Integrated Lifecycle Requirements Information Management in Construction

By

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Abstract

Effective management of information about client requirements in construction projects lifecycle can contribute to high construction productivity; within budget and schedule, and improve the quality of built facilities and service delivery. Traditionally, requirements management has been focused at the early stages of the construction lifecycle process where elicited client requirements information is used as the basis for design. Management of client requirements does not extend to the later phases. Client requirements often evolve and change dramatically over a facility's life. Changing client requirements is one of the principal factors that contribute to delays and budget overruns of construction projects. This results in claims, disputes and client dissatisfaction. The problems of current requirements management process also include: lack of integrated and collaborative working with requirements; lack of integrated requirements information flow between the various heterogeneous systems used in the lifecycle processes, and between the multiple stakeholders; inefficient and ineffective coordination of changes within the lifecycle processes; manual checking of dependencies between changing requirements to facilitate assessment of cost and time impact of changes.

The aim of the research is to specify a better approach to requirements information management to help construction organisations reduce operational cost and time in product development and service delivery; whilst increasing performance and productivity, and realising high quality of built facilities. In order to achieve the aim and the formulated objectives, firstly, a detailed review of literature on related work was conducted. Secondly, the research designed, developed and conducted three case studies to investigate the state-of-the-art of managing client requirements information. A combination of multiple data collection methods was applied which included observations, interviews, focus group and questionnaires. Following this, the data was analysed and problems were identified; the necessity for a lifecycle approach to managing the requirements information emerged.

Subsequently, an innovative integrated Framework which defines a lifecycle approach to managing client requirements information was developed; based on *information-centric, process and service-orientation.* It describes how Information Technology (IT) / Information Systems (IS) can serve as support tool to all the project stakeholders. The key features of the Framework include lifecycle requirements information availability; coordination, visibility and audibility of the request for change process; decision support; traceability and dependency checking which is crucial for assessment of cost and time impact of proposed changes in requirements. A prototype system comprising a repository and change management system (CMS) was developed as a proof-of-concept to implement and operationalise the Framework.

Evaluation of the Framework and prototype system was conducted via a focus group comprising industry experts. The findings indicated that adoption of the Framework in construction project lifecycle could contribute towards more efficient and effective management of client requirements information.

Keywords: information, requirements, requirements management, change management, Framework, construction projects, lifecycle

Dedication

I dedicate this work to my Father Mr Sulayman K. S. Jallow and Mother Mrs MamPenda Trawally-Jallow for their parental love and care, and for being the foundation and pillars of my life; and also for their unflinching support, encouragement and understanding.

'Baba' and 'Naa' may Allah reward you for all that you did and still continue to do for me. Amen!

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List of Abbreviations

AEC/FM	Architecture Engineering Construction and Facilities Management
aecXML	Architecture Engineering Construction XML
agcXML	Association of General Contractors XML
AJAX	Asynchronous JavaScript and XML
BIM	Building Information Modelling
BPEL	Business Process Execution Language
BPM	Business Process Management
BPMN	Business Process Modelling Notation
BPMS	Business Process Management System/Suite
BPR	Business Process Re-engineering
CC	Cost Consultant
CD	Compact Disc
CII	Construction Industry Institute
CMS	Change Management System
COBie	Construction Operations Building Information Exchange
CORBA	Common Object Request Broker Architecture
CPU	Central Processing Unit
CSCW	Computer Supported Collaborative Work
CW	Collaborative Working
DFD	Data Flow Diagram
DVD	Digital Versatile Disc
EAI	Enterprise Application Integration
ebXML	Electronic Business XML
EDI	Electronic Data Interchange
eRIM	Electronic Requirements Information Management
ERP	Enterprise Resource Planning
GIM	Grai Integrated Modelling
GUI	Graphical User Interface
HTTP	Hypertext Transfer/Transmission Protocol

IaaS	Infrastructure as a Service
ICT	Information and Communication Technology
IDEF	Integrated Definition
IEEE	Institute of Electrical and Electronics Engineers
IS	Information Systems
IT	Information Technology
J2EE	Java 2 Enterprise Edition
LAN	Local Area Network
M&E	Mechanical Engineer
NASA	National Aeronautics and Space Administration
ODE	Orchestration Director Engine
OGC	Office of Government Commerce (UK)
O&M	Operations and Maintenance
PaaS	Platform as a Service
PDF	Portable Document Format
PDM	Product Data Management
PFI	Private Finance Initiative
PHP	Hypertext Pre-processor
PLM	Product Lifecycle Management
PM	Project Manager
PPP	Public-Private Partnership
QS	Quantity Surveyor
RDBMS	Relational Database Management System
RFC	Request for Change
RFI	Request for Information
RIBA	Royal Institute of British Architects
SaaS	Software as a Service
SCM	Supply Chain Management
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol

SQL	Structured Query Language
UDDI	Universal Description, Discovery, and Integration
UI	User Interface
UML	Unified Modelling Language
XML	Extensible Markup Language
XSLT	Extensible Stylesheet Language Transformations
XPath	XML Path Language
WAN	Wide Area Network
WfMS	Workflow Management System
WS	Web Service(s)
WSDL	Web Services Description Language

Chapter 1. Introduction: Research Background

1.1 Motivation

Information is an organisational resource with high value crucial for the pursuit of market opportunities and the quest for competitive advantage. Within the current business environment governed by technological advances and international competition, organisations worldwide *have implemented, are implementing or looking into implementing* Information and Communication Technology and systems to enable the processing of large amount of information and manage knowledge within and outside their boundaries (Stewart, 2008; Hasan and Gould, 2003). Managing that information to improve efficiency and productivity; to facilitate support to internal and cross organisational business processes, and to enhance documentation, access and share information remains a challenge.

Faster growing market trends as a result of globalisation, growing competition and rapid technological advancements are factors leading to higher customer/client demands for the provision of quality products and services. These demands include faster delivery times with lower budgets whilst maintaining quality and performance requirements. Consequently, projects initiated to deliver such products and services are becoming larger, multinational and more complex with the involvement of different expertise to enable them to be executed globally in multiple and distributed geographical locations. The paradigm shift towards *'product-service system'* (PSS) an integrated product and service offering where consumers seek the utility of services rather than the products that generate the services (Roy and Baxter, 2009), requires the lifecycle management of the products. In a related context, McKay et al. (2008) indicate that the potential value of information and its management in large complex products and projects is increasing dramatically as traditional design and manufacturing organisations change from being suppliers of physical products to suppliers of whole-life product-service systems.

The Architecture, Engineering, Construction and Facilities Management (AEC/FM) Industry is one of the largest and most diverse commercial engineering industries. It develops most of its products and services through integrated project teams and professionals who may be dispersed over several geographical locations (Anumba et al., 2002; Griffith, 2011). The industry is characteristically recognised and dominated by a project-based paradigm of delivery of unique products and services (such as buildings) by multiple organisations (Kazi, 2005). The construction process is known to be information intensive with large amounts of information such as drawings, specifications, bills of quantities generated mostly in paper-based form (Sun and Howard, 2004). History has shown that construction projects are frequently late, over budget and suffer from poor workmanship and materials problems. This often results in conflict and litigation. Many factors are associated to this problem with a major cause being lack of a proper brief or requirements management (Davis and Zweig, 2000; Fernie et al., 2003b; Morris and Hough, 1987). The industry's fragmented nature of product development and lack of integration have also been reported to be the causes of several problems and difficulties, especially with project delivery systems (Bouchlaghem et al., 2004; Latham, 1994; Egan, 1998). The geographically distributed teams and the different heterogeneous systems used make the much needed effective information communication difficult to achieve (Anumba et al., 2002). This is emphasised by Aziz et al. (2006), who state that project teams require on-demand access to information. This necessitates appropriate project information management systems. The industry is also known for the adversarial nature of the relationship between the parties concerned causing disputes and litigations resulting parties such as the clients requiring ways of preventing and resolving construction disputes (Baldwin et al., 1999).

A typical construction project lifecycle comprises of different phases incorporating different stakeholders. Amongst these stakeholders is the client who states the purpose of the project and the needs and expectations to be

delivered or achieved at the end of a project. These statements become the requirements of the project, the foundation for design, construction and use/ operation. In this Thesis, construction project lifecycle is regarded to include all phases of a facility (i.e., preparation, design, pre-construction, construction, operation and maintenance and decommissioning).

Briefing is one of the earliest phases of any construction project. This includes client requirements elicitation, analysis, specification and validation. It is a process to gather and determine client needs, wishes and expectations for a building leading to statements of architectural problem and the requirements to be met (Duerk, 1993; Pena and Parshall, 2001). The briefing process involves understanding the client's needs and articulating them in a way that will make sure the vision of the project is compatible with the resulting product - e.g. building (Austin et al., 2002). The outcome of the briefing process is a *brief*, a document detailing the information about client requirements. This information is a vital resource needed at each project phase: design, construction and through-life of a facility. Traditionally, the brief has remained an unaltered statement of intent. However, the current trend is to look at briefing as an integrated part of the entire construction and project management processes and not just as part of an early stage (Worthington, 2000). This is important because client requirements often change dramatically over a facility’s life. This evolution needs to be understood as, for example, if the facility is to be refurbished or adapted for uses other than those for which it was originally designed, it is necessary to review all the client requirements.

Client requirements information management is becoming more challenging as a result of increasing needs and expectations of stakeholders. Rezgui et al. (2009a) recognise that the construction industry is faced with the challenge of extremely demanding clients and users whose requirements of buildings vary considerably from one project to another. Information about client requirements needs to be managed across the entire life cycle phases and

between all stakeholders (*e.g. between clients and designers*). However, lack of a common language is a major problem that hinders the exchange and communication of requirements information between stakeholders (Austin et al., 2002). It is the client requirements that form the basis for design and subsequently construction. Information collected during briefing must be properly documented in order to enable effective communication among project team members (Pena and Parshall, 2001). This research has identified and echoed that requirements information and their management are commonly dealt with and concentrated at the early phases of construction projects and become disjointed in subsequent phases. Once design begins and progresses, these requirements are left aside and the design is used to interpret client wishes. A similar observation is made by Kiviniemi et al. (2004), who state that building programme documentation is the starting point of the design process but is usually left aside and all incremental changes are made based on the previous design solution. Kamara et al. (2002) also indicate that changes to requirements are recorded as corrections or additions to sketches and drawings as the main medium for representing the brief, and not on the original brief; making it complex to trace requirements to the original needs of the client.

As the construction industry becomes increasingly dynamic due to global competition and clients' demand for delivery of quality facilities within time and budget; the quest for more efficient and effective management of client requirements becomes inevitable. This requires organisations to be agile which can also lead to competitive advantage for those firms that excel in it. "Agility is an overall strategy focused on thriving in an unpredictable environment" (Sanchez and Nagi, 2001). Stanoevska-Slabeva and Wozniak (2010c) indicate that agility is considered the key success factor for companies operating in dynamic business environments, and is the ability to rapidly and straightforwardly change businesses and business processes beyond the normal level of flexibility to effectively manage unpredictable external and internal changes. Tavčar and Duhovnik (2005) also state that the

agility of an enterprise is reflected by its capability to manage engineering changes efficiently. It is important to safeguard and maintain client requirements along with all subsequent changes to them throughout the project and building lifecycle. This is not only useful when adapting the building or facility for purposes other than those for which it was originally intended, but also relevant to provide information for compliance and regulatory purposes and project assessment. A series of efforts have in the past been made to manage client requirements within construction but no known technique takes a lifecycle approach incorporating requirements change management. In order to achieve efficient and effective client requirements management within construction for the delivery of quality facilities that meet client satisfaction, requirements management should be approached as an *information-centric, process* and *service-oriented* project management activity. In this Thesis, *process-orientation* is to regard the management of requirements from the point-of-view of lifecycle activities that are central to that management; how they are related across the lifecycle phases and executed by both people and systems. *Information-centric* takes a shift to managing the content of documents (i.e., the information itself) rather than the documents they are contained in. *Service-orientation* is to regard the development and operationalisation of software systems from the view-point of ‘services’ (i.e., independent software components) that perform specific functionalities for managing requirements information, and how they can be integrated, requested and consumed.

Increasingly, client requirements management is perceived as a necessary project management activity for proper and disciplined management of the information regarding client needs and expectations of buildings from design, to production, operation and maintenance and ultimately disposal or decommission.

Managing client requirements including their communication is not an easy task because of the large volume of information that comprises the

requirements as well as inputs from the many different people involved in the process (Charoenngam et al., 2003). According to Gallaher et al. (2004), a large number of contractors and subcontractors are often involved in large construction projects all sharing information and designs; huge delay cost can be caused in finding documents. Another major factor is the complex nature of collaboration in construction projects and the user groups especially in projects where different users have individual requirements for a building. This requires coordinated and planned structures to support requirements information management. Collaborative working is thus a fundamental quality of requirements information management. Currently, there is little support for distributing and congregating the activities of the management process amongst the people who are involved in it. Management of the requirements information is important for visibility, tracking and traceability of client needs which are crucial for the management of changes. It can also facilitate better requirements exchange, collaboration and concurrent processes in an extended dynamic enterprise.

1.2 The Research Gaps and Problems

The literature review and case studies identified major research gaps and problems of managing information about client requirements within the construction industry. These are as follows.

i. Lack of a defined approach to effectively manage client requirements information through the building lifecycle. This includes managing the requirements at each phase and between all stakeholders.

ii. Lack of an established process and system to support requirements information management collaboratively within a distributed environment.

iii. Lack of a centralised and single point repository of requirements through an information management system. The main driver for this

being the fact that requirements are currently documented and archived using paper copies and manual processes. This proved to be laborious, error prone, inefficient and ineffective to facilitate sharing and distribution in a distributed construction environment.

iv. Inefficient facilitation for a coordinated and controlled requirements change management process through the application of a change management system. This need was driven by the fact that an effective requirements change control process involves multiple and iterative activities between different stakeholders. The state-of-the-art is cumbersome and requires a defined and structured approach to facilitate excellent coordination, visibility, and historical support.

v. Lack of a defined and established process to sufficiently capture requirements change history during the change request process and to update this information in the brief or requirements repository.

vi. The enhancement of the integration and interoperability of systems used for the management of requirements information, specifically between the repository and change management systems. The basis of this being computer systems used for the management of construction information are largely in silos lacking integration and interoperability. Thus there is need to provide systems that will integrate and operate harmoniously no matter the IT infrastructure and or platform used.

1.3 Research Questions

According to Robson (2002), generating research questions may be stimulated by theoretical concerns. As a result, this research ‘addresses’ the following research questions based on the research gaps and problems identified in Section 1.2. The research questions are as follows.

- Can the state-of-the-art of client requirements information management in construction projects take a lifecycle/through-life approach?

- Would a collaborative and distributed work to managing client requirements improve the state-of-the-art?
- Is a data/information-centric orientation to managing client requirements information better than the current document-centric approach?
- Can a process-orientation facilitate a more coordinated and controlled requirements change process than the current method?
- How is the assessment of cost and time impact of changing requirements conducted? Is this process efficient and effective? If not, how can it be improved?
- Does the state-of-the-art consider requirements information flow as an integrated process between different parties, systems and lifecycle phases? If not, how can this be enabled?

These questions were put forward to help the research understand what the eRIM Framework must define and accomplish. Consequently, in order to answer these questions and solve the requirements information management problems within construction, this research set out to achieve the following aim and objectives:

1.4 Aim

This research aims to specify a better approach to requirements information management to help construction organisations reduce cost and time in product development and service delivery; whilst increasing performance and productivity, and realising high quality of built facilities.

This can be achieved through a facility lifecycle requirements information management approach to support accessibility, visibility, traceability and requirements change management in construction.

1.5 Objectives

To meet the aim of the research, the following objectives were established.

- Provide a detail review of the state-of-the-art of client requirements information management (RIM) in collaborative construction projects lifecycle (CCP).
- Identify inefficiency and ineffectiveness in existing methods, and define improvement for better client requirements information management across facility lifecycle phases.
- Develop an innovative integrated framework to enhance lifecycle requirements information management and to support production and service delivery business processes.
- Develop and evaluate a prototype of the framework base on information-centric, process management and service-oriented architecture.

1.6 Benefits

It was anticipated that achieving these objectives would provide the following benefits.

- Facilitate better documentation, storage mechanism, access, communication and distribution of client requirements information amongst all stakeholders across the lifecycle phases.
- Provide a comprehensive and improved mechanism of coordinating and controlling the client requirements information change management process, and also effective dependency checking for cost and time impact assessment of changes; enable tracking, visibility, and audit trail.
- Eliminate or reduce design and construction re-work due to lack of efficient and effective requirement change management process.
- Contribute to reducing cost and time of project delivery and improve on quality of built facilities.

- Contribute towards integration of requirements management related business processes across the lifecycle phases.

1.7 Scope

The scope of this research covers the period from when the brief is produced, through design and construction and all through the life a building. This means the research does not consider the mechanism of the briefing process, the rationale is that no matter what approach was used to produce the brief, client needs, wishes and expectations would eventually be generated and processed to become the requirements. This means that any information in the brief as client needs and expectations is been considered as requirements. The research therefore concentrated on how the requirements information in the brief are managed at each lifecycle phase of a facility and between all stakeholders. It also focused on the mechanisms involved in the management of the requirements information including the documentation, storage, access and exchange, managing requirements changes and their associated history, traceability, and dependency checking for impact analysis; updating and communicating those changes as notifications when changes are approved.

1.8 Risks to the Research

Following a thorough appraisal of research methods, data requirements, stakeholder participation and cooperation, and resources required; the following risks to the successful execution of the research were identified.

- Lack of access to construction projects to carry out research activities. This was considered a high risk factor as it was necessary to attract industry participation and gain access to ongoing construction projects in order to study and understand current client requirements, information management practice and to also appreciate the real industrial problem. To address this risk, supervisor and researcher contacts were used to attract the participation of industry contacts on current construction projects.

- Challenges to develop the intended or anticipated prototype system within the timescale of the research. Even though some of the required expertise to develop the system was available in the research, some of the implementation skills and technology such as integration and interoperability would be complex. This would require additional skills to complete the research. Consequently, a training scheme was developed during the research to provide education and skills training to secure the necessary expertise.
- Lack of availability of resources and tools such as the computer hardware and software required for the development and implementation of the prototype system. This required high specification computing and specialist software that was not readily available. Subsequently, links were established with other institutions to help contribute to providing the software required. High specification computing equipment was also purchased from researcher's private fund to meet the needs of the project.

The research gaps and problems extend from the need to complete projects on time, within budget, and with quality. This is a major challenge facing today's project managers (Mahaney and Lederer, 2010) and demands effective communication. It is noted that "generally, effective communication is about exchanging meaningful information between groups of people with the aim of influencing beliefs or actions" (Shehu and Akintoye, 2010). It is anticipated that this work will contribute towards addressing some of the failings within the construction industry which in most cases results in cost overrun and limitation of quality of built facilities. With increasing global competition and the quest to provide products (including buildings) that meet all project constraints (i.e., time, budget and quality as well as performance); the current client requirements information management practice within the construction industry is not sustainable. The industry cannot depend on the manual and paper-based practice as a basis to produce bigger and more

complex projects undertaken with vast amount of requirements information generated, processed and managed. The industry has to efficiently and effectively manage information about client requirements through a sustainable management approach. Generating new ideas and approaches as a framework to this effect is essential. Equally, if not more important, is the need to transform and implement the Framework into a working information management system incorporating and utilising the technological benefits embedded within it for better client requirements information management. Consequently, this led to the development of eRIM.

1.9 Thesis Structure

1.9.1 Chapter One: Introduction

This introductory chapter gives a general overview of the research; it describes the background to client requirements information management, the motivation to carry out the research as well as the aim and objectives. The scope of the research is discussed and the anticipated potential industrial benefits to be achieved identified. Problems and research gaps identified in the literature and through the case studies are also discussed.

1.9.2 Chapter Two: Project & Information Management, and Collaborative Working

This chapter reviewed project management in construction projects drawing relevant experiences from other industries such as project failures and their causes. The value of information to organisations was examined and the importance of managing that information in project environments with emphasis on its contribution to successful project development and delivery. Enterprise integration and systems, and collaborative working practice were reviewed with the aim of establishing its relevance not only to facilitate integrated project teams but also its contribution in the client requirements information management process. Building information modelling (BIM) was

evaluated to understand its contribution towards lifecycle building information sharing and exchange.

1.9.3 Chapter Three: Requirements Management

This chapter provides a critical review of existing literature and related work in information and requirements management as applied within the AEC/FM industry. The reviewed also included requirements management in other industries. A broad overview of requirements information and its management from different perspective is presented focusing on how information is collected, documented, stored, accessed, distributed and communicated between all stakeholders and across all project phases - i.e. information flow (share and exchange). Also discussed is how changes to requirements information is managed with respect to the coordination and control between those involved in the process and how those changes relate to the general requirements management principles with considerations on dependencies between requirements, traceability and impact analysis. Techniques and tools used in managing requirements information management, benefits realisation and value management are also reviewed.

1.9.4 Chapter Four: Business Process Management (BPM), Service Oriented Architecture (SOA) and Web Services

This research presents a process management orientation to managing requirements information and associated change processing as a component of the Framework. Chapter 4 studies theories and practice of work relating to process management from both a business and a technical point of view. Thus literature on business process management was reviewed, focussing on process modelling, automation and implementation.

Inter-organisational/enterprise business processes as applied in a collaborative context with detail on integration and interaction between people, processes, information and systems are reviewed and analysed.

The chapter also documents the philosophical theory of Service Oriented Architecture (SOA) and the associated web services (WS) technology. A review of the associated problems and difficulties of systems integration and interoperability is carried out to understand the need for a SOA approach to systems development and WS implementation to facilitate solving this problem. Current trends and technological development within this domain are analysed with the view to comprehending its applicability to the topic of this research.

1.9.5 Chapter Five: Research Methodology

The methodology adopted by this research is discussed in this part of the Thesis. Firstly, a general overview of the different types of research (Qualitative and Quantitative) is reviewed as well as research philosophy and perspectives of research (positivism and Interpretivism) and research approaches (inductive and deductive). An appraisal of data collection methodologies was conducted with a view to selecting the most appropriate for this research. The chapter also discusses the research design and how it was applied with details of the research questions addressed.

1.9.6 Chapter Six: Case Studies and Analysis

In order to solve the research problem defined in this work, a roadmap was defined which specified how the necessary data were to be collected and analysed. As a result, three case studies were conducted. This chapter discusses these case studies detailing the research approach and methods taken, the data collected and how these data were analysed and presented. Discussion of the results was made and a summary was made at the end with implications for the development of the Framework.

1.9.7 Chapter Seven: The eRIM Framework

Following the collection and analysis of data from the case studies, the Electronic Requirements Information Management Framework (eRIM) was developed. In this part of the Thesis, the development process of eRIM is

presented describing the constituents and their features. This also describes the methodological process taken in the development and the rationale behind the components based on requirements management theory and the quest to solving the described problems and bridging the research gaps.

1.9.8 Chapter Eight: Prototype Development and Evaluation

A software prototype was developed as a way of implementing eRIM as a proof-of-concept. The prototype comprises a requirements repository and a change management system. This chapter explores the development process of the prototype with a detailed discussion on the technology, the tools and the rationale behind their selection. The evaluation of the Framework and prototype is also explained.

1.9.9 Chapter Nine: Conclusions and Recommendations

This chapter summarises the work and identifies the conclusions of the research including the limitations to the study. It also provides recommendations and guidelines for future research to enable the extension of the Framework produced into an industry environment.

Figure 1.1 shows a graphical representation of the structure of the Thesis and how the different chapters are linked.

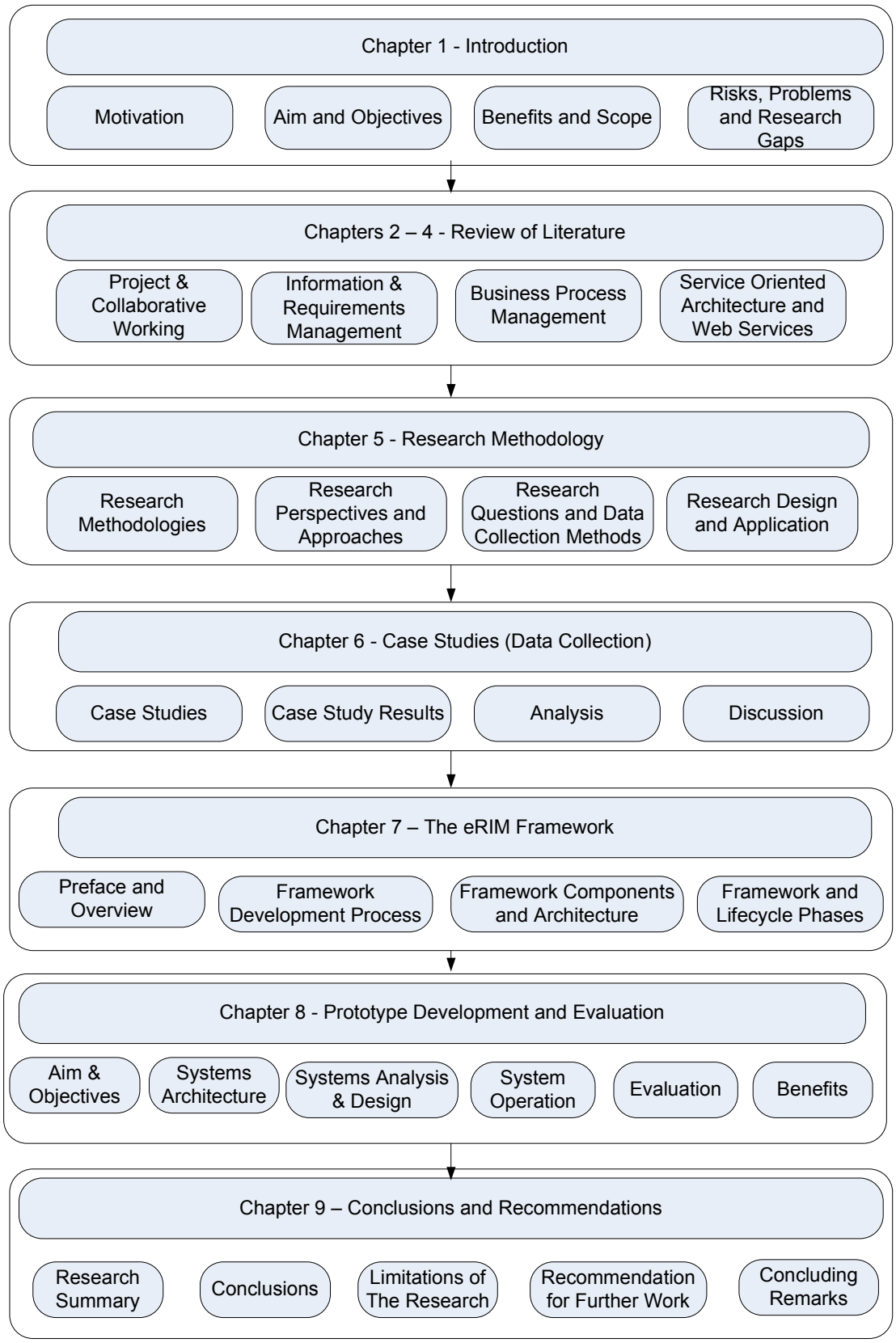


Figure 1.1: Thesis Structure

Chapter 2. **Project & Information Management, and Collaborative Working**

"Information is the life-blood of a construction project. Too little and the project becomes starved; too much and it becomes swamped"
(Brian Atkin, 1995).

2.1 Introduction

The primary focus of this chapter and the next two (i.e., Chapter 3 and 4) is to present the general review of literature and related work in requirements information management in AEC/FM industry in order to establish the research context. The review included other industries where the discipline is well established such as software and systems engineering, aerospace and manufacturing but not limited to those. This particular chapter will discuss the fundamentals of requirements management in projects including project management, information management, and collaborative working.

As discussed in Section 5.9.2, the review began by identifying key words within the sphere of the topic to use in finding relevant literature. The sources of such literature included: books, journal papers, conference papers, white papers, reports, government publications amongst others. Scientific journal databases, library catalogues, conference proceedings and other library and online sources were used to access sources of materials. The literature was divided into two main categories *primary* and *support literature*. The primary literature is made up of information management, Building Information Management (BIM), project management, enterprise systems, collaborative working and requirements management. The support literature is service oriented architecture (SOA), Web Services (WS) and business process management (BPM). The primary literature was regarded as the essentials of requirements management in construction projects, a domain in which this research makes a theoretical contribution to knowledge. The support literature was termed as the tools crucial for the implementation of the concept and to

facilitate the electronic management of requirements information. This is illustrated in Figure 2.1.

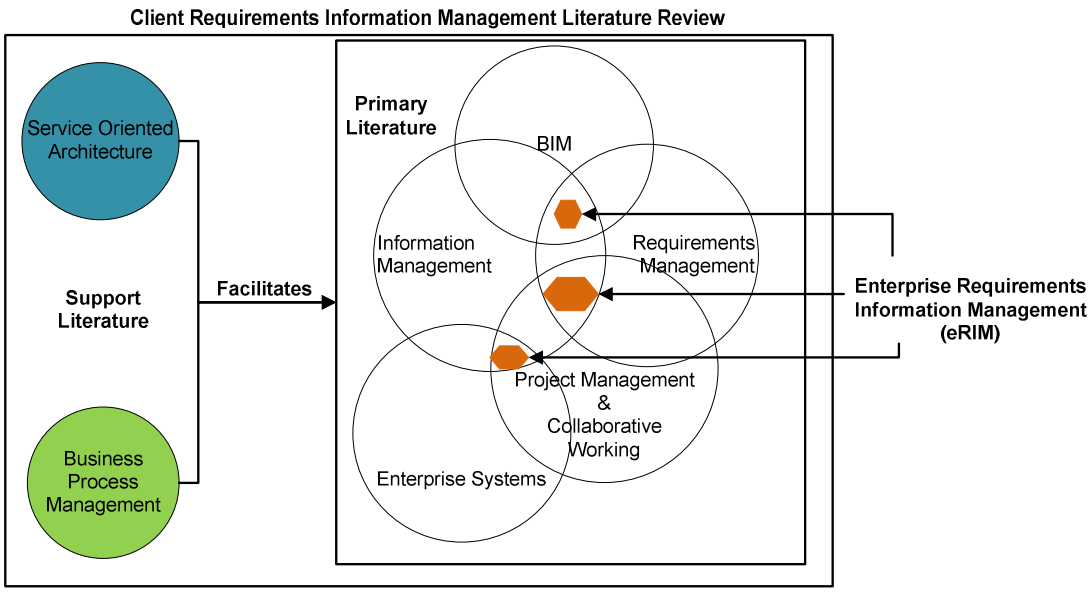


Figure 2.1: Literature review subject areas

In order to establish a foundation to the presentation of the review, the key areas of requirements management including project management, collaboration and information management will be examined first before discussing the main topic. The chapter ended with a summary of the key areas of the review.

