	Information and Knowledge Created
• Design drawings (elevation, floor plans and specifications (Contractor) • Fire Strategy drawings (Contractor) • External Access Strategy (Contractor)	• List of materials (Suppliers) • Construction issue drawings for the whole materials package (Structure Engineer, Architect) • Quality Inspection Planning (Contractor) • As Built Drawings (Contractor)

APPENDIX G

COMPANY C KNOWLEDGE FLOW ELEMENTS

Table 1 Knowledge Flow Elements in Reengineering Phase- Foundary 1 (Responsible for oil filter cover, oil filter cover, sandwich plate, cam shaft casing)

Information and Knowledge Required	Information and Knowledge Created
• Project information such as the main client, the main end product, schedule (Company C); • Material Specifications (Company C); • 2-D original pdf drawings and 3-D CAD Model of the parts (Company C); • Financial quotation for Xray scanning and materials (Material Suppliers and X-Ray Inspection Supplier)	• Quotation for tooling and casting which involves information as part number, quantities, financial value (Company C)

Table 2 Knowledge Flow Elements in Casting Manufacture Phase- Foundary 1

Information and Knowledge Required	Information and Knowledge Created
• Purchase order information • 3-D CAD Model to feed the CNC machines to produce tooling(Company C) • Tests, heat treatment, X-ray scanning and validation procedures/requirements for casting and tooling (Company C) •	• Schedule (Company C) • The list of machines and tools to be used, procedures for the protection of the production area; Technique sheet which involves numbering (as Company C defined) and naming for parts, machining procedures for the parts • Brief on the issues based on the difference between the casting produced based on the 3-D model and the CT scan of the original casting ((Company C); • Crack detection information on the X-rayed parts produced via Inspection Supplier (Company C) • Testing and validation documents for the produced parts (Company C) • Specifications of the produced parts (Company C)

Table 3 Knowledge Flow Elements in Reengineering Phase- Foundry 2

Information and Knowledge Required	Information and Knowledge Created
• Project information such as the main client, the main end product, quantity of the parts required schedule (Company C); • Material Specifications (Company C; internal data) • Client's quality requirements such as xray standards, penetrant standard, acceptable defects (Company C); • 2-D original pdf drawings and 3-D CAD Model of the parts (Company C; internal data); • Usability of the original tooling (Internal knowledge)	• Quotation for tooling and casting which involves information as part number, quantities, financial value (Company C)

Table 4 Knowledge Flow Elements in Casting Manufacture Phase- Foundry 2

Information and Knowledge Required	Information and Knowledge Created
• Purchase order information • 3-D CAD Model to feed the CNC machines to produce tooling(Company C) • Tests, heat treatment, X-ray scanning and validation procedures/requirements for casting and tooling (Company C) • Original technical data sheets for parts (Internal archive)	• Schedule (Company C) • The list machines and tools to be used, procedures for the protection of the production area (Internal production teams); • Non destructive testing results such as dye penetrate testing, X-ray information and films, and visual checks which provides information on the cracks and acceptability level of the defects (Company C) • Chemical and Mechanical test results which makes sure the metal specifications are correct (Company C) • Testing and validation documents for the produced parts (Company C) • Specifications of the produced parts (Company C) • Updated technical data sheet which involves information about the production line, sand types, the chills, the

	mould (Internal production teams) • Updated technical data sheet which involves information about the assembly line (Internal production teams)

Table 5 Knowledge Flow Elements in Reengineering Phase- Shot peening* Supplier

Information and Knowledge Required	Information and Knowledge Created
• Project information such as the main client, the main end product, quantity of the parts required schedule (Company C); • 2-D drawings with specified parts which needs the processing or which needs protecting from the process (Company C); • Financial quotation for shot peening materials as shot beads or cast steel; and for manufacturing the tool (Material Suppliers and Manufacturing Supplier)	• Quotation based on the cost of our process, and any additional cost for tooling that needs to be manufactured (Company C); • The list of machines and tools to be used, procedures for the protection of the production area (Company C); • Engineering specification (Internal) • Technique sheet which involves numbering (as Company C defined) and naming for parts, machining procedures for the parts • Shot-peening Specification (Company C)