2.2 Project Management

It is fundamental to first discuss ‘what is a project’ before deliberating on the theory and principles of project management. A project is recognised as a temporal endeavour that is initiated and performed to produce a unique outcome (The Project Management Institute, 2004). This outcome could be a ‘hard product’ or ‘soft product’. A ‘hard product’ is regarded as physical in nature such as a mobile phone or a building whilst a ‘soft product’ is non-physical such as software or a service. The Office of Government Commerce (2009b) defined a project “as a unique set of co-ordinated activities with a finite duration, defined cost and performance parameters and clear outputs to

support specific business objectives." Projects are constrained by factors such as budget and time and consume both material and human resource efforts in their execution.

Project management is a discipline concerned and focused on the delivery of projects according to the requirements specified and defined by the client and/or customer. According to The Project Management Institute (2004), project management is a discipline geared towards directing and coordinating project resources (both human and material) all through the life of a project (from inception to handover) in order to achieve the predetermined constraints (cost, time, quality and scope). It involves the use of modern management skills and techniques. The Project Management Institute (2004) also states that project management is accomplished through the application and integration of the project management processes (i.e., initiating, planning, executing, monitoring and controlling, and closing) utilising knowledge, skills, tools, and techniques to meet project requirements. Forbes and Ahmed (2011) indicate that in the project environment, the project management's role is to activate and articulate unique networks of commitments between the stakeholders that form a project team.

History has shown that large and complex projects typically suffer from a lack of good project management practice. This results in project failures. In almost every industry, this problem has been reported. The Chartered Institute of Building (CIOB) (2011) recognises that delayed completion affects all industries in all countries ranging from oil and gas, civil engineering, IT, process plant, shipbuilding and marine work contracts; and the bigger the project, the more damage delayed completion causes to costs. In the software industry some development projects are abandoned before they are completed. According to Mahaney and Lederer (2010) and Tesch et al. (2007), too many others exceed their initial budgets; some are completed beyond their target dates, whilst some lack the expected quality or performance requirements. In some cases, projects are cancelled before completion. A noteworthy information systems project failure in the U.K. was the London

Ambulance Service Computer Aided Despatch System. The system was to automate the human intensive functions of the Ambulance Service but when the system started operating; system faults resulted in ambulances sent to wrong addresses and in some cases, arriving late amongst others. This resulted in the loss of lives (Beynon-Davis, 1995). In the construction industry, projects are rarely abandoned once commenced. However, many mega infrastructure projects fail to meet client's requirements. Some get completed on schedule and on budget but fail to meet the needs of users. An example is Heathrow Terminal 5, one of Europe's largest and most complex construction projects (Potts, 2008) which, on its opening day, faced multiple problems resulting in the cancellation of flights and loss of passenger luggage (Brady and Davies, 2010). Analysis of the Terminal 5 project indicates that inadequate client requirements management contributed to the problem. Project management processes implemented to deliver such projects therefore have to incorporate innovative approaches to managing the different aspects of the project through all its life phases. Several issues are reported to cause project failures which include lack of stakeholder involvement, inadequate management of client/customer and user requirements, incompetent development team, lack of effective risk management and planning and monitoring structures amongst others. In the agriculture industry, several projects aimed at food self sufficiency and poverty alleviation particular in Africa have failed. According to Kakonge (1995), many agricultural projects in Africa have failed to achieve what was expected of them over the last years. Kakonge cites several causes including poor planning, lack of experience, bureaucratic inefficiency, technical incompetence, poor performance of government and donor agencies, complexity of agricultural projects, and unpredictable climate. Shrestha and Chhetri (1996) report that in developing countries, similar projects operate in the same region, but effective collaboration between them is often seen to be lacking; yet the need for collaboration has often been stressed by both planners and administrators.

For a project to be deemed successful, it has to be completed within the defined constraints (budget and time) and meet the quality and performance requirements. This is a challenging task, thus, efficient project management must be applied in a manner that adequate management procedures are put in place to transform client requirements into finish products. The functions of construction project management include: defining client's requirements; establishing a good communications channels in which all parties can perform effectively; developing and managing a change control procedures; and monitoring all decisions and approval in respect of the programme (Royal Institute of British Architects - RIBA, 2007). Project failure has been common over the past few years and amongst the notable common causes of failure is the lack of adequate, robust and effective project team integration between clients, the supplier team and the supply chain (Office of Government Commerce, 2005).

The Project Management Institute (2004) indicates that describing and organising the work of the project are the concerns of project management processes which can be categorised into five major groups as shown in Figure 2.2.

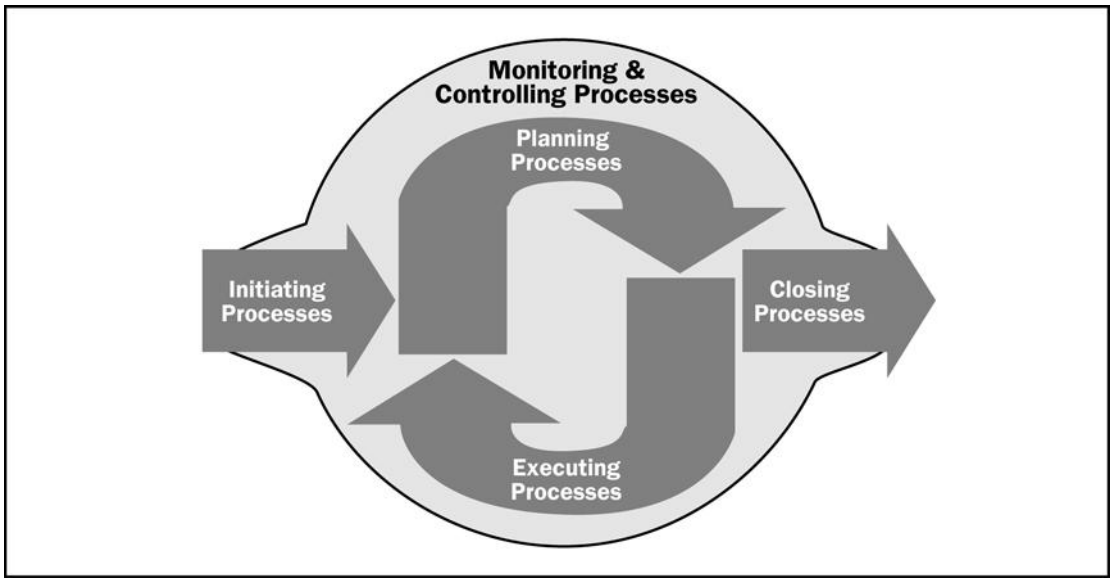


Figure 2.2: Project management processes groups
Source: (The Project Management Institute, 2004)

Each of these processes is explained as follows according to The Project Management Institute (2004).

- "Initiating Process Group. Defines and authorizes the project or a project phase.
- Planning Process Group. Defines and refines objectives, and plans the course of action required to attain the objectives and scope that the project was undertaken to address.
- Executing Process Group. Integrates people and other resources to carry out the project management plan for the project.
- Monitoring and Controlling Process Group: Regularly measures and monitors progress to identify variances from the project management plan so that corrective action can be taken when necessary to meet project objectives.
- Closing Process Group: Formalizes acceptance of the product, service or result and brings the project or a project phase to an orderly end."

Griffith (2011) identifies the following three key processes businesses use to carry out their business and all are clearly within the total construction processes.

- Core processes: these are processes that are directly engaged in producing the product or the service. They are essential to the success of the business.
- Support processes: these are processes executed to ensure the efficiency and effectiveness of the core processes. This means they are indispensable to supporting the core processes.
- Assurance processes: these are processes performed to guarantee the fulfillment of policies and responsibilities; and conduct of organisational and operational procedures appropriately.

Project management is not an easy task and construction projects are complex; project managers face output performance requirements problems

with time, cost, quality, etc (Griffith, 2011). This research focuses on managing client requirements. These are made up of a large amount of information that is needed throughout the project by all the different stakeholders in multiple and distributed locations. It has emerged through this research how important managing client requirements is within construction. Project managers must devise means of managing this information collaboratively to facilitate the work of distributed project team members. As argued by Atkin (1995) “Information management has to be seen as a necessary function, one that is key to the efficient management of a project.” Making project information available to project teams all through the lifecycle of construction projects is vital for successful completion of projects (Kong et al., 2005). It is necessary to manage the information exchange and sharing between distributed project teams and heterogeneous computer systems. However, effective integration and collaboration between the various stakeholders can also be negatively affected by their cultural dimensions. In proposing a Framework for multicultural project performance, Ochieng and Price (2009) highlight that it is essential not to lose sight about the factors associated with multicultural teamwork on projects and effective team performance; which requires greater fluidity and flexibility; as well as open decision making, commitment and good interpersonal skills.

Communication of information is essential both for the success of individual construction projects and for companies to remain competitive in challenging operating environments (Dainty et al., 2006). This is relevant to, and must take place, between all stakeholders and across project phases. To date, paper-based methods have been used extensively in the construction industry for information communication but are inadequate to achieve effective and successful communication across different disciplines and different locations (Anumba et al., 2008). Information and Communication Technologies (ICT) are now used extensively to communicate project information. Such technologies range from computer-based systems such as web-based systems, project extranets, Radio-frequency Identification (RFID), mobile

applications amongst others. However, despite their remarkable success, integration and interoperability between these systems remain problematic.

From the discussions of project management of the different industries in this section, several themes have emerged as contributing factors to project failures. These include *complexity of projects* and *lack of collaboration* and *information sharing* between projects and their stakeholders. In order to execute development projects successfully, factoring the different lifecycle phases of a project and the different processes and resources involved, teams and all other stakeholders have to work in unison and collaboratively; where integration, coordination, cooperation, and communication and information delivery has to be integrated within their activities and general project processes.

2.3 Enterprise Systems and Integration

Every organisation or enterprise has several functional areas/units each with defined processes to execute business transactions. Each functional area will model workflow processes which define how their business functions are performed. Some of these are services made available to other parts of the organisation (Cummins, 2002). The availability and use of these services demands integration between the different organisational departments/units thus creating cross functional processes. This requires management of the business processes across the functional departments/units. Cummins (2002) emphasises that managing business processes with workflow management facilities for process visibility and manageability is the goal of the enterprise integration architecture.

Enterprise systems aim to support the business processes of an organisation across any functional boundaries that exist within that organisation. They use internet technology to integrate information both within the business and with external stakeholders such as customers, suppliers and partners (Laudon and Laudon, 2010). These systems cross functional areas and facilitate business process execution across a firm's functional areas/units at all levels of

management. They help in product and process information management including the sharing of information amongst teams and between stakeholders. Such systems include: product lifecycle management, enterprise resource planning systems, customer relationship management systems and supply chain management systems. Integration is a key element for the functionality of these systems. According to Laudon and Laudon (2010), the business value of these systems include: increased operational efficiency and effectiveness; provision of firm-wide information to support decision making; enabling rapid responses to customer requests for information or products and the inclusion of analytical tools to evaluate overall organizational performance. One of their key aims is to eradicate the fragmented nature of the traditional functional areas in organisations thus bringing about the '*integrated organisation*'.

Enterprise Resource Planning (ERP) is one amongst such systems. ERP systems are increasingly being implemented in an attempt to standardise, integrate and automate organisational business processes (Belmiro and Pina, 2001). These systems integrate the different functional units of a business and stores data in a single central repository. They are vital in solving problems of fragmentation and silos of information, coordination of day-to-day operations and assist management by providing valuable information for improving decision making (Laudon and Laudon, 2010). Properly implemented, these systems can boost the performance of business processes and provide organisations with integrated information across functional areas; contributing towards improved supply chain and faster product development (Belmiro and Pina, 2001; Davenport, 1998; Shehab et al., 2004). This contributes to competitive advantage. This approach to integration can be very useful to construction projects to integrate the different project lifecycle phases in order to facilitate collaboration and solve the fragmentation difficulties.

Enterprise systems are important in today's enterprises and determine how businesses perform their business processes and deliver products and services. Their implementation and operation are crucial to facilitating internal

and external integration and enabling collaboration between business entities. Information sharing across organisation functional areas and between suppliers, customers and other business partners is relevant to success and these systems can facilitate that success.

2.4 Collaborative Working (CW)

2.4.1 Introduction to Collaborative Working (CW)

Many businesses nowadays perform their operations in several geographical locations using multiple teams and partners. Rittinghouse and Ransome (2010) underscore that global projects with teams that are increasingly decentralised have been created as a result of the global nature of the workforce and business opportunities. Construction companies develop their products, and related business processes and services in different dispersed locations (Wilkinson, 2005; Anumba and Ruikar, 2008). This requires team members to interact virtually, and to collaboratively access and share product and/or service related data and information (Wang et al., 2010). Sometimes, these operations are conducted with partner organisations, which also require interaction between the organisations involved.

The National B2B Centre (2007) defines collaborative working (CW) as the act of people working together toward common goals, lowering cost, facilitating efficient, effective and more coordinated teams. CW enables and enhances collaboration and interaction amongst partners on the development of a project or product regardless of their locations and incorporating information and communication tools (Mejia et al., 2007; The National B2B Centre, 2009). Globalisation, competition and the need of expertise from different teams are amongst the key factors towards this trend; and ICT tools are enablers of the process.

Within the construction industry, CW is hugely employed in projects through which buildings and other facilities are developed. As recognised by Kamara et al. (2000), Otter and Emmitt (2007), Anumba et al. (2002) and Emmitt and Gorse (2007), different professional disciplines and stakeholders from

different organisations, using different information systems and technology are involved in the design and construction of the facility demanded by the client which requires collaborative working. Erdogan et al. (2008) also recognise the need for CW in construction due to the nature of projects which are multiorganisational and geographically dispersed. Integration and Collaboration overcomes the fragmentation that has come to characterise the construction process (Forbes and Ahmed, 2011; Egan, 2002). An integrated team includes the client, as well as all those involved in the delivery processes who are pivotal in providing solutions that will meet client requirements; and requires team members to harness the potential of their integrated supply chains (Egan, 2002). Collaborative working is a characteristic of an integrated practice, which is a holistic approach in which all project stakeholders and participants work in highly collaborative relationships throughout the complete facility lifecycle (Elvin, 2007). In other words, referred to as collaborative working practices, methods and behaviours; integration promotes an environment where information is freely exchanged among the various parties in a construction project (Baiden and Price, 2011). It is regarded as an excellent alternative to the traditional *over-the-wall* method where the separation of the disciplines makes communication and coordination more difficult (Kamara et al., 2002; Elvin, 2007). Elvin added that this sequential method is regarded to slow information exchange as activities of one phase must be completed in principle before any subsequent activity can begin; and can increase project costs and programme, creates waste and reduces building quality. Integration and decentralisation trends in the construction industry have resulted towards using collaborative processes allowing project teams to participate from the early stages of a project (Aziz et al., 2004). Such stages include preparation where client requirements should be processed to facilitate CW (Kamara et al., 2000) and a lifecycle approach to managing those requirements should be employed (Jallow et al., 2008). In modern business environment as recognise by Combe (2006), collaboration between organisations is a key aspect and technology such as the *internet* can play a vital role in the communication between partners. Jokinen (1996) also

recognises that the internet is an advancing technology, an infrastructure which makes an excellent platform for distributed applications where different types of information can be accessed collaboratively from different locations. Consequently, distributed systems have been developed using the internet as the backbone for the access, retrieval and communication of project information (Bridges, 1997). Bouchlaghem et al. (2006) argue that communication tools are required to facilitate collaborative team interactions. The fragmented nature of the construction industry coupled with the quest to remain competitive and meeting clients' needs, collaborative working emerged as a new way of working (Shelbourn et al., 2007). Therefore, it is vital that enabling ICT tools are available to facilitate effective collaboration (Anumba et al., 2002). Such ICT tools to support collaborative working are captioned under Computer-Supported Collaborative Work (CSCW) which has received huge research attention and its application domain include distance learning, concurrent engineering, workflow management, computer-assisted design/manufacturing/software engineering amongst others (Grudin, 1994).

2.4.2 ICT Tools for Collaborative Working

The desire and demand for high quality and quick delivery of construction projects requires the participation of different teams making effective communication a challenge. Accordingly, there has been the need for effective utilisation of ICT tools (e.g. CSCW) for effective collaboration to facilitate communication. The main goal of these tools is to support people working together who may be separated by time or space to complete collaborative work and improve individual and collective efficiency (Chen et al., 2010). These tools facilitate project participants to work collaboratively from isolated locations and they have huge benefits to construction projects (Anumba and Ruikar, 2008). This is emphasised by Forbes and Ahmed (2011) that communication tools (such as Email, the most common), overcome the barriers of time and distance by helping design and construction organisations to coordinate their activities with greater effectiveness and efficiency. They are often referred to by many different names by different

authors such as virtual workspace systems, collaboration environments, web-based systems, computer-mediated tendering systems, construction project extranets amongst others (Wilkinson, 2005; Erdogan et al., 2008; Yeomans et al., 2005; Ruikar et al., 2005). Project extranets make use of a central shared storage drive and are increasingly being used and relied upon widely by construction teams for information exchange and collaboration (Wilkinson, 2005; Yeomans et al., 2005; Moses et al., 2008). They facilitate the access of project documents but are temporary repositories for the duration of projects and they do not also adequately provide process management (i.e., coordination of information flow between humans and systems and across lifecycle phases of a building). They are document-centric rather than data/information-centric (Chassiakos and Sakellaropoulos, 2008). This means they help to manage the documents themselves rather than the information they contain. Wilkinson (2005), explains that "all the drawings and other documents that have been published to the system are immediately retrievable, along with complete audit trails detailing who published them, when, and to whom they were issued, when they were opened, and by whom, and what comments may have been made relating to each document." Similar observation was made by Ozkaya and Akin (2006) that efforts in requirements management resulted in document oriented applications, which focus on the management of the documents rather than the information management approach.

The introduction of Email has been a significant factor in facilitating collaboration between different teams because of its use in communicating and distributing information. It is a preferred tool by many people but it has problems and difficulties associated with its use as an information management tool. These problems include information overload and difficulties associated with the filing and the finding of information and also in prioritising mail (Whittaker and Sidner, 1996). Earlier collaborative working technologies were tailored for use on desktop computers but handheld or laptop computers are now standard in construction and trends show the increasing utilisation of mobile devices in collaborative working environments

(Forbes and Ahmed, 2011; Aziz et al., 2004). Mobile devices are essential to construction teams and the construction process as they make project information remotely available on construction site whilst development progresses (Elvin, 2007).

There are many different collaborative working tools used by construction projects. Some of these tools are commercially developed by software vendors but quite a number are developed in-house. Work by Wilkinson (2005) and Sun and Howard (2004) recognise some of those collaborative tools and discuss their development and use within the AEC industry. Combe (2006) also identifies Account4.com (an e-business which is set up to help automate a firm's business process within the professional services and IT sectors); MatrixOne (tools that facilitate the sharing of product ideas and designs amongst the supply chain for global businesses) and CoVia, a platform for document management, project planning and personalised interactions solutions. Forbes and Ahmed (2011) identify other software such as Webster for Primavera® and MS Project for Net® which enable dispersed construction project teams to work collaboratively together sharing pictures (including drawings), documents, and real-time videos as an effective single team.

Construction companies continue to look for means to implement projects within time and budget and to improve productivity. Collaborative tools can assist construction companies including small and medium-size enterprises (SMEs) ones, to replace expensive private networks with cheaper ones based on the internet. These tools can help improve the business financial performance of companies tremendously through savings in travel costs, combined with the savings of employee down time while travelling which are required by face to face meetings. The tools (such as collaborative e-commerce) do not only contribute in shortening the duration of a transaction but also reduce formerly possible expenditure (Chen et al., 2010). The tools provide collaboration platforms where information can be passed quickly and efficiently between organisations (Combe, 2006). None of the involved parties

(e.g. in meetings) are required to spend more than the length of a normal meeting away from their company or their primary job functions. Gallaher et al. (2004) argue that improved efficiency is a key benefit of collaboration tools because employees, teams and other stakeholders have access to project information remotely thus permitting time and cost savings. Companies are also in the position to compete for business across long distances because of their technological ability to regularly meet with their customers as well as enable them collaborate on production projects without having to incur the expense and lost working time of travel to their locations.

2.4.3 Implementation of Collaborative Working Systems

Although the potential benefits of collaborative working systems are recognised and inducing, their successful implementation could be challenging. Successful implementation does not only mean technically setting up the system but also user acceptance, organisational readiness and its use and application into the operations of the business. There are several identified issues responsible for this challenge which can be categorised under technical, organisational, social, and cultural amongst others.

Technical issues include the integration of the different systems used by the different collaborating organisations to facilitate the sharing and exchange of data and information. Achieving such integration often presents many difficulties. Historically, there has always been the problem of integrating different systems operating on different platforms with different data formats (Sun and Howard, 2004). Security also comprises part of the technical issues to be considered. Collaborative systems use internet technology as communication channel, security loopholes could exist for unauthorised access. Tsai et al. (2006) indicate that access control is critical to information sharing in a collaborative product development project. They further highlight that team members from different divisions or organizations in a collaborative environment seldom want their internal information to become public. This creates reluctance for some organisations to establish such systems. Elvin (2007) also mentions security protocols as a concern in implementing a

project extranet. Therefore, implementation measures must consider the establishment of reliable mechanisms to ensure that access can be controlled. One way of doing this is through security clearance to access different types of information through the use of passwords. Locking mechanisms which can prevent the alterations of documents can also be implemented (Elvin, 2007).

Social and cultural implementation issues focus on the organisations and people involved in the collaborative work from the different organisations. Multiple activities take place requiring interaction between the various organisations and project teams often with individual differences and diverse cultures. Often this is difficult to manage and requires careful consideration. As part of the implementation process of collaborative systems of a project, Smyth and Pryke (2008) emphasise importance of managing relationships and culture for improving collaboration. Therefore, team motivation is an issue that needs to be carefully considered when and this would also demand organisational readiness such as strategy alignment to support collaborative systems implementation. This is important because lack of strategic alignment between IT strategy and organisational strategy could hinder successful implementation (Baldwin, 2004). “It is necessary for industries to understand the development conditions and current available technology so that they can properly select the best strategy for developing web-based collaborative environments" (Mejia et al., 2007). It has also been reported that stakeholders must commit to using project extranet as the primary means of exchanging project information otherwise; its implementation and functionality may be undermined (Elvin, 2007).

All these issues need consideration to enable their successful implementation. Several authors deliberated on this. Shelbourn et al. (2007) emphasise that collaborative systems implementation approach that focuses purely on technology aspect are bound to be less successful. Other soft implementation issues such as organisational, social and cultural should also be considered (Grudin, 1994; Smyth and Pryke, 2008; Baldwin, 2004). This means there should be an *alignment* between all issues for a successful implementation.

However, even though the adoption of extranets in AEC has dramatically increased over the years, they have not impacted to the communication and efficiency to the level anticipated by many information systems users (Gallaher et al., 2004). Emphasising on this, Erdogan et al. (2008), indicate that despite the many opportunities for computer supported environments offered by emerging technologies, full benefits from their implementation are not being achieved by construction organisations adopting them. On the other hand, their contribution towards data and information flow in projects often by managing the documents themselves have increased hugely in construction.

2.5 Information and Knowledge Management (IKM)

Information and knowledge is a vital component and a strategic asset of modern businesses and can contribute towards creating competitive advantage (Glazer, 1991; Christiaanse, 1994; Nonaka and Takeuchi, 1995); but its management has become a critical business challenge. According to Titus and Brochner (2005), whether it is during the preconstruction period or during project implementation, *information* plays a profound role in a construction environment and is vital to all the parties involved in the project. Data are generated, interpreted and transformed into information through a suitable mechanism. Such interpretation makes data valuable information. Understanding the information generated and the capability to use it appropriately within enterprise businesses and decision-making generates knowledge. The creation of knowledge as a result of transforming data to information creates organisational '*wisdom*', coupled with the accumulation of learning processes help successful organisations to move forwards (Milner, 2000; Awad and Ghaziri, 2003). Figure 2.3 illustrates the relationship between data and information, which generates knowledge, and how that knowledge is applied into business processes to provide organisations with wisdom for enhanced competitive advantage. For the context and scope of this research, the emphasis will be on '*Information*' as an organisational asset which requires proper management for fulfilment of business intentions.

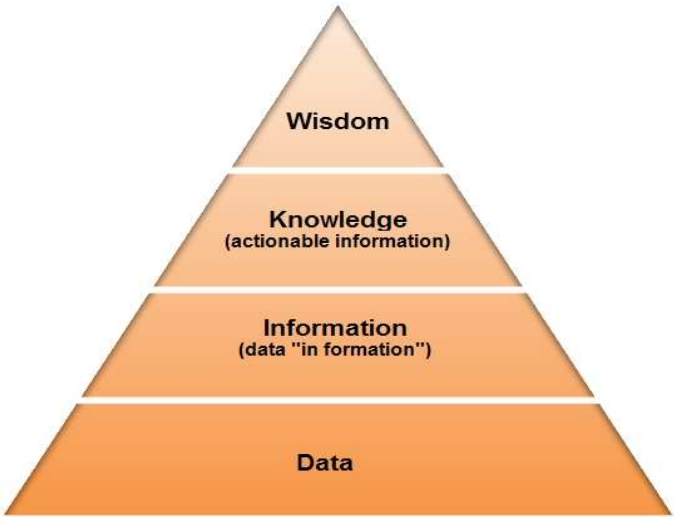


Figure 2.3: The information and knowledge management Triangle.
Adapted from: (Awad and Ghaziri, 2003)

Information should be viewed as an important business asset as any other corporate asset (Glazer, 1991; Christiaanse, 1994; Maes, 2007; Bryant, 2007; Ward and Peppard, 2002). It is vital to successful day-to-day execution of business operations and to realise desired goals. According to Abdul Karim and Hussein (2008), "Information is important to any organisation. Good quality information can improve decision-making, enhance efficiency and allow organisations to gain competitive advantage." Similarly, Hicks et al. (2002) emphasise that Information is central for strategic planning, management, control, tactical planning and daily operation noting it is a prerequisite for the production and delivery of their products or services. "Information and systems for its management are critical elements for the efficient and effective operation of today's knowledge dependent organisations" (The Treasury Board of Canada, 2004). Vast amounts of information are produced by organisations on a daily basis from different sources. Hicks et al. (2006) report that "over the last decade the amount of information that is created, stored and accessed within an organisation has risen exponentially and it continues to rise." This may be as a result of an increase in the number of information sources as well as the tools and mechanisms available to create and access the information. Different types of information exist within different individual organisations. In construction and engineering, information could include the brief, contract documents, drawings

and sketches, the minutes of minutes, bills of materials and quantities, and purchase orders to name a few. There is an increasing demand for information by different departments and different people. In some cases because information is coming from different systems, the output may not be easily understandable to those who need it and the format not easily transferable. Thus whereas information is available, it cannot always be used effectively for business operations and decision making. Information may be structured or unstructured; the latter may only be managed by its creator. As Aitken (2007) indicates, there are numerous challenges surrounding the management of unstructured and semi-structured information within organisations. This is emphasise by Davenport and Cohen (2005) who state that most unstructured content cannot be easily accessed or shared - or evaluated for business, legal, or regulatory importance; it is not vigorously managed by anyone but its creator (and often not even by the creator).

2.6 Information Management (IM)

Information Management (IM) is a multidisciplinary domain and can be drawn from various skills in the field of Information Systems (IS), Information Technology (IT), Library and Information Science, document and records management and general management concepts. Maes (2007) argues that “IM is an integrative discipline, connecting all information-related issues of an organisation;” and has traditionally been between business and ICT, and between the management discipline and information systems in academic terms. Electronic information has not only been growing in volume at unprecedented rates, its value to business has never been greater. Although information is regarded as a vital component to modern businesses, its management has become a critical business challenge. This request for continuous operations, electronic commerce, corporate governance rules and information handling are all adding to the demands for better information management.

"IM can be considered to involve the creation, representation, organisation, maintenance, visualisation, reuse, sharing, communication and disposal of

information” (Larson, 1998). The Treasury Board of Canada (2004) distinguishes information management "as a discipline that directs and supports effective and efficient management of information in an organization from planning and systems development to disposal and/or long-term preservation." IM involves all activities related to the information from creation until such a time that it is not needed by the organisation. This includes managing its creation process, information flow - storage and access, communication and distribution and eventually disposal. It also involves managing the resources that are used to facilitate its management. Such resources include the manual equipment, IT equipment, staffs and the business processes. Maes (2007) indicates that IM encompasses all the processes and systems within an organisation for information creation and its use. Demiris et al. (2008) exploring on information flow, focus on three key components, namely: access, exchange and documentation as shown in Figure 2.4. Information access focuses on the accessibility of information described by its availability and the mechanism through which it can be retrieved with ease from source. Information exchange is centred on how data and information flows between people to facilitate its sharing, communication and the interactions involved during that process and the generation of knowledge. Information documentation focuses on the gathering and storage of the information and keeping it updated. The mechanism of documentation can contribute to the effectiveness of the access and exchange.

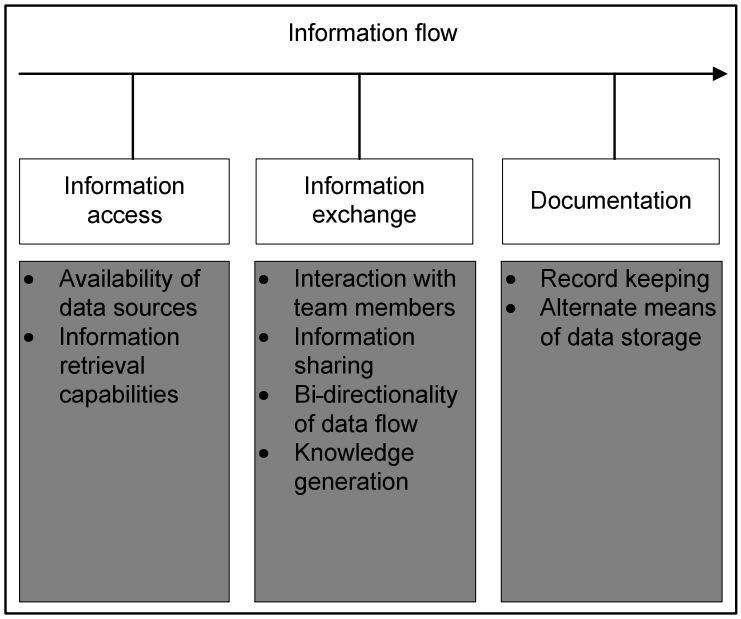


Figure 2.4: Dimensions of information flow
Source: (Demiris et al., 2008)

Apte and Karmarkar (2007) note that, "Major IM tasks are the management of the information economy, the management of information systems and the management of information and communication technology. IM, therefore, represents efficient and effective ‘treatment’ of information." They further discuss that it means creating and adapting information to the changing needs of the firm and transforming information potential into firm success/performance.

IM is traditionally based on manual processes and equipment such as paper-based information filing and access whose retrieval is very slow and inefficient (Gyampoh-Vidogah et al., 2003). This has proved to be very difficult to manage especially in a large organisation with collaborative working in practice. In such environments, information systems become too complex to maintain accessibility, security, reliability and consistency to the information. Thus with advancement in technology and information systems, database technologies were developed to assist in the IM. "An information management system includes a set of interacting components - actors, procedures, and technologies - that together collect, process, store, and distribute information to support control, decision-making and management in organizations"

(Silberschatz et al., 1995). IM systems within organisations thus emerged with the aim of managing information aided by interaction between processes, people, technology (Edwards, 2009) and systems which is crucial in the generation and management of knowledge. Figure 2.5 illustrates the interaction and support between those constituent organisational components. Froese (2008) indicates that Project Information Management is the discipline of managing a civil or building engineering project's information systems, and includes its information, ICTs and related work. Though not fully formalised in the civil and Building Engineering Industry, it has always been a component of project management.

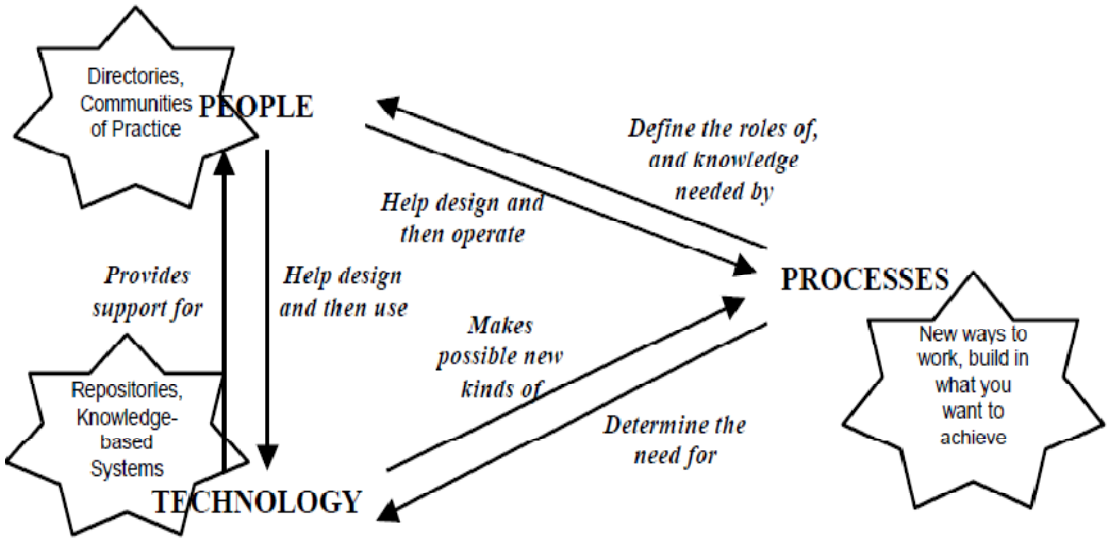


Figure 2.5: Interaction between people, processes and technology
Source: (Edwards, 2009)

In whatever capacity IM is performed, its sole aim is to make sure information is made available to the people who need it for the execution of their duties for development of products and services. All persons involved in the product value chain, clients, product designers and developers, manufacturers and building contractors, service sector administrators, service technicians and supply managers, need the appropriate information at the right time and in the right format to be able to act quickly and add value to the product according to their individual and group roles. This is emphasise by Combe (2006), that integrating elements of a value chain can add value and improve the efficiency and quality of information flows between the elements. An IM

system should be able to provide information needed by decision makers at the right time and in the right form through well-established information infrastructure (Horvath and Fulk, 1994; Krcmar, 2000). There are situations where information is not for execution of any role but made available specifically for consumption by an individual. Within the engineering disciplines, information is vital for the design and development of products and needs to be shared between individuals and teams over a long period of time. Vriens (2004) recognises that organisations are faced with an increased pressure to produce relevant information about their environment. Research demonstrating the critical importance of the flow of data between members of construction teams for project success has been reported (Fisher and Yin, 1992). This suggests that dealing with data occupies a large proportion of the time of those having project managerial responsibilities. To deal with this problem, there is considerable demand for information management and associated systems to address problems associated with storage, access and distribution of information within organisations and to gain efficiency and competitive advantage. “Whether or not the step is taken to computerise considerable benefits can be gained from better and more efficient management information systems” (Fisher and Yin, 1992). IM is therefore necessary to make sure such information is made available no matter what medium is used for that means. The timely availability of information is crucial to construction projects. Forbes and Ahmed (2011) state that construction as a multi-organisation process depends heavily on the exchange of large complex data and information, and the accuracy, effectiveness and timing of communication, and exchange between the project team determine the successful completion of the project. Inadequate information management is what contributes to delays and construction waste (Smith and Tardif, 2009). Client requirements information forms part of this information and information management problems.

2.6.1 Whole Lifecycle Information Management

A typical product lifecycle involves various phases which include design, components/materials acquisition, manufacture, distribution/sale, use, service and maintenance and recycle/end-of-life treatment. Similarly in the construction industry, a project involves various phases: preparation, design, pre-construction, construction and use; at the end of life, demolition. Data and information arise at each stage in the lifecycle and need to be acquired and managed in an integrated and systematic manner to provide timely and accurate information to various stakeholders (e.g. clients, contractors, recyclers, suppliers). However, lifecycle data occurring in distribution, usage, maintenance and end-of-life stages of the building product are usually not readily acquired and maintained. In AEC/FM, such information, for example changes to requirements, is very important especially if the product or building is to be used for a purpose other than that which it was originally designed. A series of evolutions and changes to the client requirements may occur and comparing the completed building with the initial brief may not be accurate. It is therefore important that in order to provide whole lifecycle information management, information relating to client requirements is recorded and tracked throughout the project lifecycle and during the operation of a facility. Kiviniemi (2005) highlights the fact that because of inadequate documentation of the requirements changes, it is difficult to find the approved requirements change information, and that end-users may compare the building to the original and out-dated requirements. Information therefore needs to be *properly structured*, adequately stored and managed for the entire life of the product. “The primary reasons for providing a structured environment in which changes made to objects are recorded are, first, to provide the client with a complete project history and, second, to facilitate backtracking” (Rezgui et al., 1998). Smith and Tardif (2009) also recognise the readiness of many business processes in the building industry for full automation; however, *the information should be properly structured and made available in the appropriate format*.

Whole lifecycle information ensures that information is available throughout the life of the building. The introduction of '*Private Finance Initiative*' (PFI), Public-Private Partnership (PPP) and the '*design-build-operate*' project procurement systems in construction mean that information management on projects does not end at the delivery of finished buildings but should extend to include the use and operation of the building through to the end of life. This will facilitate success of through-life service provision (Pekericli et al., 2008). Developments such as institutional repository and corporate memory (Fruchter and Demian, 2002) can provide effective force towards improved collaboration, capture, and sharing of lifecycle information and knowledge when properly integrated with effective processes and procedures (Liebowitz, 2009).

The management of the product across its entire lifecycle is increasingly becoming vital in the modern enterprise. The driver for this trend and the challenge for the modern enterprise is the demand for the production of products at the lowest price and at the right time (Terzi et al., 2007). Vast amounts of data and information are generated during the production of products. In order to achieve this challenge, it is crucial that these collections of data and related information are managed during the lifecycle of the product (i.e. from inception to end of life). Information & communication technologies such as product lifecycle management (PLM) can enable this to be achieved. Terzi et al. (2007) state that "PLM deals with the management of all the product data that are created, stored and managed along the lifecycle of a product, from its design to end of life." According to Grieves (2006), "PLM is an integrated information driven approach comprised on people, processes/practices, and technology to all aspects of a product's life, from its design through manufacture, deployment and maintenance – culminating in the product's removal from service and final disposal." Product lifecycle management (PLM) is the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal (CIMdata, 2007). Commercially available software packages for PLM already exist such as SAP PLM (SAP, 2010). This application supports for all

product-related processes, from idea generation, through manufacturing to product service, providing a single source of all the product-related information needed for collaborating with business partners and supporting processes (SAP, 2010; Yang et al., 2007). PLM is rooted on product information perspective; digitising and sharing that information across the phases of the product lifecycle and all stakeholders. It aims at integration between partners and suppliers internally and external of organisations.

However, these and other existing software packages mainly manage the product lifecycle data arising at product design and manufacture stages. Lifecycle data occurring during distribution, usage and maintenance, which have a huge potential in creating value for stakeholders, especially for manufactures and recyclers is often hard to acquire and in most cases lost (Yang et al., 2007; Moore et al., 2000; Simon et al., 2000).

2.6.2 Integrated Information Management and Building Information Modeling (BIM) for Interoperability

Generally, construction projects work with fragmented teams and often results in the use of heterogeneous IT systems in communicating, and managing information and documents (Anumba et al., 2002; Anumba et al., 2008; Otter and Emmitt, 2007). Construction projects rely greatly on document-based information exchange and sharing. Most of the document types used are unstructured and text-based. Their management, coupled with the different fragmented heterogeneous application systems, makes the management of information a very complex task. As highlighted by Mao et al. (2007), “How to effectively manage information presented in these types of documents especially in unstructured content becomes essential to improve the performance of a construction information system. The complexity is also compounded by the fragmented data environment in the construction industry.”

Many different software products claim to be able to help in managing product related information integration within enterprises and projects. However, this

can only be feasible provided standards for information exchange and interoperability are developed.

2.6.2.1 Data Interoperability (standards and specifications)

Several efforts from different industries are making progress towards solutions for interoperability to enable information exchange between heterogeneous systems. buildingSMART (2010) developed the Industry Foundation Class (IFC) model (a data schema) enabling data interoperability by the sharing of information between project team members and across the software applications that they commonly use for design, construction, procurement, maintenance and operations (building lifecycle) through a common data schema. This also enables the sharing of 3D design models. buildingSMART (2010) and Pouchard and Cutting-Decelle (2007) list the processes supported by the current version (IFC2x Edition 3) and the target applications to exchange and share information but no mention was made specifically to client requirements information management and its target application. COBie (Construction Operations Building Information Exchange) was also developed as a standard data specification for structured information exchange (Smith and Tardif, 2009; East, 2010). The COBie approach and concept is to enter the data and information as it is created during the processes of design, construction, and commissioning, which will essentially support the operations, maintenance, and the management of the facilities by the owner and/or facilities manager (Smith and Tardif, 2009; East, 2010). Another standardisation effort is the *agcXML*, a buildingSMART project as part of the aecXML Domain framework, aimed at producing a set of eXtensible Markup Language (XML) schemas of structured format for the exchange of information during design and construction process through any number of documents including request for information, change orders amongst others (Smith and Tardif, 2009; buildingSMART, 2011). The project focuses on transactional data, which may or may not be "building information" (buildingSMART, 2011). Similarly, according to Combe (2006), in response to the lack of information interoperability between applications in the *e-business*

sector resulted in the *ebXML* standard specifications; a joint development between the OASIS (Organisation for the Advancement of Structured Information Systems) and UN/CEFACT (United Nations Centre for Trade Facilitation and Electronic Business). The ebXML is an attempt aimed at overcoming restricted applications by operating a horizontal standard that can be developed for use in any vertical industry with main users being SMEs. This will enable businesses to conduct business-to-business (B2B) transactions with each other through the exchange of XML-based messages and enhance interoperability (Combe, 2006; Information Society Technologies, 2006). All these standards from different industry perspective are geared towards information exchange and interoperability.

Baldwin et al. (1999) recognise the impact of information exchange (i.e., *electronic data transfer using Electronic Data Interchange (EDI), Electronic mail (E-mail), Document Image Processing, and CAD Data Exchange*) had on some organisations business processes resulting in new ways of working. In some industries, these technologies have had a considerable impact upon the business processes and have resulted in new ways of working. Enterprise integration systems (EIS) such as Enterprise Resource Planning (ERP) are amongst those that are currently utilised in integrated product related information management across organisational functional units (Laudon and Laudon, 2010; Shehab et al., 2004). However, an integrated view of lifecycle information management at different phases of the whole product lifecycle still remains to be addressed (Yang et al., 2007). The construction industry remains fragmented, and depends on the paper-based modes of communication and the use of paper documents which often have errors and omissions, causing unforeseen cost and waste (Eastman et al., 2008).

The efforts to tackle these problems, and the quest for better management of lifecycle building information in an integrated approach, resulted in the emergence of building information modelling (BIM).

2.6.2.2 BIM and its Use Across Lifecycle Phases

During the design, construction and operations of a building, a large amount of information is generated by various stakeholders and for multiple purposes. This is emphasised by Kazi (2005) who states that during the process of constructing the building, large amount of information is produced; valuable experiences and lessons are gained, which if not properly managed (*e.g., documented and shared broadly*) may be *lost*. This indicates the need to derive mechanisms for documentation, storage, access and retrieval, and exchange of construction information across the whole lifecycle processes and between the people. Liebowitz (2009) identifies bidirectional knowledge flows: where knowledge flows from bottom up and top down (i.e. learning from each other between senior and junior employees). Similarly, this research also recognises another approach to bidirectional (i.e., backward and forward) information and knowledge flow, which exists between project phases and should be factored as an integrated view when managing information across project lifecycle. The recent emergence of Building Information Modelling (BIM) (Eastman et al., 2008) may provide a vehicle for enabling this approach which encompasses all phases, stakeholders and types of content in construction.

There are many different definitions for a BIM. buildingSMART (2010) states that a BIM model is a *placeholder* for the information about a building or a facility, or whatever information you need to collect regarding a site or a building. buildingSMART indicates that this does not have to be only 3D CAD or geometry but could be only textual information; such information could be about client requirements for and project brief. Demian and Fruchter (2005) argue similarly about the use of non-geometrical information (i.e., specifically textual information) to identify relevant building components from previous projects in support of design reuse. Elvin (2007) declares that BIM combines graphical and non-graphical information including specifications, cost and schedule data and project extranets may also be used to support it.

The *process* of generating and managing the building lifecycle information that also creates the model is referred to as *building information modelling* (Forbes and Ahmed, 2011). BIM does not only improve information exchange in design and construction phases, but has a vast importance to facility management phase (operations and maintenance), redesign and end-of-life too (Elvin, 2007; Eastman et al., 2008). Facility managers often encounter difficulties during operations and maintenance of their facilities. Transfer of design and construction information to facility managers remains a challenge; often they are faced with the complexity of re-creating information about their building/facilities; as time and again very little information from design and construction phases is habitually not transmitted to later phases in a consistent, methodical manner (Smith and Tardif, 2009). Knowledge management can be boosted through BIM by creating a relational database and interconnecting all information which can support clash detection and information updates when an object in the BIM changes (Elvin, 2007).

2.6.2.3 Adoption of BIM and Commercial Products

Vanlande et al. (2008) recognise the promise of BIM to facilitate integration, interoperability and collaboration in the future of the building industry which are amongst the driving factors in its adoption. The use of BIM is increasing in construction projects but it is currently limited to 3D and 4D. Lucas et al. (2010) argue that even though the current uses of BIM are valuable, they are far from their full potential to offering lifecycle support of a project. For example, a facility management model within BIM could greatly streamline and improve the operations and maintenance of the facility (Smith and Tardif, 2009). Similarly, from the perspective of this research, a *requirements management model* incorporated within a BIM can improve the effectiveness of client requirements information management across all lifecycle phases. BIM seeks to integrate processes throughout the entire lifecycle of a construction project and its focus is to create and reuse digital information by stakeholders through the lifecycle of a facility Aouad and Arayici (2010).

Lucas et al. (2010) review three BIM software systems, namely: Bentley Architecture from Bentley Inc., REVIT from Autodesk and VICO Constructor from Vico Software. A detailed review of several BIM tools is presented by Eastman et al. (2008). However, Lucas et al. (2010) report their shortage in supporting lifecycle processes of a project as they do not allow for easy manipulation of the information and decision making to support project processes. Mihindu and Arayici (2008) assess some BIM tools and identify shortage of compatibility between them thus creating lack of interoperability to support collaboration and communication among all the stakeholders within a construction project. Initial development of IFC Model Server has taken place and it enables storage of IFC model data in a database; and interfaces are being developed to facilitate information exchange between the model server and software applications in heterogeneous domains based on simple object access protocol (SOAP) (Kiviniemi et al., 2005).

Despite BIM being regarded as a placeholder of construction lifecycle information, it does not mean to lack integration with other systems used in the lifecycle phases. Smith and Tardif (2009) indicate that no commercially available software or technology platform is capable of containing all lifecycle information; and no comprehensive BIM residing within a single data file has been created. They suggested distributed BIM models that are designed to work together; an unmistakable trend in BIM software development.

2.6.2.4 Implementation of BIM

Implementation of BIM needs a lot of commitment from all stakeholders as there are several issues of concern which requires high consideration. In order to support BIM implementation, models and guides are necessary and some are emerging to facilitate that process. Accordingly, The Computer Integrated Construction Research Group (2009) developed the BIM Project Planning Execution Guide that can be used by project teams for designing their BIM strategy and developing a BIM Project Execution Plan. Despite a well established guide, other issues such as barriers to BIM implementation should be considered during projects. Yan and Demian (2008) investigate the

barriers and benefits of BIM and identify huge benefits at operations phase with improved communication and document storage amongst those benefits; and peoples issue amongst the barriers. Mihindu and Arayici (2008) suggest that remarkable changes in the current business practices would be required in the implementation and utilisation of BIM systems; and cultural aspects are also challenging. These include legal and cost issues as to who owns the model and responsible for financing and maintaining it (Eastman et al., 2008).

Won and Lee (2010) identify several critical success factors (CSFs) in BIM adoption but recognise potential economic impact and matching the company's business strategy for successful BIM implementation. Smith and Tardif (2009) point out that recognising an organisation's internal business processes as part of a system, and that building information created by anyone in the system is of potential value is key to the successful implementation of BIM. They further state that business owners have to perceive potential benefits to changing internal business processes and the nature of their external business relations in order to make the investment to implement BIM. This means BIM implementation will affect both organisational internal and collaborative business processes. Standardisation of the data and information structures is another pertinent issue to consider if a BIM is to facilitate information exchange between different other models. For that reason, data and information structures and standards should be established within a BIM to facilitate information exchange. An example of such standards is the IFCs developed by the buildingSMART International (buildingSMART, 2010).

Smith and Tardif (2009) indicate that COBie is an excellent example of the *information management structure* that must be included with a BIM so that information can be compiled and exchange most effectively and efficiently throughout the building lifecycle; while IFCs of buildingSMART define the actual data elements of a BIM. Effective collaboration is another important issue to consider when implementing BIM. Elvin (2007) indicates that a comprehensive and dynamic model of a project is created in a BIM and that

requires demanding collaboration and coordination; and the traditional over-the-wall method makes it hard to create and maintain because of the lack of effective communication between teams. Therefore, an integrated project delivery would be relevant to BIM implementation. However, Succar (2009) argues that "the selection of Integrated Project Delivery (IPD) as the 'goal' of BIM implementations is not to the exclusion of other visions appearing under different names."

BIM as a tool, as well as a process, can increase productivity and accuracy in the design and construction of buildings (Forbes and Ahmed, 2011) as well as their management by providing integrated project information management. A BIM when properly developed and implemented can support collaborative working of integrated project teams of clients, designers, contractors, project managers, facilities managers and all other stakeholders. Eastman et al. (2008) state that when completed, the BIM as a computer-generate model, will hold precise geometry and relevant data needed to support construction, manufacture, and procurement activities needed to realise the building. It is clear that BIM models need to be made available even after the construction process. This as discussed earlier is important to facilitate the lifecycle information needs of operations and facilities management process as well as decommissioning. Therefore, information about client requirements captured and managed through life of a facility in a requirements model such as eRIM can be beneficial. Thus, utilising BIM for client requirements information management can contribute immensely towards the quality of buildings.

2.7 Summary

This chapter presented a comprehensive review on project management, collaborative working, integrated information management and building information modelling. Earlier in the review, project management was examined and it emerged that across several industries, failure of projects is common and their causes very similar. Some of these causes include complexity of the projects, lack of proper planning, lack of effective communication and information sharing between stakeholders of which client

requirements is composed of. Lack of an integrated project delivery approach to enhance collaborative working was also identified as some of the causes of the failures.

It is clearly evident that large amounts of information are generated during project development and throughout the life of a facility. The importance of this information to organisations cannot be over emphasised, which requires effective and efficient management as any other organisational resource. Management require collaboration between all parties of a project, clearly established processes and the utilisation of support tools such as information management systems. However, it has been found that several difficulties associated with the IT tools hinder effective information management. These include the heterogeneity of the systems, which lack integration and interoperability to facilitate information sharing and exchange between the different project teams. Several efforts have been cited to solve this problem. The emergence of BIM is regarded as an approach to remedy current problems of managing information in AEC/FM. The next chapter will introduce the main topic of the research, requirements management and how it relates to the various issues discussed in this Chapter.

Chapter 3. **Requirements Management (RM)**

"Successful projects are characterised by meeting client requirements"
(Lee and Egbu, 2008)

3.1 Introduction

This Chapter discusses the main topic of this research, *Requirements Management*. It will first introduce the meaning of *requirements* and their role to the construction industry. The review intended to identify gaps in requirements research and develop research questions.

Section 3.3 will present the various categories of requirements from the software and construction perspectives. This will be followed by a detail discussion of the process of managing the client requirements information detailing activities of documentation, storage, access and sharing the requirements information as part of the management process. Changes to requirements will then be presented and mechanisms available for their management. Traceability and dependency between requirements will be discussed and a summary drawn at the end of the chapter mapping out key lessons learnt from it.

Other management disciplines and technologies such as business process management (BPM), service oriented architecture (SOA) and web services (WS) also form part of the literature review because of their relevance to requirements management but those are presented in Chapter 4.

3.2 Introducing Requirements: the meaning

In almost every aspect of life, there are needs and wishes that will be defined in meeting certain conditions. These needs are often placed by customers/clients requesting for the provision of products or for service delivery. They are conditions that will be defined at the front-end of a service or product development and become the requirements. The requirements are then documented, analysed and specifications drawn from them. Robertson

and Robertson (2006) define requirements as “something that a product must do or a quality that the product must have.” According to Oduguwa (2006), requirements are the needs of customers which are analysed and documented as engineering specifications, then designed before eventually produced as products.

From a construction industry point-of-view, Kamara and Anumba (2000) state that “client requirements can be described in terms of the objectives, needs, wishes and expectations of the client (i.e., the person or firm responsible for commissioning the design and construction of a facility).” Kamara et al. (2002) further note that “The ‘voice of the client’ (client requirements) includes the collective wishes, perspectives and expectations of the various components of the client body. These requirements describe the facility that will satisfy the client’s objectives (or business needs).” According to the Office of Government Commerce (2009c), “Requirements are capabilities and objectives to which any product or service must conform and are common to all development and other engineering activities.” Requirements may also be defined as a “description of a set of testable conditions applicable to products or processes” (Fiksel and Dunkle, 1992). Requirements are the statements of the client’s needs which are transformed into an architectural design and subsequently into a finished facility.

3.3 Categories of Requirements

Requirements are generally defined in order to develop a functional product or a service. In term of this functionality, requirements can be categorised into two, namely: functional and non-functional. Robertson and Robertson (2006) state that functional requirements specify what the product must do and describe the actions it must carry out to satisfy the fundamental reasons for its existence. The non-functional requirements add functionality to the product and enhance its usability. They are properties or qualities of a product and often describe the look and feel. From a construction perspective, an example of a functional requirement may be: ‘*The seminar room must accommodate 35 people’*. In this case, the functionality of the seminar room will be

compromised if it cannot accommodate 35 people. An example of a non-functional requirement may be: '*The interior walls of the building shall be painted with glossy orange paint'.* In this case, no matter what type of paint is used, the functional requirement of the building will not be compromised.

Kamara et al. (2002) specify three different structures to represent client requirements. These are: *primary, secondary and tertiary* requirements. According to them, primary requirements represent the most general requirements of the client. The secondary requirements are the decomposition of the primary requirements in more detail and a further decomposition of the secondary are the tertiary requirements. From construction project point of view, the original client brief could be regarded as the primary requirements and the room data sheets produced during design phase can represent secondary or tertiary requirements depending on the detail of decomposition. The 'room data sheets' are considered as secondary requirements in this thesis. However, no matter what categories of requirements or level of decomposition, all are essential to a product and must be described and documented in enough detail, and managed throughout the development process.

Kiviniemi et al. (2004) identify two types of requirements, namely: direct and indirect requirements. Directed requirements are those related to the spaces and recorded in the building program. However, they often aggregate indirect requirements to the bounding elements and technical systems. Indirect requirements according to them are difficult to notice because the detailed design process related to them often takes place late and often by people who were not involved in the early stages of briefing; the design documentation does not include requirements documentation. Therefore, it is important that all types of requirements are documented and managed adequately no matter what stage of the construction process.

3.4 Managing the Requirements

As discussed in Section 1.1, requirements are documented in a brief following the briefing process in construction projects. Once this is done, they need to be managed throughout the development process. This process is referred to as requirements management (RM). Its definition has been adapted by many experts and tends to follow its applicability within individual industry. However, no matter in which industry it is been applied; it is an indispensable feature of every product development endeavour. Aouad and Arayici (2010) indicate that Requirements Engineering (RE) is concerned with the real world problems to be addressed by a software system and is focused on the elicitation, analysis, specification and validation of software requirements; requirements management is a generic activity of RE.

Fiksel and Hayes-Roth (1993) identify RM as the process of creating, disseminating, maintaining, and verifying requirements. The Office of Government Commerce (2009c) recognises the process of elicitation, documentation, organisation, and tracking requirements information and communicating across the various stakeholders and project teams as RM. However, with many stakeholders involved and having interest in requirements, dissemination must be considered in the maintenance process. Testing the requirements is important to ascertain that they are valid and accurate for the purpose they were created. Requirements are open to change and their documentation should enable such changes to be made. As such, a variable that discusses modification has been added in the definition by Nuseibeh and Easterbrook (2000) who state that “Requirements Management is the process of identifying stakeholders and their needs, and documenting them in a form that is amendable to analysis, communication and subsequent implementation.” One can observe that all these definitions despite coming from different industrial views have commonalities in them which are documentation, storage, communication and dissemination of the information, changes and change management including updating the requirements information. In order to facilitate effective requirements

information management, sufficient information about each requirement should be documented. These are the requirements attributes or items according to Robertson and Robertson (2006). The four key items are: *requirements number, priority, rationale* and *type of requirement*.

- Requirements Number: each requirement must be uniquely identified. This means to assign a unique identifier for each requirement. Although it may not be a number 'per se' but any kind of identifier.
- Priority: this specifies the decision on the importance of the requirement's implementation relative to other requirements and the whole project at large.
- Rationale: this is the description of the reason behind the requirement's existence and explains why it is important and how it contributes to the product's intention.
- Type of requirement: this indicates what the requirement is and is relevant to sorting requirements and attaching various stakeholders to it.

As requirements must be traceable throughout the development of the product, the unique identifier is a logical approach to give to each requirement and an important item in the management process of requirements especially for traceability and change control purposes (Robertson and Robertson, 2006).

The practice of RM is a vital component of project management and highly needed if projects are to be delivered on time, within budget and meeting quality objectives. This has been emphasised by Green et al. (2004) who identify the following factors as rationale for the need of RM practice:

- projects delivered over budget;
- projects delivered late;
- no 'whole life cycle perspective' to project decisions;
- lack of customer satisfaction.

These types of problems are believed to be prevalent in the software and aerospace but also quoted in the construction industry where RM can potentially serve as a solution (Kamara et al., 2002; Green et al., 2004).

Requirements management presents significant difficulties when stakeholders are distributed, as in today's global projects and is identified as one of the most collaboration-intensive activities in software development (Sinha et al., 2006). This is also inherent in the construction industry where stakeholders are often distributed and the management of the client requirements information would require a collaborative endeavour. In product development through the extended enterprise, Roy et al. (2005) recognise the necessity to formalise and automate the requirements management process which is manual and time consuming in order to reduce the product development time and cost.

3.5 Industry Application of Requirements Management

Requirements management (RM) over the past decade has become an important focus in major product development industries such as: Software Engineering, Manufacturing and Aerospace. This has been recognised by Fernie et al. (2003b) and Green et al. (2004) who discuss that RM has a long history in the software development industry and is also used extensively within the Aerospace and Defence Sectors. Other industries have also applied the technique in their functions but not to the same scale. The discipline of RM is concerned with gathering requirements from clients, organising and analysing this information and managing the processes of reviewing and changing the information and the documents in which the information is contained (Schmidt and Souza, 2007). These processes are spread across the entire lifecycle of a construction project and the resulting facility.

Green et al. (2004) believe that requirements management has no equivalent in construction but similar practices are applied such as programming, value management and change control. It can be concluded that no matter what application industry, requirements management includes elicitation,

documentation, communication, verification and managing change. Requirements management is a broad activity which houses different sub activities across a product/facility's life cycle of which communicating and maintaining changes to requirements are important. The mechanism of performing the management of requirements may be either ad-hoc manual basis or electronic. Traditionally this was done using manual forms but recent trends show increasing interest in electronic and automated tools and techniques to ease the difficulties associated with marinating information across a project. Such tools help in understanding the relationship and traceability links between requirements and their associated processes and products. It is important to comprehend that requirements management is not an activity that needs to be performed only at the early stages of a project but should continue throughout a project. Similar thoughts have been echoed by Ozkaya and Akin (2007) that "Requirements management is an inseparable part of design and has to be considered in correlation with form exploration, rather than as a front-end task or as an activity which is addressed marginally." Halbleib (2004) indicates that *managing requirements is not an event but a process* which starts at the outset of a project and continues until the developed system has been discontinued and is no longer supported. Green et al. (2004) argue that requirements management *has to be based on a process* even where a tool is available. Miranda (2004) in defining goals of requirements management highlights managing the changes, maintaining bi-directional traceability and underscores the *establishment of a defined process*. Therefore, this research emphasises that a clearly defined process has to be instituted before applying a tool for managing requirements information. The following sections will discuss the different functions as applied in requirements management.

3.5.1 Requirements Elicitation, Documentation and Storage

In any project, requirement elicitation and capture is amongst the front end activities between the client and designers. Once the requirements are elicited and captured, the brief document is used throughout the project. Briefing is

regarded as a continuous process and the brief is normally produced in three different phases, namely: business case (in which the client establishes needs and objectives), strategic brief (provides detail and sufficient information for design to commence) and project brief (which defines all design requirements including room data sheets) (Royal Institute of British Architects - RIBA, 2007). According to the Office of Government Commerce (2007b), the project brief provides a strong foundation for projects to be initiated, it serves as a statement of the client requirements of a construction project; it should be detailed enough and should serve as an essential reference for the team. It should also be regarded as a key component of the project execution plan. Amongst the questions to ask regarding the quality of the project brief is how accurate it is to reflect the requirements of the project and if it details how the client will assess the acceptability of the completed project (Office of Government Commerce, 2007b).

At each phase of the project, activities are centred on satisfying the client requirements during which changes in requirements occur. This involves managing the requirement attributes, tracing changes, and analysing the impact of those changes. No known system exists that helps to integrate requirements management within and across all lifecycle phases of a construction project. Very few requirements management frameworks integrate into later phases from briefing. Most of these frameworks are to complement the design process. Previous research has considered the development of some models that can facilitate the process.

3.5.1.1 Models and IT support for Requirements Processing

The client requirements processing model (CRPM) was developed to help in the definition of client requirements and the incorporation of the different perspectives represented by the client body, and assist in the systematic mapping or translation of the requirements from the business terminology (“voice of the client”) that clients are likely to use into design terms (“voice of the designer”). Its aim is also to ensure requirements are presented in a solution-neutral format (Kamara et al., 2002). Kamara and Anumba (2000)

argue that “it is necessary that ‘processing’ be done before conceptual design.” CRPM has three main stages for the processing of requirements:

- defining client requirements,
- analysing client requirements and
- translating client requirements.