Table 6 Knowledge Flow Elements in Casting Manufacture Phase- Shot-peening Supplier

Information and Knowledge Required	Information and Knowledge Created
• Purchase order information (Company C) • Confirmation on the shot-peening process which highlights improvements, changes issues on the Shot-peening Specification (Company C) • Technique card for the arrived parts which will go through shot peening process (Company C)	• Schedule (Company C) • Receipt inspection information which clarifies if there is any defect due to transportation of the parts to the supplier (Company C) • Final visual inspection report after the process (Company C) • Testing and validation documents for the produced parts (Company C)

*Shot-peening is a process where the surface of the component is bombarded using compressed air, so small ball bearings are fired at the surface. Each ball bearing creates an indentation in the surface and it forms a compressive layer into the surface. The process increase the life time of the parts which are prone to stress cracking or erosion in high revolution cycles.

APPENDIX H

NEEDS FOR THE FRAMEWORK

Table 1 The needs for the framework based on the Literature Review and Case Studies

No	Needs for the Framework	Literature Review/ Case Study Based Facts Referring these needs	The thesis section where the need is referred	Framework Process code
1	Integration of SC (timely collaboration and communication between the SC actors)	• To organise relaxed forums, workshops and social networks for relationship improvement between SC actors;	(6.6.2.1) (6.6.2.4) (6.6.2.5) (7.4.4) (8.4.4)	A16 A17 A18 A21 A23 A37 A44
		• To engage the supply chain actors timely to the project and to improve communication between the parties	(2.6.2.2) (3.2.7) (3.2.14) (6.6.1.1) (6.6.1.2) (6.6.2.5) (7.6.1.1) (7.6.1.2) (7.6.1.3) (7.6.2.5) (8.4.6) (8.7)	
		• To make collaborative decisions with the Client and SC actors from early stages of the project	(2.6.2.1) (3.2.14) (6.6.1.1) (6.6.1.2) (6.6.1.3) (6.6.2.5) (7.6.1.1) (8.4.7) (8.6.2) (8.6.3) (8.7)	
		• To integrate the Designers and Specialist Consultants for the preparation of specifications and sub-contract packages	(6.6.1.2) (6.6.1.3) (6.6.1.1) (6.6.2.5) (7.6.1.3)	
		• To integrate the FM team to the Contractor in operational phase to feed the design for future projects	(6.6.1.4)	
		• To keep the SC actors informed about the future work plan	(6.4.7) (6.6.2.4) (6.6.2.5) (7.4.4) (8.4.4) (8.5.4.7) (8.4.8)	

2	Improved Information and knowledge sharing	• To have a clear understanding of the client requirements and timely collaboration with the client	(6.6.1.1) (7.6.1.1) (7.6.1.3) (7.6.2.4) (8.4.6) (8.5.4.6) (8.6.2)	A14 A16 A17 A18 A19 A110 A112 A21 A23 A24 A32 A37 A42 A44
		• To improve information and knowledge flow between the between the Client, Contractor and the SC actors	(2.6.2.7) (3.2.7) (6.6.1.1) (6.6.1.2) (6.6.2.4) (7.6.1.1) (7.6.1.2) (7.6.1.3) (7.6.2.4) (7.6.2.5) (8.4.6)	
		• To clarify the knowledge dependencies between the supply chain actors	(3.2.7) (6.6.1.4) (6.6.2.4) (7.6.1.1) (7.6.1.2) (7.6.1.3) (7.6.2.4) (7.6.2.5) (8.5.4.6)	
		• To learn from projects as a project team including the upstream and downstream suppliers, getting benefit from lessons learned knowledge.	(6.6.1.4) (6.6.2.5) (7.6.2.1) (7.6.2.4) (8.5.4.6) (8.6.2)	
		• To link FM information to construction specifications	(6.6.1.3) (6.6.1.2)	
		• To organise workshops to encourage collaborative knowledge sharing;	(6.6.2.1) (6.6.2.4) (8.4.4) (8.5.4.6)	
		• To plan and organise trainings to improve the knowledge/skill deficiencies of the SC actors	(2.6.2.5) (6.6.2.1) (6.6.2.4) (7.6.1.1) (7.6.2.1) (7.6.2.4) (7.6.2.5) (8.4.4) (8.7)	