Defining client requirements deals with the elicitation and capturing of the requirements and the identification of interested stakeholders. Analysing these requirements makes sure that requirements are structured and prioritised according to their relative importance. The last stage, translation of the requirements deals with the transformation of clients requirements into design attributes. During all these stages, managing the elicited requirements is of great importance. However it is apparent that the CRPM only feeds into the design phase of a construction project but doesn’t apply throughout the lifecycle phases of a project. The diagram in Figure 3.1 shows the graphical design of the different stages of CRPM with all of the information necessary for processing the requirements.

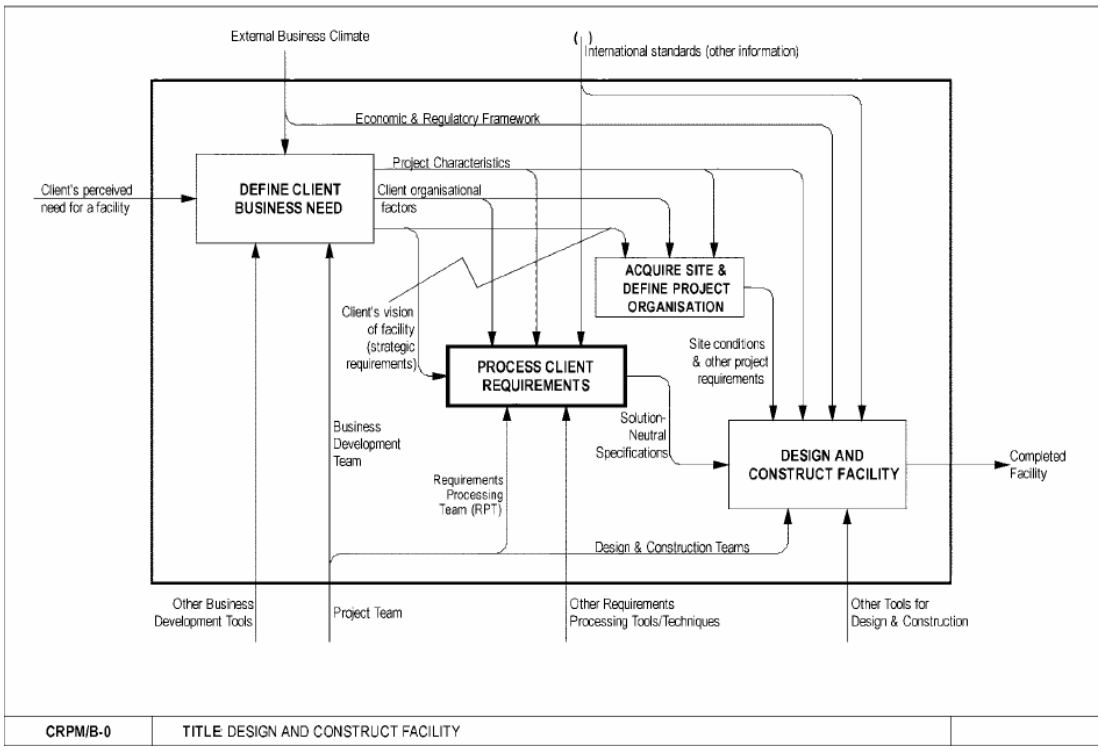


Figure 3.1: Client Requirements Processing Model (CRPM)
Source: (Kamara et al., 2002)

The CRPM helps capture client requirements and facilitates design development. It serves as a link between project conception and design. In other words, "CRPM serves as the interface between the client's business needs and design requirements" (Kamara et al., 2002). Design solutions are subsequently used to facilitate the construction of the facility as well as to aid material procurement process. The original requirements documents become redundant in the later phases of a construction project having been substituted by the schematic and detailed design. However, this research argues that requirements management process should be continued throughout the phases of a construction project and building life, and not just to aid design. Figure 3.2 shows the CRPM link between conceiving a project and the design highlighting where the model is applied.

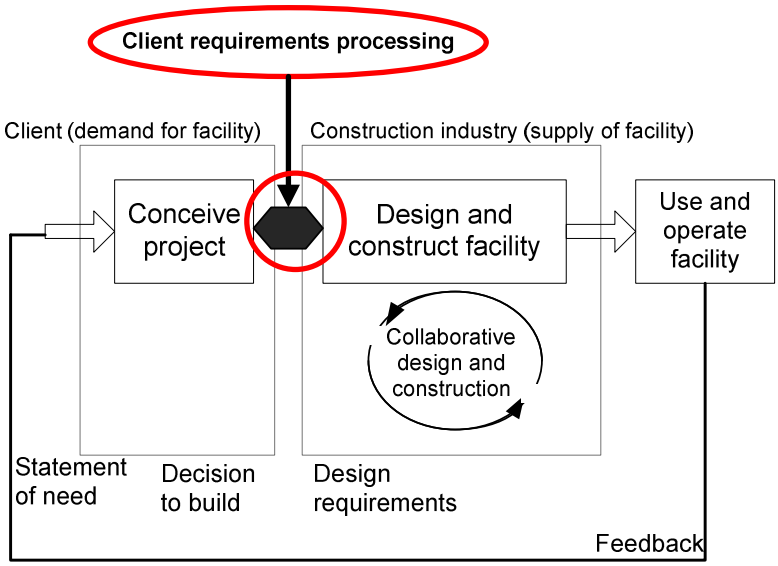


Figure 3.2: Context for the implementation of the CRPM
Source: (Kamara et al., 2002)

Managing requirements along all phases of a construction project does not only help different teams perform their work efficiently but can contribute to elimination of waste in design and construction. This is achieved because design re-works and construction defects are reduced immensely with lifecycle requirements information management. Similar observation was made by Baldwin et al., (2007), that waste can be eliminated in both design

and construction process by ensuring the timely delivery of design information and process and information modelling can facilitate that process.

Kamara et al. (2000) identify that different media such as drawings, sketches, text and other forms have been used to manage and communicate requirements. This has been emphasised by Fiksel and Dunkle (1992), who point out that “there are a variety of forms in which requirements can be represented, including documents and drawings.” Computational tools have emerged that help to manage the different media. Most of these applications are general computer applications such as word processors, spreadsheets and databases in some cases. There are many disadvantages associated with such applications, and there is a recognised need for more advanced tools. Ozkaya and Akin (2007) state that “computational requirements management and engineering strategies need to evolve, along with algorithms to manipulate requirements for architectural design as well.” To address this problem, the Computational Hybrid Assistance for Requirements Management (CHARM) framework was developed. CHARM establishes a process whereby a designer/architect needs to be aware of the requirements information of a given solution, or track emerging data by interacting with the computational system. Figure 3.3 shows a graphical representation of CHARM.

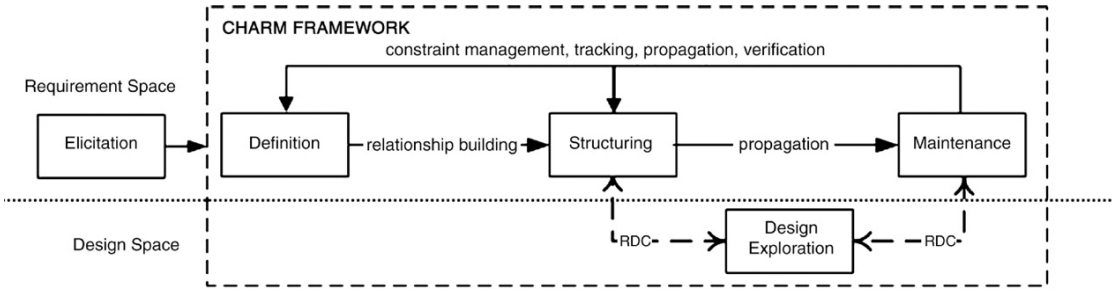


Figure 3.3:Computational Hybrid Assistance for Requirement Management process components

Source: (Ozkaya and Akin, 2007)

Kiviniemi et al. (2004) and Kiviniemi (2005) working on requirements management present a framework focusing on the requirements model and its interconnection to the architectural design model by creating a link between requirements Objects in the Requirements Model and objects in Design,

Production, and Maintenance Models. This is another improvement in requirements management in the construction industry and the concept would be useful to industry.

These links are relevant for traceability purposes, however, this research argues that the links should be categorised to help define the degree of the dependency or relationship of one requirement to another. Consequently, this research adopts the philosophy of these links as a point of departure to facilitate defining categories of the links and how they can be applied across the lifecycle phases. This research also extends the capabilities and utilisation of the links to enhance the checking for dependencies between requirements during changes which is crucial for impact analysis.

Meziane and Rezgui (2004) present a document management methodology for the management and sharing of documents in the construction domain. It aims to facilitate the identification of documents and management of the updating process of those documents, and to deal with heterogeneous and large database of documents.

All these different models and frameworks discussed have the potential to facilitate the requirement management processes within the construction industry. However, the extent to which this is done is limited compared to the need for a lifecycle requirements management support for construction projects.

Many commercial software tools exist that claim to be able to provide requirements management. According to Oduguwa (2006), the three industry leaders are recognised as DOORS from Telelogic, Slate (part of Teamcenter) now owned by Siemens (Siemens, 2011) and Calibre-RM from Borland which provide common support for requirements management but they are not able to provide detailed impact analysis when a design requirement is changed. Halbleib (2004) and Kamara et al. (2002) also identify similar commercial requirements management tools. An evaluation of some commercial requirements management tools was also made in Tvete (1999) to enable

selection of one to be used for their purpose. These software tools are generic and have been developed for use across different industry sectors. However, none have become adopted as standard for the construction industry.

Other systems were developed as research outputs notably, EGRET, developed by Sinha et al. (2006), is a collaborative requirements management tool aimed at supporting the requirements communication and management across distributed software development teams. This was specific to the software industry and no focus in construction. However, the concept addresses similar problems to those of the AEC/FM industry. It is crucial that in order to support and enable multidisciplinary teams to work collaboratively, requirements must be processed and presented in a format that will facilitate that process (Kamara et al., 2002).

3.5.2 Requirements Distribution and Communication

Elicited and captured requirements need to be documented and stored for future use across all phases of a project and throughout the lifecycle of a product/facility. Therefore, there is the need to make sure that they are kept fully accessible. How requirements are to be communicated determines how they are represented and documented. Similarly, how they are elicited depends on the intended communication mechanism. Bouchlaghem et al. (2000) state that “The mechanism used for information capture in the briefing process is largely dependent on the processes undertaken to communicate that information.”

Traditionally within the construction industry, requirements are commonly documented in static form: a brief which is subsequently transformed into sketches and drawings in hardcopy. Similar observations are made by Ozkaya and Akin (2006), that a static program document is produced following the programming stage. As information technology has developed and its popularity emerged, electronic forms of documentation have been adopted and word processing, spreadsheet packages and databases utilised. With technological advancement, communicating requirements electronically

has gained momentum with the common use of e-mail. This follows the briefing process as discussed earlier and serves to inform those involved in both design and construction after translation of requirements by the architectural designers into specifications and drawings.

Requirement documents act as carrier of information during design and production phases (Ryd, 2004). Different teams and stakeholders have an interest in specific requirements at different phases thus requiring information to be documented in a manner that is comprehensible to all concerned. Similarly, Bouchlaghem et al. (2000) identify that “any technological solution or improvement to the information capture and representation processes must be able to record information in a manner that is understandable, i.e. as a written document or some other familiar structure that professionals can make use of.”

Smith et al. (1998) indicate that communicating requirements information to the design team in a significant manner is essential to ensure that requirements are taken into account. This research contends that to guarantee that requirements information is taken in account in all project development activities across all phases, requirements should be made continuously available to all stakeholders. As Lee and Egbu (2008) observe, increasing the chance of delivering a project on time and budget requires a knowledgeable project team able to understand and interpret client requirements. Therefore, in order to get that knowledge, access to client requirements information is relevant.

3.5.3 Requirements Risk Management

Project management has many aspects including project risk management. This category has further subcategories amongst which is *requirements risk* with the following variables: requirements not agreed, requirements incomplete, requirements not detailed enough, ambiguity in requirements, no single document of requirements, stringent non-functional requirement and acceptance criteria not agreed (Cadle and Yeates, 2008). From a construction

domain, some of the elements of requirements risks includes: design not conforming to requirements, changes not updated, traceable and communicated to all parties. Such requirements risk could affect procurement and development efforts which will eventually have an overall impact to the project programme (cost and budget). Figure 3.4 shows project risk breakdown structure with 'requirements risks' highlighted.

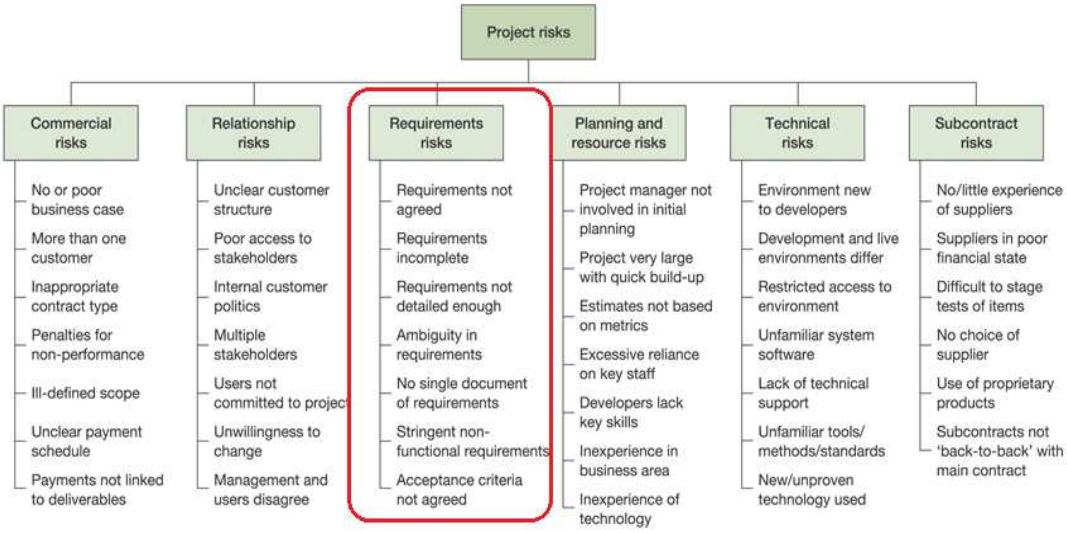


Figure 3.4: Risk breakdown structure of project risks
Source: (Cadle and Yeates, 2008)

"Software requirements risk addresses the possibility of suffering a loss of any functional or non-functional requirement of the software system" (Appukkutty et al., 2005). Similarly, construction requirements risk management should tackle the possibility of loss of any client requirement during construction projects. Client requirements keep changing throughout all phases of a project. Therefore having an efficient risk management approach within the general requirements management initiative would ensure that potential requirements risk are identified and measures taken to prevent them from occurring.

3.5.4 Changes to Requirements

Client requirements are initially defined and elicited at the early stages of a project but clients constantly review and change the requirements of their facilities. The documented requirements therefore need to be modified and

changed. In construction projects, according to Sun et al. (2004), a change is an alteration or a modification to pre-existing conditions, assumptions or requirements which can be caused by several factors (internal or external to the project).

The Chartered Institute of Building (2011) states that change is anything which is unplanned and can have both positive and negative effects on the schedule and also cost and quality of a project. “Changes arise mainly as a result of unclear or ambiguous project definition, poor communication, inadequate time spent in project planning and risk management, or changing circumstances” (Office of Government Commerce, 2007b).

Different changes may have different effects or consequences. Generally, lack of capability to manage changing requirements is one of the major principal factors that contribute to delays and budget overruns of construction projects which as a result causes client dissatisfaction. Miranda (2004) emphasises that the greatest challenge compelled to the product development engineer is managing the requirements in a manner that the intended product achieves enormous value to the customer.

Changes result in impacts to both the cost and duration of a project and inevitably demand consideration of who is accountable for the change. Sun et al. (2004) highlight that changes and adjustments are inevitable at later stages of construction projects and their effective management is fundamental to the success of a project otherwise, they can cause project delays and overspending. Cadle and Yeates (2008) also indicate that change is inevitable during the lifecycle of a project; even in the smallest Information System (IS) project and the total impact on time, cost and quality of all changes needs to be investigated before a decision to implement is made. Any change in client requirements should be traceable to the objectives of a project and be related to the lifecycle components of the building.

These requirements define the client goals and expectations which are then used to put together the processes, structures, project procurement and

contractual agreements necessary to execute the project. Change within these project elements is inevitable. “In reality, both humans and systems capital will be constantly changing and evolving, and consequently the potential value is likely to be continually changing and dynamic in nature” (Taylor, 2007). In new product development, Nadia et al. (2006) claim that “many of these changes are formally initiated by the customer as new requirements or by the company as modified specifications or manufacturing changes. These requests, called engineering changes requests (ECRs), may occur before, during or after production.” Requirements change not only during briefing but at each phase of a project through to operation and use. A change in the requirements defined in the brief will have an impact on design, construction, operations and demolition. This has been emphasised by Karim and Adeli (1999) who state that “changes in a construction project after contract award is a common occurrence.” About 50% of design defects are caused by changes which include changes in requirements, specifications and design documents changes (Andi and Minato, 2003; Shiau and Wee, 2008).

3.5.4.1 Categories of Requirements Changes

Burnes (1996) identifies two main types of changes from an organisational perspective, namely: *anticipated* and *emergent*. Changes that have prior planning and take place as previously intended and expected are termed as ‘*Anticipated changes*’ whilst those that have no prior or intended planning and happen instinctively or unexpectedly are ‘*emergent changes*’. The Construction Industry Institute (CII) (1994) identifies two types of changes, namely: *elective* and *required* from a project management perspective with respect to their requirement (need and aspiration for implementation to meet the requirements). ‘*Elective changes*’ are those changes with the option of whether to implement or not to implement whilst changes where there is no option but would require to be implemented are ‘*required changes*’. These different four terms are ideal to describe the types of changes within construction projects. These types of changes can be represented in a grid as shown in Figure 3.5 where changes can fall in any of the quadrants depending

on its nature. For example, *change 1* on the grid matrix, is emergent but at the same time a required change. Client requirements changes could fall within any one of these depending on the reason of its initiation and how much it is required or needed to meet the requirements.

There is therefore the need to manage these changes for visibility, traceability and auditability which facilitates good requirements management. This requires an effective and well coordinated change request or change control process.

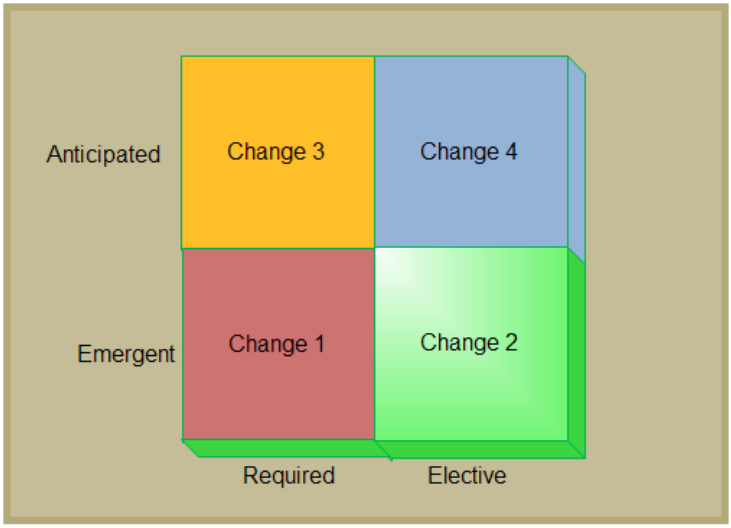


Figure 3.5: Construction project changes

3.5.4.2 Change Request and Management Process

It has been emphasised that a change management procedure should be in place in construction projects to define and manage the process adequately. This process is often referred to as 'change control'. Cadle and Yeates (2008) state that change control is the set of procedures that ensure that changes are implemented only after appropriate consideration of their impact. Halbleib (2004) emphasises that change control is an important feature of requirements management as it helps to understand which documents are affect as a result of the change and who needs to be notified. The Office of Government Commerce (2007b) highlights that a robust change control procedure should be adopted to manage changes and should consider factors

such as: who is responsible for requiring the change; analysis of the impacts; client approval for the change considering any impacts and should be documented in detail as a report for the sponsor. Change management is a crucial part of requirements management. Many researchers in AEC have worked on managing change but most of these are centred around design changes or organisational/project changes (Hegazy et al., 2001). There is a clear need to effectively manage the requirement change process as a business process-driven activity and making sure change information is communicated and updated to a central repository for consistency. As client requirements are the basis of design and subsequently construction, their changes should receive much attention. Construction client requirements are in a state of continuous change, with changes initiated by different stakeholders at different phases of a project (Hao et al., 2008). The client requirements change process is both dynamic and collaborative. “Changes frequently impact on other parts of the work that are not directly included in the change and it is sometimes difficult for the contractor to understand all of them when the change order is being prepared” (Gould and Joyce, 2009). There is the need for orderly and consistent processes to manage on-going changes of client requirements within construction projects and to update such changes. Akinci (2009) similarly highlights that “facilities under construction and operation are dynamic and the as-is conditions of a facility frequently change. There is a need for capturing the changes occurring within a facility to update federated information models and hence to provide up-to-date information to stakeholders.” As observed by Rezgui et al. (1996), multiple stakeholders are normally involved in construction projects working concurrently and often making changes. There is the need to provide complete history and traceability of those changes thus an environment to record the changes is crucial. Kiviniemi (2005) identifies two important elements of requirements management as the ownership and change history of requirements which makes it essential to know the source as well as being able to trace their evolution as they keep developing. As a result of the

importance of managing changes in construction projects, a number of tools emerged in order to facilitate that process.

Charoenngam et al. (2003) present a web-based application for managing change orders in construction projects. However, this application is generic to project changes and not specifically client requirements.

Contract change management (CCM) system, an internet based service developed by Management Process Systems, supports the implementation of the contract change management process of the new engineering contract (NEC) (Sun and Oza, 2010; Management Process Systems (MPS), 2010). According to them, this system uses both data and contract documents and is widely used by construction companies in the UK.

Motawa et al. (2007) develop a fuzzy-logic based system for predicting the likelihood and impact of changes on construction project based on a set of project characteristics. While the system was part of a generic change management process model and could be integrated with other systems, it did not have a particular focus on changes to client requirements.

3.5.4.3 Requirements Change Management as a Business Process

Client requirements change process is a business process applied to achieve change authorisation. Managing requirement changes is not a simple task; it is an integrated process of documenting, updating, controlling the information, storing and communicating those changes to all parties of a project especially those who would be potentially affected. An audit trail must be left. This information includes details of what requirements were changed, who changed them and the rationale behind the change; what time was it changed, and the dependent requirements affected by the change if any. Such information could provide visibility on the requirements change by showing the life cycle state of the change within the process as well as its relationship to other requirements. Requirements tend to flow between different parties

including engineers, clients and project managers throughout a project life cycle.

Changes should be communicated to all parties at the right time so that each member can react to a change accordingly to mitigate or avoid against cost over-runs, time implications and other issues relating to the building such as health and safety. Thus it is important that sharing requirements change information be at the centre of project management. Rezgui et al. (2010) similarly observe that the culture of information sharing is now been promoted by AEC organizations to help identify, assess and predict hazards in order to help dealing with them at an early stage. This helps improve designers' awareness and understanding of design decisions, especially changes, and their implications and encourages the practice of information sharing (Rezgui et al., 2010). Similar observations are highlighted by The Construction Users Roundtable (2004) that change should be dealt with in a timely manner and should be incorporated in the project scope of work once authorized. Austin et al. (2002) indicate that changes can affect decision-making and therefore must be recorded and communicated to all relevant stakeholders. Sinha et al. (2006) made a similar observation in the software industry, stating that "important information pertaining to a change often doesn't reach the right people at the right time; moreover the status of a change isn't globally visible making it difficult for project managers to track whether all necessary follow-up actions have been taken." Synchronous communication which involves communicating at the same time (e.g. face-to-face, telephone, dialogue during meetings) and Asynchronous communication which involves communicating at different times (e.g. Email, project extranets, postal, fax, etc.) are two common means of communicating and sharing construction information (Emmitt, 2007). It is important that the most appropriate is employed to facilitate real-time communication of change information in construction projects.

The research reported in this Thesis argues that despite research dedicated to design changes which has resulted in new information systems, research

on *requirements change management* taking a *data/information-centric approach* should be the driving force to allow for more effective requirements change management. “Although a number of off-the-shelf web-based solutions are available for the AEC industry, they cannot meet the excessive information management needs of the industry. A limitation of the existing web-based systems is that they follow a document-base philosophy (e.g., *often manage documents themselves rather than the information contained in them*)” (Chassiakos and Sakellaropoulos, 2008).

Requirements are the source for design thus understanding, documenting and managing requirements effectively would facilitate not only proper design change management but any other requirements related changes within and during a project life cycle. According to Hegazy et al. (2001), “Introducing a design change requires full understanding of the rationale behind the original design, which helps in preventing any violation of the requirements of the original design.” In order to better manage and utilise requirement changes all through a facility’s lifecycle, it is necessary in the initial stage to adequately document and store the requirements information in a central repository. As changes to the requirements often require a chain of processes for request and authorisation, effective process control is a catalyst to enable visibility and auditability as well as proper flow of information between all stakeholders. Clients who often request changes to their requirements could access the change system to make their request. Similar thoughts have been proposed by Kidd and Thompson (2000), who suggest that “Future computer based change control systems will become even more efficient. Perhaps customers proposing design changes could be directly linked by the internet to the change control manager.” This is significant as Steffens et al. (2007) identify that “research has not provided solutions as to whether flexibility-oriented change management in a dynamic business environment can be carried out in a robust, controlled manner.” Therefore, this research argues that requirements change management be viewed as a process-centric project management activity which requires a process-oriented approach to facilitate the coordination and control of the change request process.

3.5.4.4 Collaboration Support for Requirements Change Management

Communication and information sharing amongst construction teams has received a lot of attention over the past years and has resulted in the development of project extranets (Wilkinson, 2005). These systems are today used widely in construction projects to enable and facilitate collaborative working. Such systems take a document centric approach to communicating and sharing information and the architecture makes use of a shared centralised drive on which project documents are uploaded and notifications sent. Dustdar (2005) highlights that "groupware systems, in most cases, follow a shared workspace metaphor utilizing shared folders (e.g. web-based folders) and do not provide information on the relationships between artefacts (e.g. document) and the associated activity of a business process (e.g. activity "presentation for customer XY") on the status of other team members' work activities." Such systems do not contribute great potential towards efficient requirements change management as information sharing is limited within the workspace and do not support direct linkage with other enterprise systems. 'Build Online', a popular construction extranet system takes a data-centric approach to change request but is limited to sharing that change information within a shared workspace and not is integrated with other enterprise applications. Lack of integration of the information on these types of systems provided within organisational processes is a key bottleneck in enabling effective communication of information especially changes to requirements. Haymaker et al. (2006) discuss that "Many researchers have observed current practice's difficulty integrating information and processes, or developed systems to help manage this integration, for example: between requirements information and design information." This cannot guarantee information consistency and redundancy is possible.

3.5.4.5 Models for Change Management

There are known change management models or best practice for managing changes in construction projects but none has specifically defined how to manage changes relating to requirements as a process and integrating that

process with requirements repository or other enterprise systems. As claimed by Yan et al. (2008), “There are several authorised standards for engineering change management. Configuration Management II (CMII) is the norm widely used in the manufacturing companies of United States and China.” The Construction Industry Research and Information Association (CIRIA), UK, published a best practice guide in managing project changes. “The guide defines the key principles of managing change, highlighting the different types of change that may occur and how these affect a project at different stages” (Lazarus and Clifton, 2001). A Change Management Process was defined in an industrial report by a research conducted in managing change and dependency (MCD) by three universities – University of the West of England, Loughborough University and University of Salford in collaboration with industrial partners (Sun et al., 2004). In his work on change management from systems analysis and design perspective, Maciaszek (2007) emphasises that large amount of information is tracked over long periods of time in change management and without tool support, change management is doomed; software configuration management tool should be used by developers to store and track those requirements changes. Roy et al. (2005) propose an ontological framework for design requirements management with information ontologies to structure the content of the traditional requirements documents (paper-based) to facilitate requirements flow; and process ontologies to define automated workflow routines that control the requirements management process, the associated decision-making, and communication process.

Price and Chahal (2006) present a strategic framework for change management and indicate that critical to successful change is not only the development of more efficient and effective processes but alignment of organizational culture to support these new processes. Even though this framework focuses on organisation change management and not specifically requirements, this research also similarly argues that a successful requirements change management should not entirely rely on efficient and effective processes but that the changes should be aligned with the needs and wishes of the client.

3.5.5 Traceability for Dependency Checking and Impact Analysis

“Requirements traceability refers to the ability to describe and follow the life of a requirement, in both forwards and backwards directions (i.e. from its origins, through its development and specification, to its subsequent deployment and use, and through all periods of on-going refinement and iteration in any of these phases)” (Gotel and Finkelstein, 1993). Dick (2005) describes traceability from a software point of view as “documenting the relationships between layers of information - for instance, between systems requirements and software design.” The Institute of Electrical and Electronics Engineers (IEEE) (1984) states that “A software requirements specification is traceable if (i) the origin of each of its requirements is clear and if (ii) it facilitates the referencing of each requirement in future development or enhancement.” In the same software industry, Maciaszek (2007) also signifies that requirements traceability is a critical part of change management and “is about maintaining traceability relationships to track changes from/to a requirement throughout the development lifecycle.” *Traceability is therefore a key part of good requirements management.* Han (2001) emphasises that traceability “facilitates analysis of how a new or changed requirement will affect the system’s functionality and quality.” Robertson and Robertson (2006) recognise that it is easier to find the part of the product affected by the change and to assess the impact of the change on the rest of the product if the requirements are traceable.

The demand for traceability management extends beyond design and flows into construction and post-construction phases thus taking a whole lifecycle dimension. However, according to Fernie et al. (2003b), even though construction projects have change control procedures, they are not often sustained beyond the handover of the building. Current document-centric requirements management within construction makes it difficult to manage traceability. “There are relatively few documented methods that provide traceability and ability to analyse change that extend into facilities management” (Fernie et al., 2003b). Traceability helps to support impact

analysis of the changes. Requirements of a product are interrelated and a change to one could result to an un-noticeable change to another. In the Software Industry, Sinha et al. (2006) notice similarly that “changing customer needs might also modify existing requirements.” Changes are generally requested through a change order process. During this process, identifying what has changed and what is subsequently affected enables evaluation of the cost and time implications on a project. This is relevant as studies have shown that *‘change order’* is generally considered to be a major factor contributing to construction project delays and cost over-runs (Miranda, 2004; Al-Saggaf, 1998; Office of Government Commerce, 2007b).

Kiviniemi et al. (2004) and Kiviniemi (2005) identify related research areas in requirements changes and proposed storing all requirement changes during the process in a ‘history database’ but implementation requires further work.

3.5.6 Interdependency Between Requirements – Case for Dependency Links

Every system (*being it biological, organisational, social, and technological or a mechanical product*) from a systems thinking approach is made up of different components that enable the whole to function. A change in one component without a corresponding update on the other(s) may result in malfunction of the whole system. Similarly in construction, a facility is constructed from a set of client requirements. Each of these requirements could have related sub-requirements that are linked to each other. A change in one could potentially affect another. Changes in ‘Requirement X’ may affect ‘Requirement Y’ which could also affect ‘Requirement Z’. For example a change in the size of a room could affect energy consumption requirement. This is dependency between requirements. Motawa et al. (2007) observe that “it was important to identify what project characteristics lead to the causes of change and what these causes are, and then to understand how these causes are related to effects. Some of the key questions were: How does one factor relate to another? What are the internal mechanisms by which a particular factor causes a change in another factor?” Once a requirement change is authorised, it needs

to be checked against the design, the construction programme, the specifications and bill of quantities to substantiate the impact. Emmitt (2007) identifies that changes need to be checked against critical documents such as project brief before implementation which is a slow process since changes have implications for other interconnected aspects of the building. Austin et al. (2002) state that most change decisions affect cost and time of construction projects and such decisions have to be properly monitored and their impact traced. Ye and Froese (2009) identify that “where a project manager is evaluating the impact of a proposed change order, he or she will want to consider the schedule, cost, scope, resource, reference documentation, and other information relating to the change but it is traditionally left to the user to manually identify each relevant dataset and to understand the interdependencies between them.” Dependency and impact also need to be handled as part of requirements change management to help analyse the impact and consequences on project variables such as schedule, budget and performance/quality. Such changes could have an effect on different project variables such as the budget, schedule and quality. Similar emphasis has been made by the Office of Government Commerce (2007b) that “Changes to design, especially after contract award, are one of the major causes of time and cost overruns and poor value for money.” Individual requirements that are related but are represented at different phases should be mapped together to provide links between them to enable traceability. Accordingly, these links should be implemented between the requirements and “even a simple active link between the client requirements and design tools can increase the use of requirements documentation throughout the design and construction process, and facilitate necessary updates of the client requirements” (Kiviniemi, 2005). Similarly, Tvete (1999) suggests that in order to facilitate traceability, requirements need to have unique identifiers which can be an attribute, and this can make the viewing and analysis of requirements possible from different points. Traceability relationships are not only relevant for dependency checking and impact analysis, but they also provide a link between different teams using those requirements.

Maiden and Jones (2004) define dependency links between actors of a system where a link indicates dependency of one actor onto another for attaining a goal. According to them, the depending actor is called the *depender*; the actor who is depended upon is the *dependee.* The *dependum* is the process element around which the dependency relationship is centred. Maiden and Jones (2004) specify the following four different types of dependency links.

- Goal Dependency: in this dependency, the depender depends upon the dependee to bring about a certain state in the world.
- Task Dependency: this type of dependency indicates that the depender depends upon the dependee to carry out an activity.
- Resource Dependency: this implies that the depender depends upon a dependee for the availability of an entity.
- Soft-goal Dependency: this exists were the depender depends upon the dependee to perform some task that meets the soft-goal or to perform the task in a particular way.

Thus it is vital that these relationships are adequately and thoroughly maintained, if not, subscription may be the basis for change dissemination (Sinha et al., 2006). Within the software industry, Kotonya and Sommerville (1998) and Sommerville and Sawyer (1997) in Maciaszek (2007) discuss the importance of requirements dependency matrix which can be constructed once all requirements are clearly identified and numbered. They indicated that such matrixes are simple but effective techniques to identify conflicting and overlapping requirements.

A risk analysis and prioritisation should be done once the conflicts and overlaps are resolved and a revised set of requirements produced (Maciaszek, 2007). A template of a requirements dependency matrix is demonstrated in Figure 3.6.

Requirement	R1	R2	R3	R4
R1				
R2	Conflict			
R3				
R4		Overlap	Overlap	

Figure 3.6: Example requirements dependency matrix
Source: (Maciaszek, 2007)

A similar concept was also developed by Symantec Corporation (2008) in the management of service groups within their Veritas Cluster Server where service groups can depend on each. In their work, they specify the dependent group as the *parent* and the other group, the *child* and the dependency relationship is called a *link*. “For example a finance application (parent) may require that the database application (child) is online before it comes online” (Symantec Corporation, 2008). Three different link characterizations were identified, namely: *dependency category, dependency location and dependency rigidity*.

- Dependency category: this can be either online or offline group dependency. A dependency where the parent starts only by waiting for the child to be brought online first is referred to as *online group dependency*. A dependency where one of the groups needs to be offline before the other can start is referred to as *offline group dependency*.
- Dependency location: this can be local, global, or remote dependency. *Local dependency* exists on the same system where the parent group depends on the child group being online or offline. Global dependency exists where one or more instances of the child group being online on any system determine an instance of the parent group. Remote dependency where one or more instances of the child group being online on any system other than the system on which the parent is online for an instance of parent group to occur.

- Dependency rigidity: this type of dependency can be soft, firm or hard dependency in terms of constraints on how the different groups are brought online or offline. Soft dependency specifies the minimum constraints; firm inflicts more constraints and hard imposes the maximum constraints.

The philosophical approaches applied in these theories are relevant to this research and can be adopted in defining dependency links between requirements and sub requirements (i.e., secondary requirements) in order to facilitate traceability for dependency checking and change impact analysis.

3.6 Benefits Realisation and Value Management

3.6.1 Benefits Realisation

The relevance and importance of managing client requirements is to facilitate the successful completion of projects; ensuring the benefits envisaged at the start of the project are realised at the completion and all the way through the life of the facility. Often, projects such as Healthcare projects are complex and also involving a huge number of stakeholders (Yates et al., 2009).

Driven by the need to realise benefits throughout the life cycle of projects and programmes in both public and private sector, identification, monitoring and management of the benefits throughout lifecycle is being accepted as a way to ensure the success of that programme or project (Yates et al., 2009). It is reported that major capital investment programmes and projects such as Healthcare, are measured on their success in relation to cost, quality and time of delivery, and not in relation to the benefits or impact that they have delivered (Sapountzis et al., 2009).

According to the Office of Government Commerce (2009a), benefits are measurable quantification of improvements as a result of a change. They indicate that programmes differ from projects in that the former are initiated to realise outcomes (i.e., benefits) through change, whether to do things differently, to do different things, or to do things that will influence others to

change. Projects are geared towards outputs (i.e., deliverables). However, benefits can be realised through the combination of projects and their deliverables (Reiss et al., 2006). Benefits are realised towards the end of a benefit management process which identifies, tracks and manages the expected benefits to their successful realisation (Office of Government Commerce (2009a). Sapountzis et al. (2007) indicate that elements from other disciplines discipline such as benchmarking, performance measurement, and operation management should be embraced by a benefits realisation process. Similarly, the discipline of requirements management including change management should also be embraced in the process.

One of the major causes of budget over-runs in construction projects is delay in the completion time which can result in loss in financial return and other benefits of the project (Shen, 1997). Increase on the budget and time spent on the project can also be as a result of changes in policy during the lifecycle of a project, which can also mean that what is delivered seldom matches the vision set out at the initial stages of a programme stage; resulting in the need for changes which were not anticipated (Yates et al., 2009). This can also be as a result of poor benefits management (Sapountzis et al., 2007) and lack of effective requirement management also contributes to delay of construction projects. Therefore, incorporating requirements management within benefit management and realisation plans can increase the chances of delivering successful projects and programmes; realising benefits.

It can also be argued that benefits should be identified during the requirements gathering and documentation processes and should be carried along through the lifecycle processes of facilities. This should also apply to emerging and changing requirements. This means that benefits related to a change should be identified and related back to the initial benefits of the original requirements. This will require adequate assessment to identify conflicts in between the emerging benefits as a result of the changes, and the originals. Where a conflict between the two is identified, stakeholder decision should be sought before implementation. Benefits often are not realised until a

project is completed, thus it is relevant that benefits management as a method, supports organisations in the identification and management of benefits through the whole lifecycle of programmes and projects (Sapountzis et al., 2009); equally important is that lifecycle client requirements management are incorporated in that process.

Several tools, techniques and frameworks have been developed for benefits realisation and management. Sapountzis et al. (2009) introduce the Benefits Realisation (BeReal) Framework which aims to address primary healthcare sector's need for benefits realisation and support Local Improvement Finance Trust (LIFT) community in identifying, managing and realising the benefits that it has been created to deliver. Managing Successful Programmes (MSP) is a methodology which comprises a set of principles and processes for use when managing a programme including benefits management and realisation was developed by the Office of Government Commerce (Office of Government Commerce, 2009a; Office of Government Commerce, 2007a). Yates et al (2009) discuss Tools and Methods for Implementing Benefits Realisation, and indicate the use of appropriate ICT tools and collaborative environments for implementation of benefits realisation which should be process-led and not technology-led.

3.6.2 Managing Value in Construction

Managing and delivering value in construction is challenging due to the complex nature of projects often characterised by multiple stakeholders. As a result, in order to understand and reflect stakeholder attitudes, opinions and values in the final construction solution, projects are becoming concerned with engaging directly with stakeholders (Thomson and Austin, 2006). For example during the design process, assumptions should not be made about stakeholders' requirements or expectations according to Thomson et al. (2003); stakeholders must be involved so that the values relevant to each construction project can be identified and understood.

Value in BS EN 12973:2000, may be described, according to the definition of given by EN 1325-1, as the relationship between the satisfaction of needs and the resources used in achieving that satisfaction (British Standards Institution, 2000). The Office of Government Commerce (2007c) states that in its broadest term, value is the benefit to the client (i.e., the project is worth doing and can be quantified in business terms; although not necessarily in financial terms). For the past decades, several project management techniques such as value management have been applied in construction to help provide value to stakeholders. Kliniotou (2004) states that seeking to satisfy or exceed the requirements of the various stakeholders; value management is commonly concerned with maximising the benefits of a project or a business. Value management provides a structured approach to the assessment and development of a project to increase the likelihood of achieving stakeholder benefits at optimum whole life value for money (Office of Government Commerce, 2007c). Although it is not aimed at cost-reduction which may be a by-product, it is about maximising project value. Value management encompasses value engineering which considers specific aspects of the design, construction, operation and management of built facility (ibid., p.8). Management tools and methodologies such as Value in Design (VALiD) have emerged to facilitate value delivery. Austin and Thomson (2005) indicate that VALiD, which is structured around a three-part framework, is a flexible approach to managing stakeholder engagement for value delivery, and can be used in whole or in part to suit project requirements.

Figure 3.7: The VALiD Framework
Source: (Austin and Thomson, 2005)

Austin and Thomson (2005) explain the framework as follows.

- Understand Values; stakeholders understand each others' values so that compromises can be made when reaching a single solution.
- Define Value: stakeholders or their representatives inform project design by setting targets and criteria for value delivery in the form of benefits, sacrifices and resources.
- Assess Value Proposition: stakeholders judge value-delivery performance emerging from the deliverable throughout the project life cycle, from inception through to obsolescence.

It is reported that in helping stakeholders express their values, expectations and judgements of value delivery, VALiD has been shown to be effective (Austin and Thomson, 2005).

It is a clear manifestation that there exist an integrated link between value management and benefit realisation. The research reported in this Thesis also relates firmly to benefits realisation and value management in understanding the relevance of designing, managing and delivering successful projects base on client requirements management (i.e., client needs and wishes) in order to achieve the expected benefits out of the project. The management of those requirements are significantly critical to the production of a valid design and can relate with the VALiD framework. This is feasible in that the process of managing requirements which includes effective documentation and storage for collaborative access can facilitate all project stakeholders to be aware of the requirements when defining the value of their projects. The availability of the requirements at design stage is also vital when representatives inform project design by setting targets and criteria for value delivery. Dependency checking as applied in requirements management is crucial to make sure that changes are adequately assessed before implemented. This can be a useful feature within the VALiD process so that changes in design are assess to understand their implication to benefits and value.

3.7 Summary

This Chapter provided a review of literature in requirements information management in AEC/FM industry. However, the review also included other industries such as software engineering, manufacturing, aerospace and defence.

From this review, it is understood that requirements are very important in helping in the early phases of construction project planning. Planning the entire development activities follow as soon as the clients' requirements are agreed. During this time, important key decisions are made, including: sub-contractor selection, supplier selection, costing and budgeting; programme scheduling all based on the requirements information. Initial and emerging requirements also form the basis of determination of architectural design, use and operations; maintenance and refurbishment and eventually, disposal. However, these requirements change constantly during the life of a facility and could have potential impact to the success of a project.

Several change management models and web-based systems were identified; however they did not specifically focused on client requirements information management. The systems did not also take a lifecycle information-centric approach. Limitations were highlighted regarding the management of changes which include manual checking of dependencies, lack of updating the originally sets of requirements after changes are authorised and notifications not widely communicated. This necessitated for adequate management efforts to control and coordinate the change management process. Traceability of requirements is crucial in facilitating impact analysis which can be enabled by dependency links.

Comparable discussions have been made from a systems development point of view in which planning is done for entire development to follow during which time, key decisions are made including: "determination of purpose, from which stem detailed requirements; planning the rest of a system's lifecycle, including subsequent development, testing, deployment, maintenance and future

upgrades; allocation of resources to those phases (e.g., budget, schedule, testing platforms), and the determination of the architecture and early phase design" (Feather et al., 2006). Benefits realisation and management of value delivery are important aspects of construction project management. These two approaches are firmly related to the process of managing information about client requirements.

This thesis argues that a properly developed and maintained requirements information management system, supported by an established process, will support the efforts of lifecycle requirements management in order to contribute to successful construction projects.

Consequently, the research ventured into looking for remedy to these problems. This included the search for appropriate tools and techniques, particular IT to serve as support mechanisms. Accordingly, the next chapter will discuss identified IT tools and technologies that could potentially be utilised to contribute to effective and efficient requirements information management. These technologies can be used to support effective coordination of processes in a collaborative working environment, and integrating heterogeneous systems to facilitate interoperability.

Chapter 4. **Business Process Management (BPM), Service Oriented Architecture (SOA) and Web Services (WS)**

"The integration of business activities occurs through the integration of business processes rather than the integration of business applications"
(Fred A. Cummins, 2010)

4.1 Business Process Management

4.1.1 Introduction

All organisations perform processes either in the form of a project or operations (Jallow, 2006). Processes define work procedures and resources necessary to accomplish specific tasks and deliver the needs of the client. They need proper management if the business is to deliver expected outcomes and to maintain core values. Processes change in response to changes in business objectives and should be able to adapt to such changes without interruption to operations. Medina-Mora et al. (1993) identify three main processes within organisations, namely: material processes, information processes and business processes. Georgakopoulos et al. (1995) clarify that the scope of a material process is to assemble physical components and deliver physical products. That is, material processes relate human tasks that are rooted in the physical world. Such tasks include, moving, storing, transforming, measuring, and assembling physical objects. Information processes relate to automated tasks (i.e., tasks performed by programs) and partially automated tasks (i.e., tasks performed by humans interacting with computers) that create, process, manage, and provide information. Business processes are market-centred descriptions of an organization's activities, implemented as information processes and/or material processes.

From this clarification it is argued that business processes are an excellent delivery medium of information as well as an arena for the creation of

information and knowledge. Information about a process itself (and process execution results) is valuable corporate asset and decision making item. Information derived from business process must be gathered and formalised to enhance the performance of business processes and the organisation.

4.1.2 Business Processes

Every business or organisation is set out to achieve specific aims and objectives, with processes and procedures which need to be followed. Therefore, all the processes that interrelate in providing a product or a service should be identified and understood in order for an organisation to function efficiently and effectively (Griffith, 2011). Taylor (2007) defines a process as a series of activities undertaken to produce a specific deliverable. “A business process is a clearly defined set of activities and a set of well-defined relationships between those activities that identify appropriate ordering and sequencing of behaviours to achieve the goal or output of the business process” (Houck, 2007). Georgakopoulos et al. (1995) state that “Business processes are market-centered descriptions of an organization's activities, implemented as information processes and/or material processes. That is, a business process is engineered to fulfil a business contract or satisfy a specific customer need.” Business processes are a set of functions starting with an external event and performed as a collection of related activities in a certain sequence that produce a product or a service and delivers at the end a value for an internal or external client, organisation and business partners (Kirchmer, 2009; Rainer and Cegielski, 2011).

Business activities are performed as a workflow and recent trends for efficiency and agility driven by competitiveness have resulted in the automation of business processes. These work activities are sometimes referred to as tasks which are performed by humans, machines or a combination of the two. In some cases, this requires interaction with other subsystems such as databases or other enterprise systems such as enterprise resource planning (ERP).

Traditionally, business processes have been executed manually and tasks pass from one person to another with the use of paper-base systems. As competition for early product delivery and globalization became necessary, organisations started producing large amounts of information on a daily basis. Tasks became repeatedly performed demanding adequate staffing to deal with the overload of work processing. Thus the execution of business processes became complex to handle manually. With advancement in computers and related technologies, automation of human tasks started taking centre stage. Workflows emerged to automate organisational business and information processes. They define the sequence of operations and participants responsible for the execution of tasks according to defined procedural rules. Becker et al. (2000) discuss that workflows are based on process models and are temporal and logical sequences of activities that are necessary to perform operations on economically relevant objects. Their control logic lies within the control sphere of an information system. Becker et al. further state that a workflow management system (WfMS) is an information system that supports the execution (and optionally the specification) of workflow models. WfMS evolved to enable office automation during which work related information and documents are electronically passed from one point to another; one participant to another; and one computer to another. Jallow et al. (2007) argue that “The operational continuity of a business process is an important performance indicator that contributes to the perceived quality of service delivery; hence it is important to understand and monitor the underlying issues that can affect the performance of the process.” Consequently, business processes undergo re-engineering or redesign for optimisation purposes. Business process models which specify workflows are catalysts for process optimisation.

4.1.3 Collaborative Business Processes (Intra and Inter-enterprise)

Intra-organisational (*otherwise referred to as intra-enterprise*) business processes are those processes that span across different organisational functional units/departments with systems used by those units/departments

BUT remain within a single organisation; whilst inter-enterprise business processes span beyond an organisation's internal boundary (Kirchmer, 2009). In recent years, an increasing number of companies are targeting the integration between collaborating and partner enterprises resulting in inter-enterprise processes and systems used across business boundaries. Recent business trends and models such as globalisation, decentralisation and partnerships are amongst the pushing factors towards inter-enterprise business processes in which multiple parties take part and large numbers of heterogeneous applications operate in a distributed environment with dynamic availability and evolving contents (Chen and Hsu, 2001). In these types of business environments, companies or businesses have teams in different geographical locations, operating on separate and individual business processes which need to be brought together in a collaborative setup in order to share/exchange information across the supply chain during transactions and execution of business activities. This requires giving partners access to information or one partner transmits/shares information to/with another which has been facilitated by the internet and the fast advances in communication and information technologies coupled with global competition (Attaran and Attaran, 2007; Lee et al., 2003). A Service Oriented Architecture-based (*SOA-based*) IT environment supports inter-enterprise processes; enabling integration and results in internet based processes when the integration is supported by web-enabled technology. They are often called 'e-business processes' and such organisation integration must be organised through an appropriate BPM approach (Kirchmer, 2009). When implemented and executed properly, collaborative business processes facilitate the efficient and effective collaboration between internal business units and between enterprises (Kirchmer, 2009). The current workflow modelling methods and management systems cannot articulate completely this kind of cooperation, and they lack adaptability and flexibility (Wang et al., 2010). BPM is an excellent alternate solution to provide modelling and automation of such process. More efficient and effective supply chain coordination is expected through the implementation of inter-organizational business-process

collaborations with service-oriented technology (Norta and Eshuis, 2010). At any point in the execution of business processes, whether internal or external, one should be able to connect with the information and/or expertise needed in order to get things done. This means all *business processes should include collaborative capabilities* so that they are not impacted with the negatives of time, distance and latency (Rittinghouse and Ransome, 2010).

4.1.4 Process Modelling and Management

4.1.4.1 Process Modelling

Process modelling is an integral element of business process management (BPM) and a requirement for successful orchestration of BPM. Business processes can be visually represented graphically in models (also referred to as maps) by process modelling (i.e., drawing a business process diagram) which ideally is the first step of any business process lifecycle (Koskela and Haajanen, 2007). According to Lyridis et al. (2005), normally, supporting text is used when documenting business process models as diagrams. “Process modelling becomes more and more important task not only for the purpose of software engineering but also for many other purposes besides the development of software” (Becker et al., 2000). Process maps are used to create clarity about the logical sequence of activities in an organisation and to describe the resulting products and services and the organisational units or the functional areas involved in the value chain (Becker et al., 2010). They can also be used to design current state (AS-IS model) of business activities which can then be which can then be analysed and improved into a new optimised model (TO-BE model) (Okawa et al., 2008). Organisations are always pursuing performance improvement in which business process execution is vital. According to Polyvyanyy et al. (2010), these processes are documented as process models in order to be able to execute, study and improve operating procedures crucial for performance improvement needs. Griffith (2011) indicates that “the concept of the ‘process model’ is fundamental to structuring an organisation, its activities and their management.” Amongst other important use of the models include

communication, knowledge sharing, process re-design or optimisation, precise instructions for executing business task or to enable performance review and improvement (Polyvyanyy et al., 2010). In other words, business process maps can be used to simulate process execution which can help identify process bottlenecks and their optimisation for efficient and effective business operations. Visualisation of the important steps and the relationship of those steps in a process; actors and systems involved in carrying out the various steps in a process are amongst the uses of process models (Reijers et al., 2010). Similar observation was made by Lyridis et al. (2005), who state that process modelling and the subsequent models helps to identify all fundamental aspects of a company and are an approach to understanding and communicating what really happens in existing processes. Process Modelling notations (otherwise referred to as modelling languages) are used to model process maps. For the purpose of this Thesis, the term 'process language' will be used instead of 'process notation'. There are several modelling languages and business process modelling tools can be used to develop process maps. The languages have different capabilities and approaches to developing the process maps. Some of them take a '*data*' view describing how data flows across a process; some take an '*activity*' view describing the various activities that take place whilst some take a hybrid view describing processes with both the data and activities that take place including the actors and functional areas involved in the process. Lyridis et al. (2005) indicate that development of process models are implemented in a three-step approach.

- "Step 1: is to set the scope of the process mapping. The goal is to set boundaries and identify the main actors and stakeholders to the business or along the chain subject to modeling.
- Step 2: describes how to develop the process model. The goal is to build a model in several levels where each new level gives a higher degree of detailing. It is important to ensure the documentation of all relevant information and to structure it in an appropriate way so that it meets the scope of the project.

- Step 3: describes how to present the process model. The goal is to ensure that people involved in the processes, understand the model, its presentation and that they really think the model actually reflects the way they do their job. Important elements are roles, activities, information flow, and information systems."

The language used will entirely depend on the purpose of the map to be developed. Some of the commonest languages used for processing modelling are: Data Flow Diagrams (DFD), Unified Modelling Language (UML), Grai Integrated Modelling (Grai-GIM), Integrated Definition (IDEF), standard flowchart, and Business Process Modelling Notation (BPMN) amongst others. However for the purpose of this research, only BPMN was considered for use because of its de facto application with BPM and BPMS. It (BPMN) is an emerging modelling standard that has large reception in different industries especially in the BPM domain. According to Interfacing Technologies Corporation (2010), by using BPM standards to model business processes, it becomes simple to determine what services must be called upon throughout the ongoing business processes.

- Business Process Modelling Notation (BPMN)

BPMN has emerged as the standard modelling notation for business processes (Object Management Group (OMG), 2009; Owen and Raj, 2003). It is described as "the most comprehensive notation for process modelling so far" (Juric and Pant, 2008). According to Owen and Raj (2003) BPMN, easy to use and understand, is the new standard for modelling business processes with the ability to model complex business processes. It was also designed specifically with web services in mind. Juric and Pant (2008) confirm this by stating that BPMN was developed much specifically for modelling business processes in conformity with SOA and to bridge the gap between process analyst and technical architects and developers. They further argue that BPMN for modelling business processes has been designed explicitly for SOA and process execution. This means it can be used to design business processes and web services and for the integration of both. The OMG (2009)

highlights that thousands of business analysts analysing organisational work processes use simple flow charts to define business processes but this creates a technical gap between the formats of defining the processes and those that will execute the business processes such as BPEL4WS. The OMG (2009) indicates the need to bridge this gap with a formal mechanism to model processes for analysis and execution. Consequently, according to the OMG (2009) BPMN was designed to:

- provide models designed for use by the people who design and manage business processes;
- provide a mapping to an execution language of BPM Systems (BPEL4WS);
- provide organizations the ability to communicate procedures in a standard manner with the capability of understanding their internal business procedures.

BPMN follows the traditional format of flowcharting concepts to represent the logic of business processes, but at the same time provides a mapping to the executable constructs (Object Management Group (OMG), 2009; Juric and Pant, 2008).

One of the advantages of BPMN is that models developed with it can be used both by business analysts and developers (Juric and Pant, 2008). White and Miers (2008) identify that most of the process modelling projects have the objective of documenting (understand) and analysing an organization's key business processes but the same models can be used for other purposes such as becoming executable (in a BPM Suite or workflow tool) if elaborated and built upon with further detail. BPMN models posses this dynamism whereby they can be used by business users and business analysts; and on the other, executable processes according to White and Miers (2008). BPMN is the natural complement to BPEL for the design and orchestration of services as BPMN models can be transformed into executable BPEL code explain Rezgui et al. (2009b) and Juric and Pant (2008).

This means a business analyst can use it to develop the business process from business procedure point of view and the developers can use the same models convert them to executable process models which will be deployed and executed. Process enactment is the 'automation' of business process execution. From a BPM point-of-view, it is not only enough to model business processes but also to do process enactment which is a key component of its philosophical approach. Modelling executable process involves transforming BPMN process maps into BPEL which can be deployed for execution. Process maps should depict cross-functionality within functional areas (internally of an organisation) and externally (between the organisation and its partners including suppliers, customers/clients and all other stakeholders). BPMN diagramming technique supports this approach. In his work on improving information delivery, Wix (2009) emphasises the significance of the software support tool BPMN possesses, with wide industry application and can also support transformation of business processes to BPEL.

The BPMN diagramming technique uses different symbols or notations (*as shown in Table 4.1*) and presented in an inter-connected flowing manner. There are many different symbols but for the purpose of demonstration, only the core will be discussed here in order to set the scene. The technique along with all the different types of notations has been covered in detailed by Owen and Raj (2003), OMG (2009). It is important to note that the current version of BPMN (BPMN 1.2) is being revised and a new version (BPMN 2.0) called *Business Process Model and Notation* is currently at beta phase and will have robust execution semantics, extended modelling capabilities and portability standards (Object Management Group (OMG), 2009; Cummins, 2010).

Table 4.1: Core BPMN notations/symbols

Process element and Notation/symbol	Description of use
Pool 	A pool represents participants or actors/roles in a business process map. Pools contain activities to be performed by process participants. This could be a department or a function.
Lanes 	A lane is a sub-division of a pool and extends the entire length. It is used to categorise and organise activities within sub-units of a department (pool) for example
Task 	This is an atomic activity used to represent work to be performed by a participant. They are represented by rectangles with rounded corners. An activity can also have sub-activities and in that case, the rectangle will have a 'plus sign' at 'centre bottom' to indicate that the activity can be decomposed.
Message Flow 	A message flow shown with a dashed line is used to represent the flow of messages/information/documents between two participating pools (participants).
Sequence Flow 	A sequence flow or order of activities represented by an arrow is used to how the order in which activities are performed in a process. It cannot be used between pools.
Start Event  End Event 	The start event specifies where a process begins and the end event indicates when the process ends.
Gateway  AND  OR 	Diamonds, referred to as gateways are used to show decisions. They are used in a process to control or indicate the divergence or convergence of the sequence flow. The logical OR (X) gate is used for decisions and merging whilst the logical AND ((+) parallel)) gate is used where multiple task takes place or forking and joining activities.
 Collapsed Process	Activities can be grouped as a sub-process in a parent process and are represented with a collapse process with a plus sign.

4.1.4.2 Process Management

Several definitions have been proposed for *business process management* (BPM) without any consistency. It is important to look at the term from two angles (*i.e., (i) business process and (ii) management*).

Business process management from an organisational viewpoint is about planning, organising, directing, leading, coordinating and controlling resources in order to achieve success. Several resources form business processes which include people, systems, technology and procedures/rules. Managing these resources for the effective and efficient handling of business processes is vital for businesses to perform. As discussed earlier, as a business' objectives change, its related processes are also bound to change to reflect and accommodate those changes when business process re-engineering (BPR) takes place. However, it should be noted that business process re-engineering is not all about business process management but part of it. With the use of IT based systems, the application of 'process' discipline has received wide adoption by various organisation in project management and is now well established and acknowledge in the construction industry (Sun and Oza, 2008). The process-orientation management approach can be executed with the use of BPM. As Kung and Hagen (2007) put it "BPM cannot be considered simply as BPR. Rather it is concerned with how to manage processes on an on-going basis, and not just with the one-off radical changes associated with BPR." BPM is about "Supporting business processes using methods, techniques, and software to design, enact, control, and analyse operational processes involving humans, organizations, applications, documents and other sources of information" (Van der Aalst, 2004). Kirchmer (2009) emphasises this philosophy by stating that BPM is a management discipline providing process-oriented organisation with governance with the goal of agility and operational performance using methods, policies, management practices and software tools for improved organisational performance. Wyron (2010) also indicates that BPM is about the automation and optimization of organisations workflow. BPM (as a management

technique to support the design, analysis, implementation, management and optimization of business processes) includes the use of specific methods and tools (Rainer and Cegielski, 2011). Another important dimension of BPM is its capability of bringing together different distinct disciplines apart from process management into a single standard; such discipline includes Process Modelling, Simulation, Workflow, Enterprise Application Integration (EAI), and Business-to-Business (B2B) integration (Owen and Raj, 2003). Similarly, Tian-peng (2009) explains that based on an enterprise's strategy with a set of operational theories and tools, transforming an enterprise's strategy into operational processes, BPM is a technology based on Enterprise Application Integration and Workflow. Much more than that and from a business perspective, it can adapt to changes and integrate with legacy systems.

Business Processes take data or documents with the data as input. This input is processed and then as output. The origin of such information is as important as the output. Its accuracy and how often it is updated are essential part of BPM. Taylor (2007) observes that “by looking specifically at the information required to complete business processes, one can start to determine whether the information is fit for purpose; is it taken from the most appropriate source; is it accurate as it needs to be; how long does the information remain current; what is the frequency of update; and who or what triggers the update? This may be part of the process but alternatively could be part of a peripheral activity.”