3	The need for structured design and construction process	• To identify the opportunities for design standardization-checking repeatability in design, offsite/ DFMA (Design for Manufacturing and Assembly) solutions, fully coordinated BIM modelling early in the project	(6.6.1.1) (6.6.1.2) (6.6.1.3) (6.6.2.4) (7.6.1.2) (7.6.1.3) (7.6.2.5) (8.4.7)	A15 A19 A111 A21 A24 A25 A26 A32 A33 A35
		• To make structured planning and to provide effective design coordination	(6.6.1.3) (6.6.2.4) (7.6.1.1) (7.6.1.2) (7.6.1.3) (7.6.2.4) (7.6.2.5)	
		• To improve the capture of collaborative input between design and construction teams	(6.6.1.3) (6.6.2.5) (7.6.1.3) (7.6.2.5)	
		• To use real time collaboration tools during design and on site to enable seamless transfer of design revisions to construction	(6.6.1.3) (6.6.2.5) (7.6.1.3)	
4	Standardisation of KM process (standardisation of formats, forms, tools and transfer channels to create and share project knowledge)	• To have interoperability between software tools used by the SC actors,	(6.6.1.1) (6.6.1.2) (7.6.1.1) (7.6.1.2) (7.6.1.3) (7.6.2.4) (8.4.6)	A19 A110 A24 A32 A33 A37 A42 A44
		• To explore the opportunities for the effective use of BIM for effective information flow and better visualisation	(6.6.1.1) (6.6.1.2) (6.6.1.3) (7.6.1.3)	
		• To identify the tools, processes and procedures to be used during the creation of design knowledge	(6.6.1.1) (6.6.1.2) (6.6.2.4) (7.6.2.4)	
		• To use a standardised tool for collaborative knowledge sharing with well defined procedures	(6.4.6) (6.4.7) (6.6.1.3) (6.6.2.4) (6.6.2.5) (7.6.2.4) (7.6.2.5)	
		• To identify a unit/people responsible for the coordination and knowledge flow	(3.2.7) (6.6.2.4) (6.6.2.5)	

		• To implement standard procedures to benefit from lessons learned knowledge	(6.6.2.4) (7.6.2.4) (7.6.2.5) (8.6.3)	
5	Standardisation of SCM process	• To plan actions according to the strategic supply chain issues such as becoming leaner, sustainable procurement, establishing long term relationships, balancing between local procurement and national procurement, allocating time and budget for innovation, better procurement planning to prevent delays, improving skill deficiencies.	(3.2.5) (3.2.8) (3.2.11) (3.2.12) (6.6.1.3) (6.6.2.4) (6.6.2.5) (7.4.4) (7.6.2.4) (7.4.7 (8.4.7) (8.4.8) (8.5.4.7)	A15 A16 A18 A23 A36
		• To standardise the supplier selection, evaluation and feedback on the supplier performance process	(6.6.1.2) (6.6.1.3) (6.6.2.4) (7.6.1.2) (7.6.1.3) (8.4.2) (8.5.4.6) (8.7)	
		• To standardise the process of the supplier appointments.	(6.6.2.4) (8.7)	
		• To get input from design team and Specialist Consultants on the selection and performance of the suppliers	(6.6.1.2) (6.6.2.4) (6.6.1.2) (6.6.2.5) (7.6.2.4)	
6	Need for long term, trust based, mature SC relationships	• To establish a culture based on trust and collaboration	(2.6.2.1) (2.6.2.4) (3.2.14) (7.6.2.4) (8.4.3) (8.4.8) (8.5.4.6)	Consistent Application of the Overall framework
		• To benefit from agreements and partnerships to increase trust and to improve confidentiality	(2.6.2.3) (3.2.14) (6.6.1.4) (6.6.2.4) (6.6.2.5) (7.4.4) (7.6.2.4) (8.4.3) (8.5.4.7) (8.7)	
		• To benefit from to past collaborative relationships to improve knowledge sharing	(2.6.2.2) (3.2.7) (3.2.14) (6.6.1.4) (7.6.2.4) (8.4.3) (8.4.6) (85.4.6) (8.6.3) (8.7)	