BPM helps streamline organisational processes to become effective, agile and transparent. It can be used to automate the execution of processes by integrating the business model with the process execution, coordinating the workflow and providing information in a clearly defined form to help people in their activities. This is also important in minimising information overload. Processes automated with BPM should be visible and transparent which is crucial in situations where visibility is required and audit purposes especially for regulatory matters. They can also provide real-time monitoring of processes which can be vital to enhance performance and productivity and

contributes to effectiveness by better coordination of people involved in the process and the information they handle in the process and as well as the workflow it follows. BPM is able to provide organisations the agility required to change automated processes without compromising productivity and also enables organisations to conduct analysis on the processes to understand where 'bottlenecks' are before even implementing and also during re-engineering. The use of BPM has consequently resulted in approaches like the 'agile organisation' or 'agile businesses' and the 'real-time enterprise' according to Kirchmer (2009). BPM systems help to manage processes between people, systems and between people and systems. Kirchmer (2009) recognises that "change is a dominant factor in today's business environment. This is a key driver for applying BPM-oriented management approaches in modern enterprises." "BPM systems include integrated features such as enhanced (and portable) process modelling, simulation, code generation, process execution, process monitoring, customizable industry specific templates and UI components, and out-of-box integration capabilities along with support for web-services-base integration" (Tanrikorur, 2007). Business process management is not just about process modelling and execution but it is about the lifecycle (as shown in Figure 4.1) management of processes including analysis and optimisation for better and improved business performance.

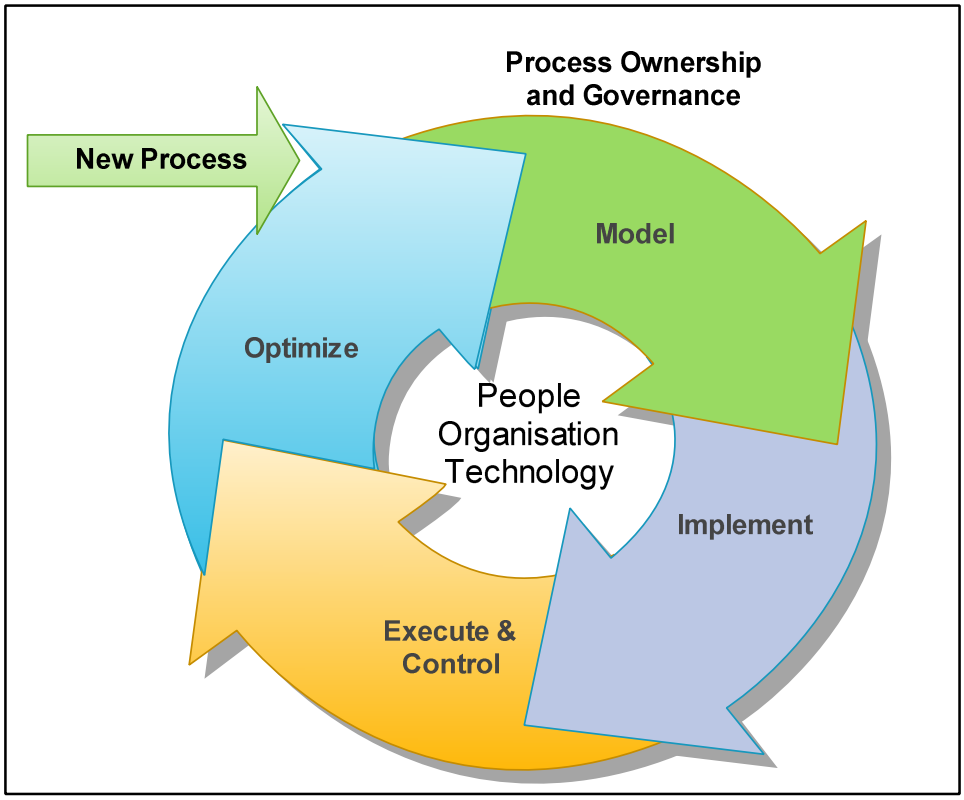


Figure 4.1: Business Process Lifecycle
Source: (Juric and Pant, 2008)

BPM technology is concerned with workflow management, process performance, business rules that governs workflows, process modelling and monitoring. Erl (2008) deliberates that "BPM places a significant emphasis on business processes within the enterprise both in terms of streamlining process logic to improve efficiency and also to establish processes that are adaptable and extensible so that they can be augmented in response to business change." In their research on the fruits of business process management: an experience report from a Swiss Bank, Kung and Hagen (2007) focus on a more IT-oriented view of BPM and identify and discuss the following five main IT-related components.

- "Process modeling: business processes are modeled according to a standard notation; e.g. event-driven process chains (EPC) or activity diagrams of UML. The process models are used either by the human actor who carries out the process manually or by a process engine (e.g. a workflow system).

- Process/workflow engine: these IT systems are used as components of process-based applications. They guarantee that processes are performed according to their specification.
- Real-time monitoring: this function addresses the fact that the state of running processes (instances) should be easily identifiable.
- Process performance measurement: to determine the performance of business processes via a given set of performance indicators. This is crucial for optimization requirements.
- Business rule management: it aims at extracting business rules from traditional software applications and to store and manage them via a separate component, called business rules engine."

Through automation of manual and paper-based processes, a BPM system can help an organization to streamline business processes, thus reducing waste and virtually eliminating the need for physical paperwork; closing the bridge among people, systems, and information throughout a department or agency (Wyron, 2010).

There are several BPM commercial software applications that can model business processes using process maps and can develop business rules and workflows. They also have simulation facilities to enable process analysis for improvement and optimisation purposes. They provide visibility to process and traceability for audit purposes. Integration with other enterprise systems such as ERP and organisational transactional databases is possible and can be implemented in collaborative or groupware systems to facilitate distributed working. Leading brands amongst these are: Metastorm BPM, TIBCO, Oracle BPM, Quask, and Ultimus to name a few. However, due to cost implications, commercial BPMS were not considered for use on this research. Their capabilities vary but in general, they perform similar functions (i.e., process modelling, simulation and automation, etc). Only select open source BPMS were considered and presented in Section 4.1.6 to enable selection of one of them for use in this research.

Industrial change focuses on intra-enterprise system integration to inter-enterprise business process integration. Benefits rely heavily on the integration of disparate systems as opposed to traditional point-to-point interfaces (Boddy et al., 2007).

4.1.5 Business Process Agility and Flexibility

Process models define the set of organisational activities and tasks, the people who execute them and the resources used for their execution including information. These activities often change responding to modifications to organisational strategies and business needs. Therefore, process models need to be dynamic and flexible in order to be able to vigorously respond to those business changes to avoid delay which could affect performance. In their work on process support environment for design management, Platt and Blockley (1995) state that “process model handles the sequencing of activities, and is continually changing as people define and redefine activities in response to changes.” They continue to highlight that the existence and evolution of process models depend on interactions with people whose responsibilities they model and that they must be dynamic.

Traditionally, workflow management systems (WfMS) automate the flow of the activities (Khalaf et al., 2006). However, according to Georgakopoulos et al. (1995), WfMS can only have limited interoperability (in terms of the types of heterogeneous, autonomous, and/or distributed (HAD) systems they can integrate and tasks they support), may not ensure correctness or reliability of applications in the presence of concurrency and failures. They suffer from performance and scalability problems and cannot support enterprise-wide workflow applications effectively. WfMS are more static and inflexible in terms of how they perform automation. They have a complex rule base, offer no simulation of processes and lacks integration functionalities with external systems. In recent times, business processes are required to be flexible and dynamic in order to response to changing business needs, the capabilities of which traditional workflow systems lack.

4.1.6 Automation and Implementation of Business Processes

Effective management of organisations business processes has become more important in a bid to respond to the intensity of globalisation (Ko et al., 2009). Simchi-Levi et al. (2000) identify driving factors for this such as the need for faster information transfer, cost savings, quicker decision making, agility and adaptability to changing demands and shorter cycle times amongst others. Consequently, in the quest to counter these challenges, IT was exploited to help manage business processes by transforming organisational manual processes performed by employees into automated processes (Georgakopoulos et al., 1995; Davenport, 1993; Harmon, 2003) bringing about what is known as BPM (Ko et al., 2009). BPM can automate the execution of process tasks previously handled manually and can combine new and existing services for that purpose; coordinating the workflow by notifying people and presenting them with the information needed for human executable tasks (Garimella et al., 2008). Combe (2006) notes that organisations can save cost and increase efficiency by automating their business processes but those have to be the right ones. This means it is important to identify what business processes require automation that can facilitate organisational improvement.

There are many different business process management systems/suites (BPMS) available that can be employed to design and automate business processes. These systems (BPMS) provide modelling, execution, monitoring and analysis of business processes; have been accepted as standard software systems for improvement of business process efficiency and effectiveness and can also facilitate interoperability of heterogeneous systems (Rhee et al., 2010; Smith and Fingar, 2003). The majority of these have a graphical user interface (GUI) and can generate most of the implementation codes depending on the process maps designed, meaning less programmer coding. These features make it easier and quicker to develop automated business processes as compared to the traditional approach to developer generated code development. However, additional coding has to be done to

further enhance and customise the automated system thus requiring additional programming skills for such implementation. Most of these BPMSs are offered on a commercial basis with huge annual licence fees. This research however, did not consider using commercial BPMSs but instead those offered on the open source business model were considered as follows:

- Process Maker: Process Maker workflow management software allows public and private organizations to automate document intensive, approval-based processes across departments and systems. It has two editions (Community and Enterprise) with the Community Edition is free, open source and perfect for evaluations and small businesses; whilst the Enterprise Edition offers more functionality and is commercial (Process Maker., 2010).
- Intalio BPMS: designed around the open source Eclipse BPMN Modeler, Apache ODE BPEL engine, and Tempo WS-Human Task service, it can support any processes, small or large. It has two editions (Community and Enterprise) with the Community Edition entirely free of charge and supported by an online community; whilst the Enterprise Edition is licensed through yearly subscriptions on a CPU basis and comes with professional support and maintenance (Intalio Inc., 2010).
- JBOSS jBPM Community: community driven, jBPM is a flexible Business Process Management (BPM) Suite bridging the gap between business analysts and developers. jBPM has a dual focus: it offers process management features in a way preferred by both business users and developers (JBOSS, 2010).
- XFlow: XFlow, a pure J2EE platform is extremely powerful and designed to be easy to use from the development, deployment and management standpoints and use for building collaborative applications as well as integrating processes across an enterprise (XFlow, 2009).
- BonitaSoft: this is an intuitive and powerful BPM solution to build process based applications for optimum cost. This Business Process

Management solution is smart enough to let the user model processes graphically, as naturally as on a whiteboard (BonitaSoft, 2009).

- CuteFlow: according to Haberkern (2009), CuteFlow “is a web-based open source document circulation and workflow system. Users are able to define "documents" which are sent step by step to every station/user in a list. All operations like starting a workflow, tracking, workflow-definition or status observation can be done within a comfortable and easy to use web interface.”

A selection of the features of these open source BPMSs is presented in Table 4.2. However, it must be categorically made clear that the list of features for each of the BPMS is not completely exhaustive. Nonetheless, some of the key features have been listed which were used to determine the selection of the BPMS to be used for this research. Some of these included: support for BPMN modeling, graphical process designer, BPEL engine, SOA and web services support, database connection capability, support for both human and system based processes amongst others.

Table 4.2: Open source BPMSs and their features

BPMS	Features
Process Maker	Process map designer, dynaform builder, business rules and logic, easy logo replacement, request inbox, input/output documents, calendar, support BPMN, runtime engine, user interface.
Intalio BPMS	Support for BPMN, graphical process modeler, document management system, live process updates, BPEL process engine, SOA, multiple deployment options, lifecycle management, case management system, supports both human and system processes, attachments, documentation generation, business rule engine, database connection, Dashboard, etc.
JBoss JBPM	Eclipse process designer, web modeller, runtime engine, supports both human and system processes, etc.
XFlow	Supports SOA and distributed and parallel processes, integration with legacy systems, local and distributed processes, rule base, GUI workflow designer, GUI dashboard, process collaboration within a workflow, etc.
BonitaSoft	BPMN process design studio, database connection, end user interface, inbox task interface, BPM and workflow engine, etc.
CuteFlow	Web-based user interface, file attachments, integration of workflow documents in Email messages, process engine, etc.

As a result of the review and analysis of the capabilities of the selected BPMS, Intalio BPMS was selected for this research.

Automated business processes are performed by participants and Intalio BPM has identified three different types of participants: people, system and process (*as shown in Figure 4.2)* that performed process tasks which could be either

manual or automated. Manual tasks are performed by people and automated tasks are performed by systems or other process instances.

- People participants: these are humans who perform the process tasks within the business process system. No system or process takes part in those processes.
- System participants: these are other system components that perform process tasks in an automated manner. They could be databases, web sites such as e-commerce sites, ERP modules or any other computer system without human intervention. An example of this is when a process consumes a web service and writes data into an external database.
- Process participants: these are processes that are 'called' during the execution of business process tasks. (i.e., a business process task could trigger the execution of another business process in order to get the process performed.

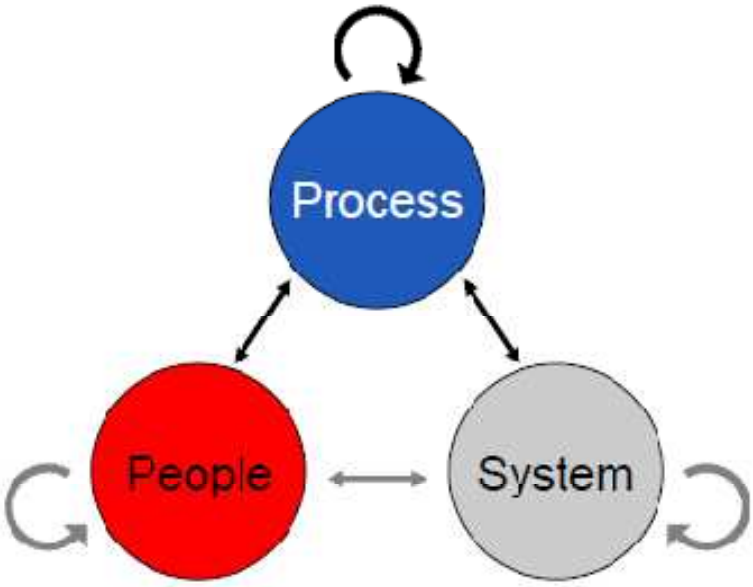


Figure 4.2: Interaction between business process participants – (people, system and process)
Source: (Intalio Inc., 2009)

It is important to note that each of these participants can interact with participants of the same category and also of other categories as demonstrated on Figure 4.2. For example, a people participant can interact with another people participant; and can also interact with a system participant. Similarly, a system participant can interact with another system participant; and can also interact with participants of the other categories. The same interaction trend also applies to a process participant.

Automated business processes can be made up of many participants (including people, system and processes) and activities and tasks. A BPMS can help in the automation and orchestration of all the activities and between the participants involved. Figure 4.3 shows the interaction between various participants and tasks including interaction with application systems.

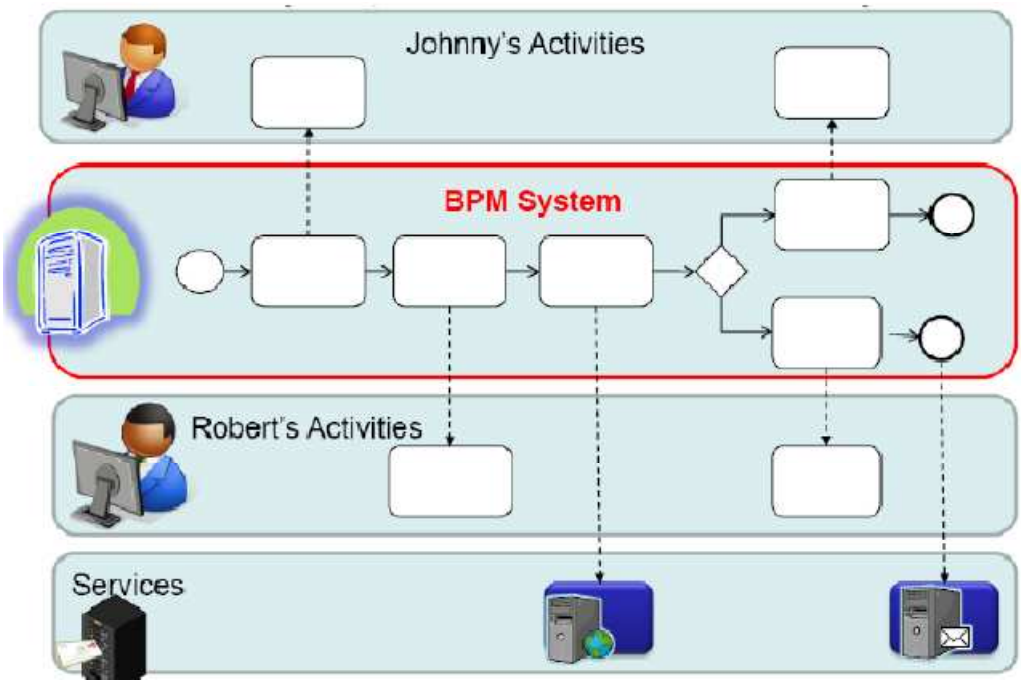


Figure 4.3: Interaction between participants and tasks in a BPMS
Source: (Intalio Inc., 2009)

4.2 Service Oriented Architecture (SOA)

4.2.1 Introduction

Current business and engineering trends driven by globalisation, advancement in computer networks and requirement for e-business mean that organisational computer systems should be capable to operate beyond their internal IT architecture and to collaborate with other systems in partner organisations. Thus integration of some sort is required to facilitate that process. Such inter-organisational systems (*computer systems that facilitate information flow between collaborating organisations*) might run on different operating systems; different software systems which have distinct data and database structures and different network systems. Historically, integrating distributed and heterogeneous computer systems to enable sharing and exchange of information is difficult to implement. This is because of the different IT platforms the systems used including the software and operating systems. Sherif (2010) highlights that advances in computer networks and information processing, globalisation, the quest for organisational agility in order to cope with competition and rapid development, are amongst the factors that have stimulated and facilitated systems integration projects. Similarly, Cummins (2002) indicates that as a result of the many different technologies and architectures, enterprises are fragmented resulting to barriers to capture, communicate and integrate the necessary management information for improved operations and business performance. To facilitate integration and interoperability between such systems, ‘middleware’ such as the Common Object Request Broker Architecture (CORBA) need to be implemented. SOA has emerged as a preferred model for integration because it reduces the burden and difficulty of IT on the overall organisation, and represents an architectural model that aims to enhance the agility and cost-effectiveness of an enterprise (Erl, 2009).

4.2.2 Integration and Interoperability

These two terms (*integration* and *interoperability*) will be discussed from the perspective of computer systems as applied in facilitating communication through sharing and exchange of information between organisations, analysis will be made from the view point of their relation to information flow within organisational functional units/departments and across enterprises.

The principal philosophy of systems interoperability is the sharing of data. Software systems can easily share and exchange information if they are interoperable and such systems would need to be integrated to enable interoperability (Erl, 2008). From a construction industry point of view, Gallaher et al. (2004) define interoperability "as the ability to manage and communicate electronic product and project data between collaborating firms' and within individual companies' design, construction, maintenance, and business process systems." They further emphasise that the highly fragmented nature of the capital facilities industry is the root cause of interoperability problems which is further compounded by lack of adaption of advanced information technologies by the large number of small companies involved in the construction and facility management.

A number of researches have demonstrated the complexity of heterogeneous systems to integrate and interoperate. In his study of the National Airspace System (NAS), Glickman (2007) identifies that a custom application-to-application interface is built when information is required from one application to another. He emphasised that this requires *tight coupling* which is expensive to develop and maintain thus increasing complexity of the system. *Tight coupling* is a system design paradigm where single-platform solutions or applications are created through integrated dependencies among software components which hinder flexibility of IT architecture (Interfacing Technologies Corporation, 2010; Erl, 2004). Through this approach, changes in a software component would require modification of the entire system resulting in closed and difficult systems to maintain. Stanoevska-Slabeva and

Wozniak (2010c) recognise the *inflexibility of hardwired processes and applications* that still exist of most corporate IT infrastructure that cannot be changed swiftly and easily despite efforts to increase their flexibility.

Loose coupling is a system design approach where autonomous software components are developed as services, and combined to interact and provide flexible composite business processes and applications (Erl, 2004; Connolly and Begg, 2010).

Sherif (2010) deliberates that Enterprise Application Integration (EAI) was one of the first architectural concepts applied in order to integrate various tools, platforms and applications across various departments and organisational boundaries to enable information flow. EAI (*often referred to as a middleware*) enables interconnection of numerous enterprise applications and can facilitate exchange of data (Cummins, 2002; Combe, 2006). SOA however, has emerged as a novel philosophical approach based on service oriented computing to facilitate seamless integration and interoperability between heterogeneous systems. It promises to remedy some of the inherent difficulties with traditional integration technologies. Service Orientated Architecture (SOA) which according to the World Wide Web Consortium-W3C (2004b), is “a set of components which can be invoked, and whose interface descriptions can be published and discovered;” coupled with web services technology (which can support interactions between systems using Extensible Mark-up Language (XML) based messages via the Internet) can facilitate information sharing and interoperability of heterogeneous systems. Sabri et al. (2007) identify SOA “as a *design principle* that presents an *architectural framework* for developing software-based business solutions.” They further argue that it stresses interoperability and location transparency and is made up of components and interconnections. The ‘*services*’ in a SOA solution consists of business services that are interconnected which realise an end-to-end business process (Rittinghouse and Ransome, 2010).

4.2.3 Service Oriented Computing

SOA philosophy has emerged as a promising solution for system-to-system integration problems is based on the principles of service oriented computing. According to (Papazoglou et al., 2007), “Service-Oriented Computing (SOC) promotes the idea of assembling application components into a network of services that can be *loosely coupled* to create *flexible, dynamic business processes and agile applications* that span organizations and computing platforms.” It takes the approach of services where separate system functionalities can be developed as a distinct service which can be invoked and consumed independently by other external systems over the web (Sabri et al., 2007). This enables *loose coupling* where heterogeneous systems can function and operate independently but can also share and exchange information using these services. Erl (2008) states that SOC represents a new generation of distributed computing platform which builds upon past distributed computing platforms and adds new design layers and a set of preferred implementation technologies. Web Services technology can be used as mechanisms to achieve SOA implementation (Sabri et al., 2007). In the other way round, Service-orientation can be applied to the design of Web services (Erl, 2009). This means that the two complement each other.

There are various elements to service oriented-computing. These are *Service-Oriented Architecture (SOA), Service-Orientation, Service-Oriented Solution Logic, Services, Service Composition and Service Inventory* according to Erl (2009).

- *SOA* establishes an architectural model by positioning services as the primary means through which solution logic is represented and aims to enhance the efficiency, agility, and productivity of an enterprise.
- The design paradigm which comprised of a specific set of design principles is the *service-orientation*.
- The applications of the design principles to the design of solution logic results in service-*oriented solution* logic. The most elementary unit of service-oriented solution logic is represented by a service.

- *Services* are independent software programs or components of an application with distinct functionality and a set of capabilities which can be invoke and consumed by an external consumer.
- A coordinated collection of services composed to automate a particular task or business process is a *service composition*.
- A *service inventory* is a governed collection of complementary services and independently standardised within a boundary or segment of an enterprise.

These elements form the basis of SOC platform, which are collectively applied to achieve its goals with each element representing a specific aspect (Erl, 2009).

4.3 Web Services (WS)

According to Connolly and Begg (2010), a web service (WS) is a software system that is designed to support interoperability and interaction between computers over a network. They are developed as software components based on the open internet-based standards; that use the HTTP (internet protocol) to communicate by sending and receiving data in XML format (Erl, 2004; Papazoglou et al., 2007). They do not depend on the state of other services they interact with. WS are network-centric and loosely coupled application components designed and developed to support the execution of business processes (McNurlin et al., 2008). WS (*which can be sequenced into complicated business processes*) act as data transfer agents and can be described as the access of software services via the web (Sabri et al., 2007). WS therefore enable the access and utilising of software services with the use of the internet. According to W3C (2004a), a web service is a software designed to facilitate interoperable machine-to-machine interaction over a computer network. Such software services are developed with a Service Oriented Architecture (SOA) philosophy which argues that software can be developed as a service which can be reused by different applications independent of any Information Technology (IT) architecture. “All Web Services standards are Extensible Mark-up Language (XML)-based, which

are machine readable and enables service communication" (Stanoevska-Slabeva and Wozniak, 2010b). Business Process Execution Language for Web Services (BPEL4WS) is the language used for specifying business processes and their communication protocols. Rezgui et al. (2009b) explain web services approach by stating that they are self-contained, web-enabled applications capable of providing a more flexible middleware solution that suits interacting applications and can leverage both inter and intra enterprise information systems.

Services can be used internally within an organisation's business processes and utilised between various functional areas. They can also be used externally by other business processes where their service can facilitate the execution of those processes thus facilitating business-to-business operations. This is done through a service *requester/consumer* and service *provider* mechanism (Erl, 2008; Erl, 2004; Connolly and Begg, 2010; Sabri et al., 2007). This is illustrated in Figure 4.4.

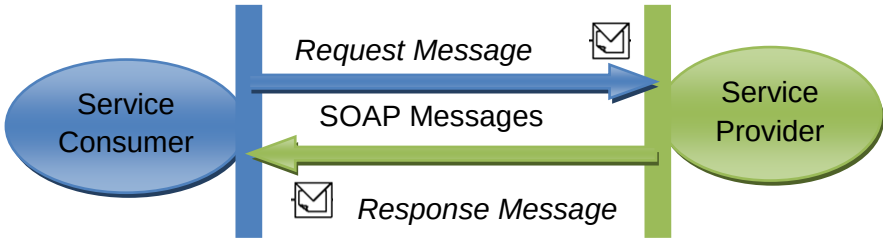


Figure 4.4: Illustration of service consumer and provider

In order for web services to work, they need to be designed, developed and made available to those who require their services. According to Owen and Raj (2003), this can be done in a four stage process.

i. Design the processes using BPMN.
ii. Simulate the processes and modify them for efficiency.
iii. Using a Business Process Execution language to publish the services making them available.
iv. Orchestrate the web services into end-to-end business flows. BPMS can be utilised at this stage by bring them together, and coordinating and controlling their behaviour.

Service consumers/requesters consuming ‘services’ would have permanent runtime dependency on those web services they require to operate (McNurlin et al., 2008). This means adequate care should be taken to ensure the services are up and running all the time, if not they can impact on the functionality available to their consumers. The functionality of web services are generally enabled by software and communication standards such as: WSDL, UDDI and SOAP. These will be briefly discussed below in order to shed light on what they are and how they can be applied in the context of SOA and web services.

4.3.1 WSDL

WSDL is a W3C specification providing the foremost language for the description of web services definition (Erl, 2004). WSDL describes a web service, listing its methods, the data types used for all parameters and return values and the supported methods of communication (Ferrara and MacDonald, 2002). In other words, Web services are described and presented in a Web Services Description Language (WSDL) document which is based on an Extensible Mark-up Language (XML) document style (Erl, 2008). Essentially in a SOA, the abstract description of a web service is the description of the messages that are exchanged between requester and provider (W3C, 2004a). XML is a data exchange standard that facilitates share/exchange or transmission of information between heterogeneous systems over the internet (Lee et al., 2003; Brandl, 2000). XML documents can be transformed into a new XML document using the XML Style Sheet Language (XSTL) and the XML Path (XPath) is the language used as a mechanism for accessing the elements and attributes within an XML document (Cummins, 2002). Cummins further state that this transformation is important to define documents in a format to support different display devices and to meet the input requirements of another application. Sabri et al. (2007) recognise that XML has become the standard for information exchange as it rapidly emerged as a means of exchanging information between applications, especially heterogeneous applications. WSDL documents/files once generated are published and

registered in a service broker or UDDI to enable their search, discovery/locate and use by those requesting them (Erl, 2008; Connolly and Begg, 2010). The communication of the messages or information described in the WSDL is enabled by SOAP.

4.3.2 Simple Object Access Protocol (SOAP)

SOAP is a technology originally conceived to bridge the gap between disparate and distributed systems and has evolved into the most widely used and supported messaging format and protocol for use with web services (Erl, 2004). SOAP uses XML to specify its messaging format and uses Hypertext Transmission Protocol (HTTP) for message transmission between a service requester and provider (Sabri et al., 2007). Anumba and Ruikar (2008) highlight that “advantage of using web services in a construction context is to efficiently communicate the relevant information and knowledge representations fast, regardless of time and geographical location constraints and in a reliable format.” SOAP enables *communication and information sharing* between applications built using different programming languages and running on different infrastructures in general. It serves as an *excellent communication protocol* as it is both platform and language independent (Connolly and Begg, 2010). SOAP provides an appropriate substitute to traditional protocols used for integration and interoperability such as CORBA (Erl, 2004). Thus by encoding WSDL information within SOAP, interoperability can be achieved.

4.3.3 Universal Discovery, Description, and Integration (UDDI)

According to Erl (2004), in order to establish a web service framework, a central directory is required to host service descriptions. UDDI within SOA architecture serves as the directory or registry that stores web services generated and published by the services providers. Connolly and Begg (2010) indicate that UDDI is a platform independent protocol *registry* based on XML for businesses to list their services on the internet and was designed to interact with SOAP messages. UDDI provides the mechanism for web

services to be discovered by consumers and used within their service provision and can be part of an organisation or an internet community (Erl, 2004). In essence, all elements necessary to publish and locate a Web service are contained in the UDDI registry (Sabri et al., 2007). The registry can either be private or public. Private registry could be hosted within an organisation providing access to select authorised parties such as external business partners but may also be restricted for internal used only and often in that case, it is referred to as internal registry; whilst the public registry can be accessed from the public to add and edit service description profiles and the services may be leased or for sale (Erl, 2004). Figure 4.5 and Figure 4.6 illustrate the relationships between the SOA framework.

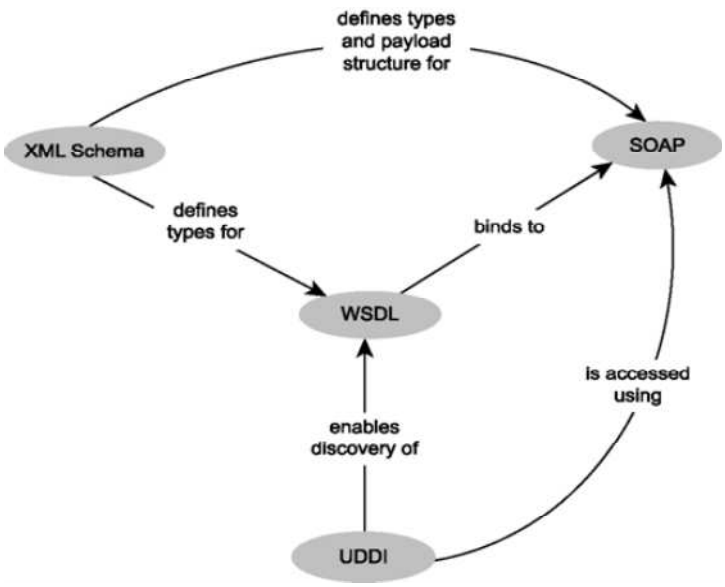


Figure 4.5: The operational relationship between core SOA specifications.
Source: (Erl, 2005)

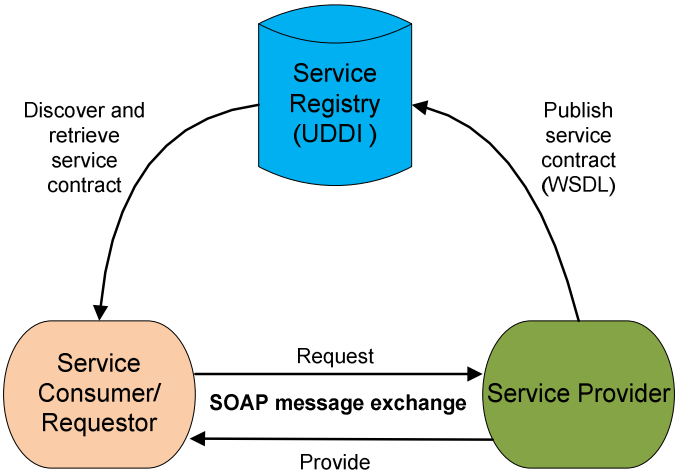


Figure 4.6: Architectural representation of SOA
Adapted from: (Erl, 2008)

The following points explain the SOA architecture.

- The service provider: generates or creates the services and provides them as per contract by publishing and registering them at the service registry (UDDI). This publication is done by registration of the WSDL documents.
- The service consumer: searches, finds or discovers the services required performing business activities from the service registry and them uses them as per the contract.
- The service registry: stores the web service (i.e., the WSDL documents) to enable their discovery and consumption by consumers. In other words, it acts as the web services directory.
- Relationship between the provider and consumer: this is based on making a request (invoking) to use a service from a provider and the messages between the two are communicated based on SOAP protocol. The interface between the two is enabled by XML.

In adopting and implementing a SOA-based enterprise architecture, using web services alone may come along with some limitations such as security and reliability because of the use of HTTP and may not be suitable for mission-critical applications (Juric and Pant, 2008). Enterprise Service Bus (ESB) is an integration architecture can that facilitate SOA and provide a more

reliable communication mechanism and interaction between services and business processes as well as legacy systems (Juric and Pant, 2008).

SOA carry huge potentials and benefits in the way business processes are modeled and automated and how IT systems are developed and integrated. As a result of its component base development approach, software services can be made available independently, which organisations and individuals can access and use through the internet, with the new cloud computing business model.

4.4 Cloud Computing

4.4.1 Brief Review of Traditional IT Service Provision Model

Traditionally, IT, software and data/information were delivered, accessed and managed based on a centralised model. This model where software is purchased and installed on personal computers is sometimes referred to as Software-as-a-Product (SaaP) (Rittinghouse and Ransome, 2010). According to Miller (2009), documents and software can be accessed only on a single desktop computer or through the client-server technology on the same network but cannot be accessed outside of the network. Sometimes, the services are outsourced to an external company that hosts the company's data or applications; yet can only be accessed through the company's network. This approach demands organisations to employ expertise to maintain the IT resources and includes high cost to keep the services running. With the availability of high speed internet coupled with the need for collaboration and mobility of employees, this approach faced limitations to meeting current computing demands. Riley and Delic (2011) state that there is pressure on business enterprises to continually evolve and improve as a result of constantly changing markets; as a result complex IT solutions are implemented.

4.4.2 The Concept of 'Cloud Computing' and its Driving Factors

In today's dynamic business environment, enterprises' IT infrastructures are required to support three major trends: *the agility of the business, globalisation of activities and mobility of employees and resources* (Stanoevska-Slabeva and Wozniak, 2010c). They indicate that IT infrastructure should be flexible enough to respond to the changing nature of the business and the business processes. This means the infrastructure should be quickly and efficiently adjusted to react to new business ideas. The infrastructure should also be capable of providing services and support the remote activities and multiple branches of the business in various geographical locations. The third requirement demands IT to provide support to mobile workers who may not be stationed at a single location and may be using mobile computing devices to access computing services and data. Figure 4.7 illustrates these three requirements.

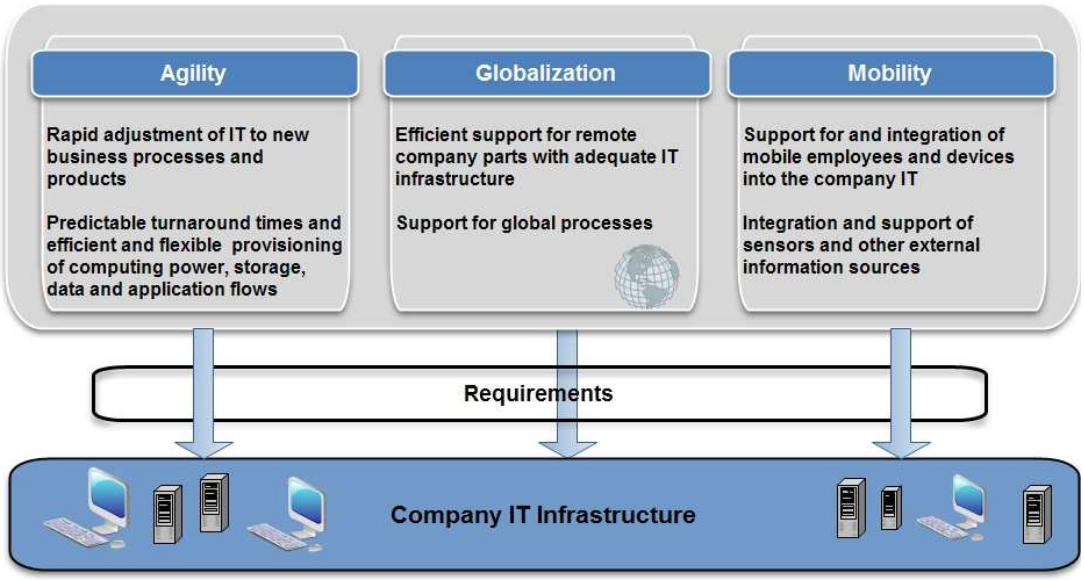


Figure 4.7: Main factors impacting requirements upon company IT infrastructure
(Source: Stanoevska-Slabeva and Wozniak, 2010c)

These IT requirements demands an approach towards distributed and decentralised IT services, as well as flexibility, coupled with current economic austerity resulting in enterprises cutting down on budgets; requires a re-think

on how IT/computing services are provided and consumed. Consequently, a new business model referred to as '*cloud computing*' emerged with the promise to solving these problems. Riley and Delic (2011) amongst others, recognise that business enterprises today use the existing internet infrastructure to provide a wide variety of services and execute various business operations.

Cloud computing is a new computing paradigm in which computing capabilities are provided as services across internet made available. It builds on the foundation of *Grid Computing*, which is "distributed computing that implements a *virtual supercomputer* made up of a cluster of networked computers acting in unison to perform very large task" (Rittinghouse and Ransome, 2010). Dikaiakos et al. (2009) point out that cloud computing as a recent trend in IT, moves computing and data into large data centers; and the applications delivered over the Internet are referred to as services. Taylor and Harrison (2009) reveal that cloud computing allows the provision of computing capabilities as services across the internet via a web interface by businesses instead of locally on computers. They also emphasise support for huge storage capacity and redundancy, and parallel processing. In their definition, Armbrust et al. (2010) declare that "Cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services." According to Namjoshi and Gupte (2009), "Cloud provides a dynamically scalable, abstracted computing and storage infrastructure that is typically based on a virtualized, distributed, fault tolerant, parallel computing architecture."

This means storing and accessing data online; executing software programs hosted on servers through the internet. The cloud computing model can also enable use of other capabilities such as improved memory, processing power, available as platform and infrastructure. The provision of these computing services through the internet makes it possible for users to access their data and make use of other computing facilities wherever they are using various computing devices, and not worry about loss of data and software updates

and upgrades. Security and data back-up is provided by the providing organisations. Services can be paid for on a utility basis (pay-per-use) (Taylor and Harrison, 2009).

4.4.3 Cloud Computing Models

Generally, three types of cloud layered services are offered, namely: *Software-as-a-Service, Infrastructure-as-a-Service and Platform-as-a-Service* (Miller, 2009; Taylor and Harrison, 2009; Stanoevska-Slabeva and Wozniak, 2010a). These are described as follows.

- *Software-as-a-Service (SaaS)*: the heart of cloud is the provision of applications or software as services. In this approach, software can be delivered and accessed through the internet as a subscription service. The services can be accessed by multiple users in various locations simultaneously. According to Rittinghouse and Ransome (2010), SaaS is increasingly becoming the prevalent delivery model as underlying technology that supports web services and SOA mature. Examples of SaaS include Google Docs and Google Apps (Rittinghouse and Ransome, 2010; Miller, 2009; Stanoevska-Slabeva and Wozniak, 2010a).
- *Infrastructure-as-a-Service (IaaS)*: this service offers computing resources and comprises of computing infrastructure such as hardware, networking, software and storage servers, and virtualized operating systems; this service is hugely used for ‘On-Demand computing such as processing or storage purposes (Miller, 2009; Stanoevska-Slabeva and Wozniak, 2010a).
- *Platform-as-a-Service (PaaS)*: this service model provides access to unlimited computing power and development environment for the building of custom applications through the internet (Rittinghouse and Ransome, 2010; Miller, 2009). PaaS is mainly targeted for software developers who can develop their applications without worrying about the hardware of the provider infrastructure (Stanoevska-Slabeva and Wozniak, 2010a).

Armbrust et al. (2010) refer to the data center hardware and software as *cloud* and describes two types of their service delivery model.

- *Public cloud*: This model is when a cloud is made available to the general public in a pay-as-you-go manner; the service being sold is utility computing.
- *Private cloud*: This model is when a cloud is not made available to the general public, and refers to internal data centers of a business or other organization.

From these two classifications and considering that the services themselves are referred to as Software as a Service (SaaS), the "cloud computing is the sum of SaaS and Utility Computing, but does not include Private Clouds" (Armbrust et al., 2010). People can be users or providers of SaaS, or users or providers of utility computing; the same actor can play multiple roles where SaaS providers can also be a SaaS users. This relationship is illustrated in Figure 4.8.

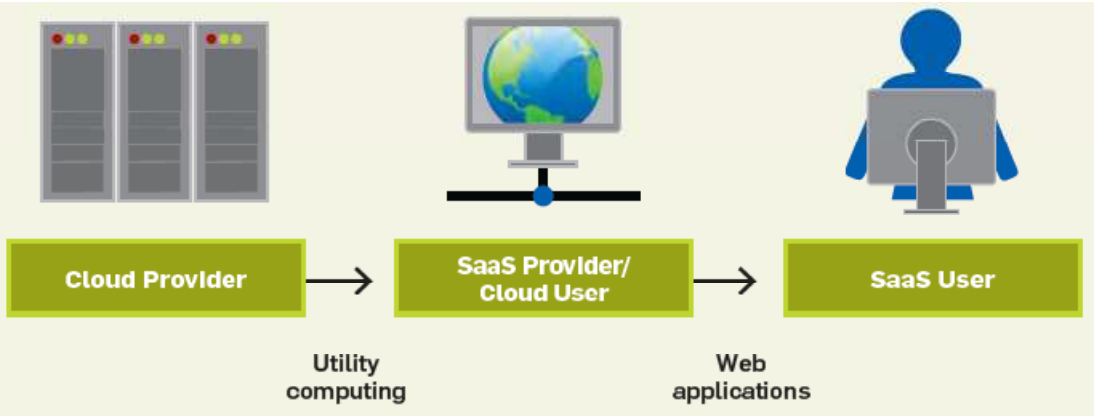


Figure 4.8: Users and providers of cloud computing
Source: (Armbrust et al., 2010)

4.4.4 Adoption and Application of Cloud Computing

Several organisations are adopting cloud computing for the application and provision of their computing services. These ranges from SaaS to IaaS and PaaS and some large organisations are pioneering this trend. Cloud computing is gaining wide popularity with Amazon Web Services and Google

amongst the major providers. Amazon Web Services (AWS) provides several of these services, one of which is Amazon Elastic Compute Cloud (Amazon EC2), designed to make web-scale computing easier for developers, is a web service that provides direct access to Amazon's software and machines and resizable compute capacity in the cloud (Miller, 2009; Taylor and Harrison, 2009; Armbrust et al., 2010; Amazon Web Services, 2011). Google Apps Engine and Google Apps are amongst the cloud services Google offers; the latter offers simple, powerful communication and collaboration tools and by offers online access to most common office and business applications (Rittinghouse and Ransome, 2010; Armbrust et al., 2010; Google, 2011).

SOA is an excellent enabler of cloud computing. According to Goyal and Mikkilineni (2009), SOA concept is the orchestration of highly-decoupled, nuance grained, distributed services to satisfy the organization's requirements and the cloud is well suited to deploy these SOA services. However, Rittinghouse and Ransome (2010) identify the differences between SOA and cloud by indicating that SOA delivers web services from applications to other programs, whereas cloud is geared toward delivering software services to end users.

However, they recognise the following relationships between the two.

- "SOA model is to architect and design services into the cloud so that it can expand and be accessed as needed;"
- "SOA as an enterprise architecture is the intermediate step towards cloud computing;"
- One can use SOA to enable cloud computing or as a transit point to cloud computing;
- SOA can provide the framework for using cloud computing resources (Rittinghouse and Ransome, 2010).

Due to the possibilities of leveraging SOA to enable cloud computing, Goyal and Mikkilineni (2009) introduce a Policy-based event-driven Service-Oriented Architecture (PESA) that enables the manageability of loosely coupled services distributed across multiple public or private clouds or a hybrid cloud.

Namjoshi and Gupte (2009) describe an approach for design of travel reservations solution for use by corporate business travellers based on Service Oriented Architecture, Software-as-a-Service, and Cloud Computing paradigms. They called this solution as Travel Reservation Software as a Service (TRSaaS). Even though cloud computing pledges huge potential benefits to both individuals and enterprises, there are several challenges associated with its service provision. Key amongst these is *security and privacy* of data. Cloud computing is an ideal platform for collaboration between project teams or groups working together because of the ability to share and edit documents in real time from any location between multiple users. This is facilitated with *web-based applications provided as SaaS*. Such applications are called *cloud service* (Miller, 2009).

The utilisation of cloud services matters immensely in industries that work with distributed teams particularly the construction industry. This is relevant to the construction industry because it can enable innovative ways of information access; sharing and can connect various project teams from multiple locations. Because the cloud service will be available on the cloud, companies will no longer worry about some of the current barriers to implementation of such systems such as finance and expertise. This will in fact be a catalyst to facilitating SMEs utilisation of computing capabilities in their operations, who often find it difficult to acquire the required computing services. Another major benefit to the industry for using the cloud model is reduction in expenditure in IT infrastructure and improved availability of services.

Developed on the SOA philosophy and BPM technology, eRIM Framework and its associated prototype system can benefit enormously from the cloud where its services can be offered as a SaaS. It can be accessed and used as a *Requirements Information Management Software as a Service* (eRIMSaaS).

4.5 Industry Application and Benefits of BPM and SOA

BPM and SOA have recently gained widespread recognition and use being applied in different industries: banking, energy, insurance, travel and airline, and e-government are amongst those that are reaping the benefits. BPM and SOA along with web services bring huge potential and significant benefits to organisational business process implementation and execution. McNurlin et al. (2008) have recognise the potential of these technologies in the transformation of the traditional IT architecture into web services based on the openness of the internet; thus enabling faster market response and cost reduction (i.e., paying only for needed IT functionalities or services), flexibility and adaptability to changing IT and business requirements. These are amongst motivating factors to the next generation of enterprise integration and distributed systems, and services thus the emergence of '*cloud computing*'.

Liu et al. (2008) observe that combining SOA and BPM improves the agility of an enterprise because they offer advantages such as loose coupling, genuine platform independence and language independence. Businesses are faced with the difficulty of integrating their disparate applications and business processes. Connolly and Begg (2010) suggest that this can be addressed by providing flexible composite business processes and applications by designing loosely coupled and autonomous services through the SOA approach.

Kung and Hagen (2007) in their report on the use of BPM in a Swiss Bank, emphasise that BPM has been effectively applied in industries such as financial, insurance and public institutions in order to improve the weakness, increase efficiency and streamline their processes.

American Airlines developed SABRE (Semi-Automatic Business Research Environment), an integrated centralised computer services to solve the communication problems and providing seamless access to their service information with travel agents, hotel and other businesses. Recently, Amazon's web services provide integrated access to their products and data online (McNurlin et al., 2008).

Ertan Hydropower Development Company decided to implement BPM in order to provide effective collaboration among multiple projects and organizations and the establishment of a new effective management system (Tian-Peng, 2009).

ULLICO Insurance (US), pursuing to align some of its business processes with the existing IT infrastructure, was able to successfully implement a BPM solution and plans to extend its application to transform other business processes and IT systems (Onibokun, 2009).

Yorkshire Water (UK), with its goal of reducing IT costs, improving efficiency, and increasing visibility of its business processes; improve streamlining the speed and quality of customer communication and ensures adherence to the water regulations, BPM and SOA solutions to drive enhanced customer service and improve operational excellence (Oracle, 2010).

Within the e-government domain, recommendations and some applications of BPM have been made. Many governments all over the world with the belief that the internet and IT applications can help bring about significant performance improvements; widespread programs to implement electronic government by countries such as the United Kingdom and Singapore, have been developed according to Fagan (2006); and a BPM approach can help break down organizational and departmental barriers bringing the diverse participants to work toward in order to focus on their client's needs. This is a clear indication of the potentials of BPM and SOA in helping organisations enhance performance through improved efficiency and effectiveness of their business processes.

4.6 Summary

This chapter has presented a review on BPM and SOA and examined their application in managing business process and systems integration and interoperability. BPM as a management approach is used to facilitate process management including coordination and control of business activities. It has huge recognition and use in industry because of its support for design, implementation, execution, and control of business processes. Because of inefficiency and ineffectiveness of manual execution of business processes, automation plays an important role for business to achieve process excellence. IT and IS can be employed to provide the tools for automation.

BPMN has emerged as a standard process modelling notation which can be used to sufficiently map processes which can be used by developers to developed and implement executable processes with the help of BPMS (which usually have both process designing features and engine for their deployment and execution). BPMS are software systems that can be used to model and automate manual and paper-intensive business processes that are often tedious and slow to complete. They provide improvement, standardisation of work procedures, quicker completion of work and cost savings. Visibility and auditability (which are crucial for meeting regulatory issues of processes are other key benefits of the application of BPM.

The vision of SOA and web services is that application packages can be assembled into services, exposed, published, consumed and run across enterprises, computing platforms and data models by linking them to business processes as needed explained McNurlin et al. (2008). SOA and web services coupled with the potentials of BPM can facilitate process integration between internal functional units as well as external business partners. This combination could utilise the enormous potentials of both BPM and SOA to provide businesses with the capability of excellent service provision with flexibility, agility and efficiency thus creating pathway for competitive advantage. Integration and interoperability of heterogeneous systems is

achievable through loose coupling and web services using SOAP as communication protocol.

Cloud computing, which is a paradigm shift to the way computing services are provided to users has also be reviewed with the intention of understanding its business model and the associated technology. It is categorically revealed that cloud has immense potential to the construction industry particular how applications are delivered across the supply chain. It has also emerged that there is a close relation between cloud computing, SOA and BPM pertaining to how services can be offered and consumed within business processes across the internet. The combined potentials of BPM and SOA have relevant applicability in this research. They can be applied towards the design and development of the prototype system based on *process orientation* for the implementation of the change management system, and *service orientation* for the integration between the repository and change management system.

From the literature, research gaps were identified and difficulties in managing requirements information across the lifecycle of a facility demonstrated. In this chapter, tools and technologies have been identified and their combined capability established that can be utilised to improve client requirements information management across the lifecycle of facilities and collaboratively between project teams. They can also provide integration and enable interoperability between heterogeneous systems. Consequently, the research designed a scientific approach in order to address the research gaps and solve the identified problems. This is discussed in the next chapter and will include discussion on research philosophy, the methodology and different data collection methods used, as well as the analysis and evaluation mechanisms employed.

Chapter 5. **Research Methodology**

5.1 Introduction

The research reported in this thesis was concerned with the study of managing information about client requirements in construction projects lifecycle. It aims to help construction organisations reduce cost and time in product development and service delivery; whilst increasing performance and productivity and realising high quality of built facilities. Particular issues of the study included how client requirements were documented, stored and accessed; exchanged/communicated, and how changes were processed and managed. The literature review on client requirements information management highlighted key research gaps (Section 1.2) which contributed in the formulation of the research aim and objectives (sections 1.4 and 1.5). The research gaps and questions required further investigation by this research. Consequently, in order to conduct the study, a systematic research approach was designed and several activities employed. The design was based on scientific research techniques.

This Chapter divided into two main parts, reports on how the research was designed and conducted. The first part focuses on the review of literature on research design and implementation; particularly it reviews research philosophy (approaches, paradigms, methodologies, and strategies) and data collection methods. This review was necessary to facilitate the selection of the most realistic and appropriate techniques to accomplish this research.

The second part of the chapter (i.e., from Section 5.9) presents the research techniques which were deemed appropriate and adopted to conduct the research in order to achieve its aim and objectives. This includes the chosen research approach, strategy, methodology and data collection methods and how the research was implemented. Discussion was also made on how the findings were analysed and presented and the evaluation mechanism used. The chapter concludes with a summary of the key areas and the next phase of the research. Figure 5.1 illustrates the steps taken in conducting the research.

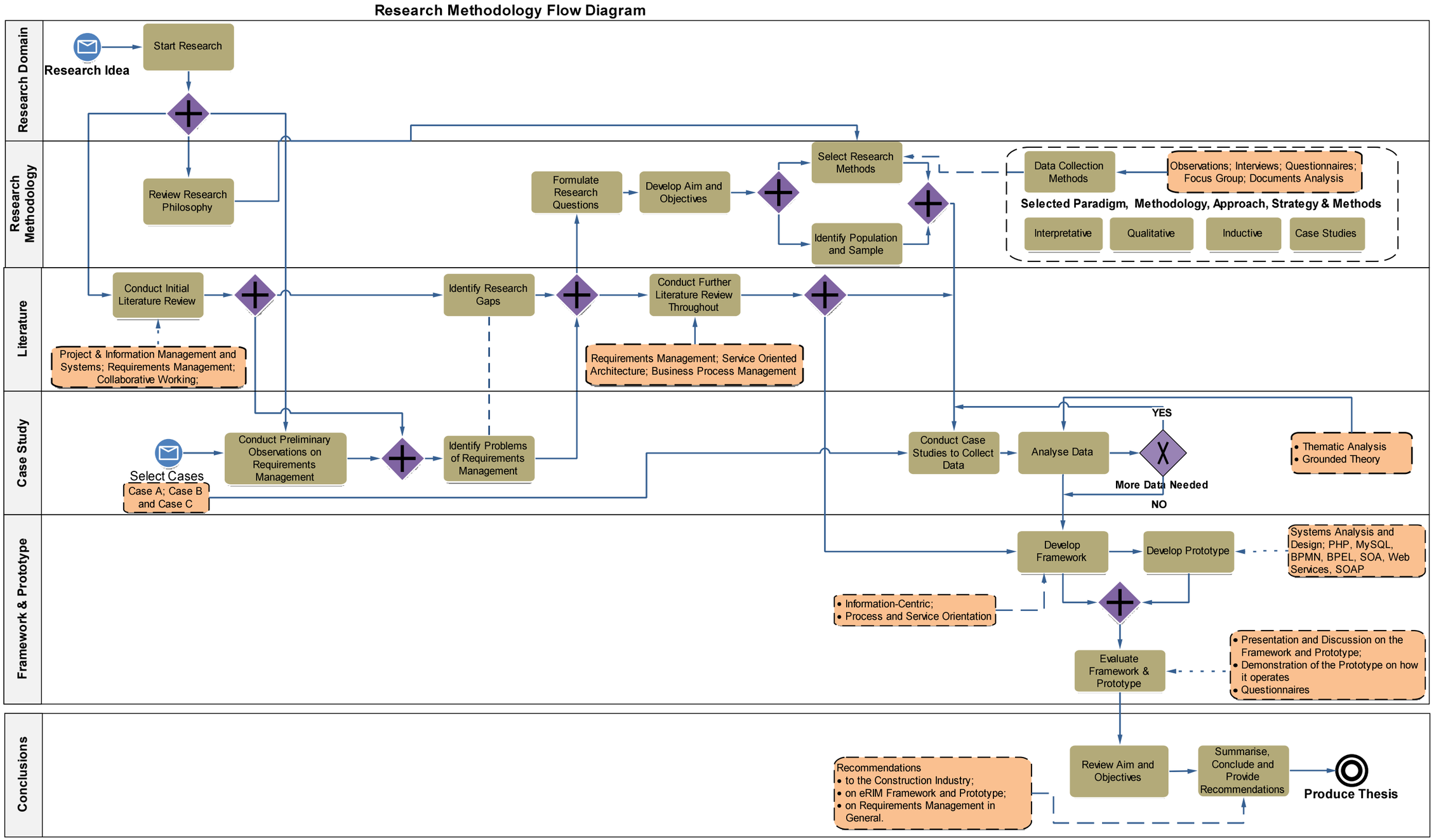


Figure 5.1: The Research Methodology Flow Diagram

5.2 Research Paradigms: Positivism and Interpretivism

Knowledge is often required in the process of defining a solution to a research problem. However, it is highly likely that in some cases, that knowledge or theory would not be readily available to apply to problem solving and would need to be investigated and constructed. Lincoln and Guba (2000) refer to *Positivism* and *Interpretivism* as research paradigms. “Different research paradigms will inevitably result in the generation of different kinds of knowledge” (Dainty, 2008). It is therefore prudent to review philosophically the epistemological perspective and formation of knowledge or paradigms as applied in research context and the mechanisms or modus operandi for acquiring the research data that is required to construct knowledge in order to solve the problem. Knight and Turnbull (2008) deliberate on epistemology as primarily concerned with theories of knowledge, its limit and how to acquire the knowledge. This means to say there needs to be identification on what is and is not knowledge. If there is knowledge, how do we obtain it; if not, how do we create or formulate it.

According to Love et al. (1993), Positivism and Interpretivism approaches to research have different viewpoints and functions when pursuing knowledge. Smyth and Morris (2007) point out that “positivism, in its various forms, pursues generalisations in order to establish principles or laws to govern its object.” Positivism entails elements of both inductive and deductive approach to research or problem solving (Bryman, 2008).

Empiricism is the philosophical believe that observational evidence is indispensable for knowledge. Empiricism acknowledges that conceptualisation and generalisation cannot be made on a problem when inadequate knowledge is known about it (Smyth and Morris, 2007). Thus, facts are investigated taking a number of different approaches superior to which is observation without theory (i.e., inducing generalisation and building theory based on observational evidence).

Interpretivism which emerged as a reaction to positivism, insists that people are not objects that can be studied by means of natural science's methodologies; it is the study of what things mean to people and how people feel and react to that interpretation (Bryman, 2008). Accordingly, Gray (2009) buttresses that "interpretive studies seek to explore peoples' experience and their views or perspectives of these experiences;" and is characteristically inductive in nature and often associated with qualitative approaches to the collection and analysis of data.

It is relevant to point out that all research is open to criticism (Knight and Turnbull, 2008) no matter what research paradigm is employed to generate or utilise theory or knowledge. This is why it is critical, if research evidence and arguments are to be taken seriously, to explore and justify claims to knowledge which will help to ensure that the work is judged against appropriate epistemic criteria as Knight and Turnbull (2008) emphasise.

5.3 Qualitative and Quantitative Research Methodologies

Research as a study mechanism has been applied to many different contexts, from different perspectives as a means of understanding and solving or outlining an approach to solve a problem. Various definitions of research have been adapted with considerations to varying process and approaches. However a common definition is that research is a '*systematic, organised and planned investigatory or inquiry work which can involve enquiry and learning with the aim of contributing to knowledge'* (Fellows and Liu, 2008; Sekeran, 2007; Soanes and Stevenson, 2005). In other words, research is about appreciation and comprehension of a problem defining an appropriate solution. Research methodologies can be discussed under two major headings namely: quantitative and qualitative.

5.3.1 Quantitative Research

According to Fellows and Liu (2008) "quantitative research approaches adopt a 'scientific method' in which initial study of theory and literature yields precise aims and objectives with proposition(s) and hypotheses to be tested." Such

scientific method involves the collection of ‘numerical’ data which will then be analysed statistically to test a theory or hypothesis. It aims at investigating a defined problem; collecting factual data in order to study relationships between facts and how those facts and relationships relate to theory and a set of defined variables (Robson, 2002; Fellows and Liu, 2008; Neuman, 2005).

5.3.2 Qualitative Research

Creswell (2009) discusses that quantitative research is based on objective views of a phenomenon and is inclined towards measuring *how much* of a something and includes using experiments, surveys amongst other methods to conduct findings which can be expressed numerically. Qualitative research is subjective and aims at investigating social beliefs, opinion and understanding of human problems and it often involves people investigating problems within natural settings or environments (Robson, 2002; Fellows and Liu, 2008).

Qualitative research involves using research strategies such as case study, grounded theory and/or ethnography; employs data collection methods such as interviews, observations, questionnaires amongst others to conduct findings which can be expressed in words (Robson, 2002; Gray, 2009). It is a research methodology which by contrast to quantitative research, usually emphasises words rather than numbers in the collection and analysis of data (Bryman, 2008). The main aim of qualitative research is for researchers to see and understand the world as their subjects see it and not to test or construct theories (Runeson and Skitmore, 2008). Qualitative research is often criticised for being weak and subjective, and lacking rigor in data collection and analysis (Howard and Davis, 2002). However it is important to highlight that both qualitative and quantitative research have limitations or disadvantages and as a result, triangulated studies (i.e., using a mixed methods approach) may be employed in order to reduce or eliminate disadvantages of each individual methodology and researcher’s bias (Robson, 2002; Gray, 2009; Fellows and Liu, 2008; Creswell, 2009; Howard and Davis, 2002; Gray et al., 2007).

5.3.3 Purpose of Research

Research studies can be classified into different further categories according to their purpose (i.e., what the study is trying to achieve or why is it being done). Robson (2002) identifies three of these categories as exploratory, descriptive and explanatory. *Exploratory study* finds out what is happening about a phenomenon especially when little or not enough is understood about it; '*Descriptive study*' is to portray or provide an accurate profile of a phenomenon (e.g., a person, event, situation or institution) whilst '*Explanatory study*' seeks to provide an explanation and report of a situation or a problem (Robson, 2002; Gray 2009; Fellows and Liu, 2008). A central feature of exploratory study is the use of hypotheses (Fellow and Liu, 2008). In addition to these three, a fourth purpose was discussed by Maxwell (2005) as '*Interpretive study*' which explores peoples' experiences and the views, perceptions and beliefs of those experiences. Fellows and Liu (2008) state a fifth purpose as '*Instrumental study*' which is to "construct/calibrate a research instrument, whether physical measuring equipment or as test/data collection (e.g., questionnaire or rating scale)."

However, in practice, it is often that multiple methods will be used. The reason for this according to Gray (2009) is that a research usually includes multiple questions; so a method appropriate for one question may be inappropriate for another.

5.4 Research Approaches: Deductive and Inductive

5.4.1 Deductive Approach

In research terms, deduction means making conclusions out of theory (*i.e., things that are previously known*). Gray (2009) identifies deductive and inductive as research approaches. According to Bryman (2008), the deductive research approach defines a problem, uses existing theory to develop hypothesis that will be tested and then to collect and collate relevant data for review. Findings from these data are then analysed to enable the testing of a hypothesis which is either confirmed or rejected depending on the outcome of

the test. Revision is then made on the initial existing theory based on the results of the test. This process has also been similarly described by Robson (2002), Creswell (2009) and Gray (2009).

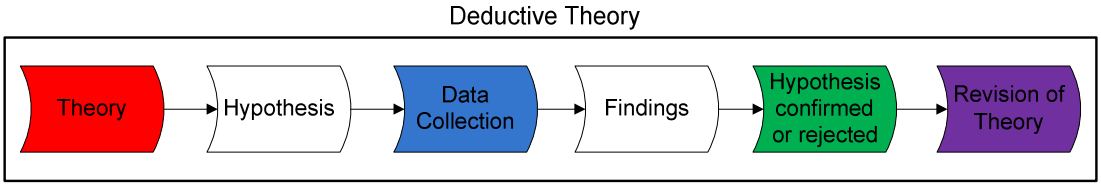


Figure 5.2: The process of deduction
Adapted from: (Bryman, 2008)

5.4.2 Inductive Approach

In contrast, the inductive research approach is an approach where by theory or knowledge emerges from the findings of data collected. As Bryman (2008) states, “usual application of inductive theory, however, is to allow theory to emerge from our findings. We find an interesting question, we gather data on it and we 'theorise' from our findings.” Fellows and Liu (2008) argue that deductive reasoning occurs within the boundaries of existing knowledge whilst inductive reasoning is valuable in extending or overcoming boundaries to current knowledge. However, they note that induction should be employed with due caution. Inductive approach is usually employed where little or no theory exists and hence is helpful in theory building. It is however important to understand that the deductive process will usually entail some elements of induction; and the inductive process is likely to entail some modicum of deduction (Bryman, 2008). Thus it is important to note that the two approaches can be combined and are not mutually exclusive (Gray, 2009).

5.5 Research Strategies

5.5.1 Case Study

A case study is research strategy that entails the detailed and intensive analysis of a single case or of multiple cases *where a case is interpreted very widely to include the study of an individual person, a group, a setting or an organisation* (Robson, 2002; Bryman, 2008; Gibson and Brown, 2009). Focus of such studies is on a case but often it is sometimes extended to include the

study of just two or three cases for comparative purposes. Fellows and Liu (2008) and Yin (2003) indicate that the case study as a research strategy uses set procedures, sometimes comprising a combination of several different data collection techniques such as interviews, observations and documentary evidence with emphasis on examining a phenomenon within a real life environment. The case study approach according to Gray (2009) is useful to uncover a relationship between a phenomenon and the context in which it is occurring and the data collection and analysis process can benefit from prior development of a theoretical position. Simons (2009) indicates that a case study could be *theory-led or theory-generated*. Theory-led means exploring, or even exemplifying, a case through particular theoretical perspective whilst theory-generate refers to generating theory arising from the data itself. Bryman (2008) highlights that case study research favours qualitative methods and frequently both quantitative and qualitative methods are employed. 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). It is crucial that particular attention is paid to the type of cases to be studied which will provide the researcher with the required data of the study. The research methodology, strategies and methods for collection chosen for a research entirely depend on the research questions. But also important is the time and resources available to conduct the research (Proverbs and Gameson, 2008).

Selecting and determining the number of cases (single or multiple) to be studied is generally difficult to decide. There is often criticism and suspicion of validity of a single case project as opposed to multiple cases. This is due to the fact that people are not sure how results generated from a single case can be applicable to other cases. Therefore it is important to select and investigate the case(s) carefully to meet the objectives of the study (Proverbs and Gameson, 2008). Yin (2003) identifies key areas to consider when deciding the number of cases. For example a single case can be used if it represents a

critical case to test the theory or a longitudinal study where the same case will be studied for a longer period of time.

5.5.2 Survey

Quantitative in nature, survey is a research strategy that is generally used to systematically collect data in order to understand patterns, knowledge and to be able to explain attitudes and behaviours of the subject. Example, surveys can be used to collect data on voting patterns of voters. Survey research is conducted or principally collects data by asking people structured and predefined questions using questionnaires; however, often, and sometimes, structured interviews or structured observations are used to conduct surveys (Robson, 2002; Bryman, 2008; Gray, 2009). According to Bryman (2008), researchers conducting surveys need to decide the population that is suitable for investigation depending on the topic of their study and also to decide on the research instruments (i.e., the data collection methods such as structured interviews). “Surveys work best with standardized questions where it is possible to be confident that the questions mean the same thing to different respondents, a condition which is difficult to satisfy when the purpose is exploratory” (Robson, 2002). From the work of Gray (2009), surveys are categorised into two: *analytical* and *descriptive*. According to that work, analytical survey takes many of the features of experimental and deductive research emphasising reliability of data and statistical control of variables. On the other hand, descriptive survey uses inductive approach employing open-ended questions to explore perspectives and may be quite ethnographic in character. Surveys are common in modern life and businesses use it to gauge customers’ attitudes towards their products and services; educational establishments use surveys to understand and review students’ opinion about the courses they provide; and governments, to judge the mood of the populace on their services such as education, health and other government services (Gray, 2009).

5.5.3 Ethnography

Ethnography studies, first associated with or has its root in anthropology (Robson, 2002; Gray, 2009) and involves the study of a social structure or social setup of people or organisational settings (Robson, 2002; Bryman, 2008; Gray, 2009; Fellows and Liu, 2008; Fetterman, 2010). Ethnography can be referred to as the research process it describes but also the outcome of the research (Bryman, 2008). Gray (2009) indicates that ethnography around the 1970s came into use for describing *participant observation* research within the social and organisational settings. The definitions of these two terms (*ethnography* and *participant observation*) are very difficult to distinguish according to Bryman (2008). Ethnography involves the process of direct observation of the social set-up over a very long period and further data could also be collected through interviewing, questionnaires and the collection of documents to complement observations (Bryman, 2008; Gray, 2009; Gibson and Brown, 2009). Although ethnography is a distinctive approach which can be linked with case study or grounded theory, a case study can be approached ethnographically; an ethnographic study can be approached by means of grounded theory (Robson, 2011).

Participant observation very closely coupled with the practice of ethnographic study and is sometimes referred to as the research method to conduct ethnography (Robson, 2002; Bryman, 2008). Researchers who conduct ethnographies are referred to as ethnographers; and “ethnography is what ethnographers actually do in the field,” and it is principally descriptive in nature (Fetterman, 2010). An important aspect of ethnographic research is the task of being accepted as a member of the community or social environment in order to be able to participate in its activities (such as cultural life and practices) (Robson, 2002). Bryman (2008) emphasises that “one of the key and yet most difficult steps in ethnography is gaining access to a social setting that is relevant to the research problem in which you are interested.” The manner in which the ethnographer conducts the observations could be either ‘*covert*’ or ‘*overt*’. However, these two terms will be discussed in detail in the

data collection section – 'observation' (Section 5.7.2). Robson (2002) highlights that ethnographic approach to research is particularly indicated when one is seeking insight into a new or different domain and can provide valuable understanding which can guide later research using different approaches. Robson (2011) indicates that depth rather than breadth of coverage is the norm, with a moderately small number of cases being studied.

5.5.4 Action Research

According to McQueen and Knussen (2002), the main aim of action research is to identify problems in a particular social setting, define solutions, implement those solutions and evaluate their impact to the problem. This would include generating hypotheses after problem identification. Robson (2002) recognises the purpose of action research as primarily to influence or change some aspect of whatever is the focus of the study. This means that involvement, interaction and participation of the researcher are central to the process of action research; which requires cooperation and collaboration between the group and the researcher (Robson, 2002; McQueen and Knussen, 2002). This means that action research is a strategy where the researcher actively participates and takes part in the research.

The anticipated change to be implemented should be geared towards improvement of the situation where the study takes place. Kemmis and McTaggart (2005) emphasise this by stating that action research is aimed to explore the potentials of different perspectives, theories and discourses based on the particular situation, that might help illuminate practical settings for developing insights and ideas about transforming that situation. Action research does not differ in principles in terms of data collection and can use the same types of data collection and analysis methods as available in other social research such as observations and interviews (Robson, 2002). Other authors use participatory research or participatory action research to refer to action research as recognise by Robson (2002) and stipulates eight stage cycle the research goes through.

i. *Define the inquiry*: this stage asks what the issue of concern is, which will help to determine research questions and the participants.
ii. *Describe the situation*: this stage is to find out what is required to be done.
iii. *Collect evaluation data and analyse it*: using any particular research method, this stage is to find out what is happening as understood by the participants.
iv. *Review the data and look for contradictions*: this stage is to comprehend contradictions between the current and the expected situations.
v. *Tackle contradiction by introducing change*: at this stage, the change is implemented which is believed will transform the situation based on critical analysis of the contradictions.
vi. *Monitor the change*: this stage is very useful as the change is monitored to understand its effect on the situation.
vii. *Analyse evaluative data about change*: this is the stage when the researcher tries to make comparisons between what is happening now and what was happening before.
viii. *Review the change and decide what to do next*: results of the analysis are reviewed and the change is gauged if it was worth implementing; and determining what the next step will be.

There are some disadvantages cited of action research and these include the researcher's capability of facilitating the research and being able to inter-relate with the participants. McQueen and Knussen (2002) observe that during the process of change, the researcher may be called upon to provide emotional and practical support. This could be time consuming and draining and the researcher has to be capable to handle such situations.

5.5.5 Grounded Theory

According to Hunter and Kelly (2008) and Bryman (2008) grounded theory is the process of developing theory based upon data and involves a systematic process of gathering and analysing that data. It was first developed by Glaser and Strauss (1967) and seeks out to generate a theory which relates to the particular situation forming the focus of the research (Robson, 2002). It involves the process of going out to the field to collect data and mostly, interviews are the data collection method; however other methods such as observations and document analysis can also be used as added sources (Robson, 2002). Grounded theory is qualitative and inductive in nature; in that theory emerges from the empirical data instead of applying theory to the subject being studied and testing hypothesis (Gray, 2009; Hunter and Kelly, 2008). It is observed that grounded theory is both a strategy for doing research and a particular method of analysing the data emerging from the research (Robson, 2011).

5.5.6 Experiment

In experimental research, variables are identified (dependent and independent) where observation will be made in relation to the dependent variable(s) before a test is carried (pre-test) and after a test is conducted (post-test) in manipulating the independent in order to examined the effects on the dependent variable(s) (Bryman, 2008; Gray, 2009; Fellows and Liu, 2008; Robson, 2011). Experimental research is usually deductive with the tendency of making use of research questions or hypothesis which it will seek to test in order to support or refute (Gray, 2009). The hypothesis will be tested after statistical analysis is made after carrying out the test of the variables. They can be categorised into two main groups: field experiments and laboratory experiments. Lab experiments are conducted in a laboratory or contrived setting whilst field experiments are held in real-life settings such as an organisation (Bryman, 2008). It is a method that aims to produce results that are objective, valid and can be replicated by other researchers or by the initial researcher (Gray, 2009). It is quite uncommon, but has been used in

sociology especially by social policy research in order to evaluate the implementation of new reforms or policies (Bryman, 2008).

5.6 Population and Sampling

In order to be able to carry out research, a group of people and/or elements; units (i.e., *population*) that would be the principal focus of the research investigation need to be identified at the initial stage. Sometimes, this group is so large that it becomes impossible to evaluate the entire group thus part of that group or a selection from the group (i.e., *sample*) will be made which will then be the focus of the study. Population in research context is the entire potential units or elements that are included in a research study from which the sample is to be selected (Bryman, 2008; Gray, 2009). Therefore, a sample in research is the selected segment of the population which will be investigated and the method of selection could be based on either a probability or non-probability approach (Bryman, 2008). Similar definition had also been made by Robson (2002) who states that population refers to all the cases and a selection from the population is a sample. A *sampling frame* which is the list of the population elements or units will be developed from which the sample will be selected (Bryman, 2008; Gray, 2009). The *sample size* defines the number of a sample and its determination would depend on constraints of time, cost and the need for precision (Bryman, 2008). Samples need to be representative of the population in order to produce results that would be of value and approximate as closely as possible to those which would have been obtained if the entire population was studied (Fellows and Liu, 2008). Samples can be generated based on either *probability samples* (where the probability of selecting a respondent is known) or *non-probability samples* (where the selection is unknown) (Robson, 2002; Bryman, 2008).

5.6.1 Probability Sampling

There are four types of probability sampling discussed as follows.

i. *Simple random sampling*: the most basic form of probability sampling, in simple random, each member of the population has an

equal probability of being selected in the sample (Bryman, 2008). This approach is completely random and relies on having the sampling frame from which the selection will be made (i.e. the complete list of the population) (Gray, 2009).

ii. *Systemic sampling*: this sampling approach is believed to have an element of randomness where every x^{th} member of the population is sampled from the sampling frame having determined the sample size (*where x is the interval between the members and is kept constant*) (Fellows and Liu, 2008). For example, once population and sampling frame is defined; selecting a starting point in the sampling frame and picking every x^{th} person or element (Robson, 2002). For example "if a sample of fifty is required from a population of 2,000, then every fortieth person is chosen" (Robson, 2002).

iii. *Stratified random sampling*: in applying this sampling approach, stratification (i.e., the grouping members or elements of the population into homogeneous subgroups) is necessary in advance. According to Gray (2009), it consists of taking a sample from various strata (i.e., the different stratum/ subgroup).

iv. *Cluster sampling*: this sampling approach divides the population into groups called clusters which are selected randomly providing the total sample members of the investigation (Fellows and Liu, 2008).

5.6.2 Non-Probability Sampling

Non-probability sampling can be categorised into four main areas as follows.

i. *Snowball sampling*: In this sampling approach, Robson (2002), Gray (2009) and Fellows and Liu (2008) discuss that a researcher identifies a small number of data sources or participants/subjects and collects data from them. Following this, the researcher makes a request from them for pointers to other potential participants. Those identified will then be approached, who if they agree will form part of the sample and data will also be collected from them; who in turn

can identify other members of the population and so on until the right sample size is gained (Robson, 2002). This approach is used greatly where data is difficult to obtain and in most cases because the participants cannot be easily identified (Robson, 2002; Fellows and Liu, 2008).

ii. *Convenience sampling*: this sampling approach involves the selection of a sample that is easily or simply accessible to the researcher (Bryman, 2008; Fellows and Liu, 2008). In a case study, it involves choosing the nearest and most convenient persons to act as participants or sources during the data collection (Robson, 2002). A key problem with this approach is that the sample may not be representative of the population and needs to be treated with extreme caution (Gray, 2009). Fellows and Liu (2008) point out that where there is no indication of any particular form of sample by the nature of the research question(s) and the population, convenience sampling approach may be used. It can also be fairly acceptable to use convenience sampling when there is a chance to gather data from a *convenience sample* and it represents too good opportunity to miss; the data may not allow definitive findings to be generated as a result of the problem of generalization; but can provide a catalyst for further research (Bryman, 2008).

iii. *Purposive sampling*: this sampling approach depends entirely upon the judgment and or interest of the researcher where a deliberate selection of the subjects is made to provide what is assumed to be a representative sample (Robson, 2002; Gray, 2009). This enables the researcher to build up a sample that will satisfy his needs in a project (Robson, 2002). A major disadvantage of this approach is the unintentional omission of an essential characteristic from the population by the researcher and may be subconsciously biased in picking the sample (Gray, 2009).

iv. *Quota sampling*: in this sampling approach, a researcher selects the subjects or representatives of the population until the planned

sample size is obtained. Usually the population is divided into various groups or strata from which the subjects are selected (Robson, 2002; Gray, 2009). For example in construction, dividing the project stakeholders into categories such as: projects managers, architects, users, facilities managers and so on. A quota will then be decided for each category that will form part of the sample. Convenience sampling is normally used within the category (Robson, 2002). An advantage of quota sampling is that each group is of equal size which is crucial for certain inferential statistical tests whilst certain strata may not precisely echo their proportion in the overall population is a disadvantage (Gray, 2009).

When taking samples from a population, it is crucial that the amount of variation is considered. The variation could be caused as a result of heterogeneity (i.e., where the population or sample is highly varied) or homogeneous (i.e., the amount of variation of the population or sample is very narrow or less) (Robson, 2002; Bryman, 2008). This means that a larger sample will be needed when the heterogeneity is greater (Robson, 2002).

5.7 Data Collection Methods

There are many different types of data collection methods that can be employed based on the particular research methodology (qualitative or quantitative) used. As discussed, this research adopts qualitative research methodology and a case study strategy of inquiry thus only those data collection methods relating to qualitative approach will be discussed. However, it must be made clear that mixed method approach was utilised in the data collection. This is to make sure all aspects of data required for the research is acquired and a single method would not be appropriate for that; consequently different research techniques could be employed for efficiency (Robson, 2002; Creswell, 2009).

5.7.1 Interviews

Probably the most widely used method in qualitative research (Bryman, 2008), interviews are effective technique of collecting data and when conducted properly, a vast amount of data can be collected within a short period of time. It is a great approach to obtaining highly personalised data (i.e., where individual accounts are required on a particular phenomenon) and making *implicit* (tacit) things *explicit* from people by expressing their feelings and understandings about things (Robson, 2002; Gray, 2009; Arksey and Knight, 1999). However in order to achieve this, special interviewing skills are required by an interviewer which in most cases are learnt through experience and practice (Gray, 2009). They are also very useful where respondents may prefer and enjoy talking about their work rather than filling in questionnaires (Gray, 2009).

Interviews can be categorised into three main headings: *structured, semi-structured* and *unstructured*.

i. *Structured interviews*: These types of interviews use standardised and predefined questions that are used to ask all the participants (*i.e., the same predetermined and fixed wording questions are asked to all respondents*) in the same order (Robson, 2002; Bryman, 2008; Gray, 2009; Gibson and Brown, 2009). It is stated that structured interviews are employed in order to collect data for quantitative analysis and interaction between the interviewer and interviewee is kept to a minimal (Gray, 2009).

ii. *Semi-structured interviews*: These types of interviews are non-standardised but could still use predefined questions. The researcher prepares a list of questions to be covered but may not follow them exactly as outlined (i.e., the order of asking the questions is flexible and could change and take any direction) (Robson, 2002; Bryman, 2008; Gray, 2009; Gibson and Brown, 2009). They can be used to develop conversation on the topic but not necessarily in any fussy order (Gibson and Brown, 2009). Semi-

structured interviews bridge the gap between structured and unstructured interviews (Fellows and Liu, 2008).

iii. *Unstructured interviews*: In these types of interviews, no predefined questions are generated, and questions are open-ended and can take any order (i.e., the interview can be completely informal) (Robson, 2002). The interviewer uses sets of points on a general topic of interest as an aid to asking the questions and the respondent is allowed the conversational space to response freely to the topics in their desired manner (Gibson and Brown, 2009). The interview develops further with the interviewer asking follow-up questions on points worth following up (Robson, 2002; Bryman, 2008). Although informal, the process needs to be controlled otherwise it could get out of context thus defeating its purpose.

According to Gray (2009), unstructured interviews can also be broken down into three further sub categories: *Non-directive, focused* and *informal conversational interviews*.

i. *Non-directive interview*: questions are not generally predefined and respondents are allowed to respond to the topics in depth. Though the researcher must have an idea of the research objectives and the issues to be addressed in the interview.

ii. *Focused interview*: this is based on the respondent's subjective responses to a well-known situation he/she was involved and the interviewer had prior knowledge of the situation. This will help the interviewer to re-focus the interview if it tends to drift away from the subject matter.

iii. *Informal conversational interview*: as the interview develops/progresses, spontaneous questions are generated. It is the most open-ended form of interviews and is advantageous because of its flexibility and the path it can take.

Gray (2009) further emphasises that the disadvantages of conversational interviews is that the interviewer may influence the path of the interview; it may take some time before similar questions are asked to the set of people being interviewed, and the collected could be difficult to analyse because different people were asked different questions requiring the interviewer to sift through the data in order to find emerging pattern.

Group interviews can also be conducted especially where a consensus is needed. They encourage interaction so that respondents may change their initial responses following discussion in light of other responses thus generating a cohesive consensus (Fellows and Liu, 2008). The best recognised group interviews are the *Delphi* and *focus group* (Section 5.7.4) methods (Fellows and Liu, 2008). With the Delphi method, a selected group of experts in different locations are interviewed or asked to complete a questionnaire individually. The results collated and circulated to the experts and may be asked to respond in a second round (*number of rounds may depend on reaching a consensus but need not be too much*). Changes could be made to initial responses and this process could be repeated until an indicative consensus is reached (Fellows and Liu, 2008).

5.7.2 Observations

Observational research is used by researchers to discover theory rather than using data to confirm or support existing theory. According to Gray (2009), observations can be performed through two different types of observations: a participant observer or non-participant observer (also referred to as *observer-as-participant* by Robson (2002) and Bryman (2008).

Participant observation lets us see the world as others see it–"in their own terms" and researchers use it to try to understand human action or processes being studied by entering, as far as possible, the worlds of those they are trying to understand (Gray et al., 2007). An observer can take many different approaches during observational researcher either *overt* or *covert*. *Overt* observation (open observation) is an approach where those being observed

are aware of the observation and the presence of the observer whilst *covert* (hidden) is where they are unaware of the observation is taking place (Robson, 2002; Gray, 2009). It is argued that validity of research findings could be compromised when overt observation is used because those observed could change their natural behaviour (Bryman, 2008; Gray, 2009). As a result, some researchers tend to adopt the covert observation approach. However, this could also be regarded as unethical when researcher/observer hides his/her identity from those observed. According to Gray (2009), the meaning of observation is to produce data through observing and listening to those observed (i.e., subjects) within their real life settings in order to study their social meanings and understanding of their own activities. This can be done either being a participant or non-participant observer. A participant observer is a researcher who seeks to become and take part in the activities of the group or institution observed whilst a non-participant observer is one who doesn't take part in the activities.

Ethnography initially favoured by anthropologists is a research method that is based on observations. They argued that in order to understand a group of people, an extended period of observations must be engaged in (Silverman, 2000). In addition to observations, observers can collect further data through interviews and collection of documents for analysis (Bryman, 2008).

5.7.3 Questionnaires

Generally, sometimes data collection in research will involve many respondents located in many different places. To collect data from such respondents could be challenging because it may involve commuting to meet each of the respondents which may not be viable especially where time is scarce. An alternative is to use questionnaires which are generally an efficient way to gather information in research from many respondents where interviews are not also possible (Maciaszek, 2007). However, Maciaszek further asserts that they are not as productive compared with interviews in terms of information to be collected because of lack of clarification regarding the questions or possible responses. Although, questionnaires can be

advantageous in that respondents have enough time to respond to the questions and can remain anonymous, its disadvantages as earlier mentioned is the difficulties respondents can face in clarifying and understanding some of the questions. For that reason, questionnaires should be designed and developed in such a way that questions are easy to interpret and comprehend by respondents. This can also result in quick response and return of completed questionnaires (Maciaszek, 2007). As a result, closed questions (e.g., multiple-choice, rating and ranking) should be preferred to open-ended questionnaires which should be avoided (Whitten et al., 1998). Multi-choice, rating and ranking questions are discussed by Whitten et al. (1998) as follows.

- Multiple-choice questions: allow the respondent to select one or more answers from a set of answers provided for each question and sometimes respondents can be allowed to add comments to their selection.
- Rating questions: statements are provided and respondents are allowed to state their opinion from given opinions. Examples of such opinions about a statement are: ‘strongly agree’, ‘agree neutral’, ‘disagree’, ‘strongly disagree’, or ‘don’t know’.
- Ranking questions: in these types of questions, respondents are asked to rank their answer by means of sequential numbers or percentage values or a similar ordering means such as a likert-scale. Example of such ranking would be a scale of 1 to 5 with 1 being the lowest and 5, the highest.

The potential of technology is also transforming the way questionnaires can are designed and executed. Web-based and Email questionnaires offer a powerful tools to gather data from respondents much easily and faster compared to paper-based though requires additional skills for their design (Gray, 2009).

It must be made clear that it is highly likely that not all questionnaires will be replied and returned. Consequently, analysis of questionnaire data should be carefully treated especially where some respondents did not reply to the

questionnaire; and could have provided different responds and opinions; which could cause possible distortion to the results (Hoffer et al., 2007).

5.7.4 Focus Groups

A '*focus group'* is a set of people brought together as participants for the purpose of being interviewed on a 'specific' issue (*i.e., the focus*) in a research inquiry (Robson, 2002; Bryman, 2008; Gray, 2009). The use of focus groups originated in market research as noted by Krueger and Casey (2000), Robson (2002) and Gray (2009). People were brought together to test their consumer attitudes and decisions with respect to new products. However, the popularity of focus groups has grown and they have been applied in wider areas of study and research. According to Barbour (2007), amongst the most common uses of focus groups is its application in the exploratory phase of a research project and to explore problematic areas of professional practice by a number of researchers. Instead of one-to-one interviews, focus groups can be conducted and it is useful to collect data from several participants and at the same time avoid the problems associated with the traditional interview format (Robson, 2002).

Amongst the advantages of focus groups is the significant reduction of the cost for conducting one-to-one interviews and the high response rate of respondents that can be generated (Gray, 2009).

According to Robson (2002), some of the disadvantages of focus groups include:

- facilitation requires considerable expertise;
- providing confidentiality can be problematic as participants discuss and interact in a group environment;
- generalization of the findings cannot be made as the group cannot be regarded as representative of the wider population;
- conflict may arise between participants and the potential danger that one or two persons may dominate.

Focus groups can be used in conjunction with other data collection methods such as observations and individual interviews; notes taking and audio-recording are generally recommended to facilitate the transcription and analysis of the data (Robson, 2002). The number of groups needed for the research project depends on several factors such as the time and the resources available to conduct them but is unlikely that a single group will suffice; although too many will be a waste of time and could increase the complexity of the analysis (Bryman, 2008). Therefore, since they can be complemented and used in conjunction with other methods, a single group could be enough for research exploration. A typical size of a focus group may range from five or six to ten but could be as low as four according to Bryman (2008), Litosseliti (2003), Krueger and Casey (2000) or even as few as three (Kitzinger and Barbour, 1999).

5.8 Analysis

Research requires interpreting and analysing data. According to Creswell (2007), this involves making sense of the data. There are several approaches to analysing and representing data according to the research approach chosen. These different approaches are tabulated in Table 5.1.

However, other scholars have argued that data analysis should be carried out in conjunction with data collection and not entirely at the end (Hunter and Kelly, 2008). They emphasise that this will help to ensure that the method used is well suited and also to identify areas of research interest early on.

Often in qualitative research as applied in this research, analysis is conducted around the themes represented in the question topics or themes specified in the collected data. This often involves some form of thematised analysis using pre-formulated emergent themes to categorise the collected data (Gibson and Brown, 2009). When grounded theory is used in the analysis, these themes can form the basis of the emerging theory.

The following points discuss the approaches to analysing and representing data according to the research approach chosen as represented in Table 5.1 according to Creswell (2007).

- *Data managing*: this early stage of the analysis process involves the organisation of the collected data often in files, folders (*i.e. either manual or computer base*) and index cards. It also involves converting those into appropriate text units (such as words, sentences or an en entire story).
- *Reading and memoing*: this stage of the analysis process involves reading through the transcripts of the entire data and doing this many times. In order to get absorb the content in detail. Often whilst reading through, write short notes, ideas or concepts that occur (memos) in the margins of the field notes or transcripts. This can also be done whilst taking observational notes or during interviews.
- *Describing, classifying and interpreting*: at this stage of the process, the data is further described and coded or categorized into themes. These themes are then interpreted by making sense of the data. This can be based on own view, insights and intuition of the data.
- *Representing and visualizing*: in these final stages, the data is presented as findings and this could be in text, tabular, or figure forms. For example tables can be used to create a visual image of the information.

Table 5.1: Data Analysis and Representation, by Research Approaches
Source: (Creswell, 2007)

Data Analysis and Representation	Narrative	Phenomenology	Grounded Theory Study	Ethnography	Case Study
Data Managing	• Create and organise files for data	• Create and organise files for data	• Create and organise files for data	• Create and organise files for data	• Create and organise files for data
Reading, memoing	• Read through text, make margin notes, form initial codes	• Read through text, make margin notes, form initial codes	• Read through text, make margin notes, form initial codes	• Read through text, make margin notes, form initial codes	• Read through text, make margin notes, form initial codes
Describing	• Describe the story or objective set of experiences and place it in a chronology	• Describe personal experiences through epoche • Describe the essence of the phenomenon	• Describe open coding categories	• Describe the social setting, actors, events; draw picture of setting	• Describe the case and its context
Classifying	• Identify stories • Locate epiphanies • Identify contextual materials	• Develop significant statements • Group statements into meaning units	• Select one open coding category for central phenomenon in process • Engage in axial coding–causal condition, context, intervening conditions strategies, consequences	• Analyse data for themes and patterned regularities	• Use categorical aggregation to establish themes or patterns

Data Analysis and Representation	Narrative	Phenomenology	Grounded Theory Study	Ethnography	Case Study
Interpreting	• Interpret the larger meaning of the story	• Develop a textural description "What happened" • Develop a structural description, "How" the phenomenon was experienced • Develop the "essence"	• Engage in selective coding and interrelate the categories to develop "story" or propositions • Develop a conditional matrix	• Interpret and make sense of the findings – how the culture "works"	• Use direct interpretation • Develop naturalistic generalizations
Representing, visualizing	• Present narration focusing on processes, theories, and unique general features of the life	• Present narration of the "essence" of the experience; in tables, figures, or discussion	• Present a visual model or theory • Present propositions	• Present narrative presentation augmented by tables, figures, and sketches	• Present in-depth pictures of case (or cases) using narrative, tables, and figures

5.9 The Process of Research Design: Selection and Application of Methodology and Methods

The process of research design involves the planning of how a research project will be conducted. This process involves specifying the purpose of the research (i.e., research topics and questions), the selection of the techniques to be used for data collection (i.e., methods and how to implement them), selecting the research site, population and taking a sample to be studied; how to collect the data and conduct the analysis, and presentation of the findings (Gray, 2009; Gibson and Brown, 2009).

5.9.1 Research Purpose and Selection of Methods

The research reported in this Thesis was designed to achieve a better understanding of managing client requirements information in construction projects lifecycle by identifying the critical factors of good management of client requirements which contribute to successful projects (i.e., *projects that meet budget, cost and quality as specified in the client requirements*). A careful selection of the most appropriate research paradigm, strategy, and methodology; approach, and data collection methods was made following their complete review. Various considerations play an important role into this decision amongst which is the research problem (Creswell, 2009). However, methodological decisions were also dictated by certain circumstances such as availability of data; access to the social set-up to be studied (i.e., construction projects) to conduct case studies; availability and willingness of participants to participate. These circumstances informed the establishment and conduct of the research. Another important consideration was the purpose of the study which was a combination of exploratory, descriptive and explanatory in order to be able to understand the method of requirements management and to define an innovative and better approach. Robson (2011) emphasises that the selection of method(s) is based on the kind of information sought, the source and under what circumstances, although supplementary method(s) can be added during the project. At the initial stage of the research, exploratory study was necessary and applied in order to discover the realities about managing

information about client requirements within an industrial context. It was also essential for the formulation of the questions for later study in the research. This was followed with a descriptive study in order to draw a picture by means of explicit details regarding requirements management. Building on these two studies (i.e., exploratory and descriptive), an explanatory study was crucial to report and examine the findings from the previous two studies on requirements management. Consequently, the research design incorporated those circumstances as 'governing factors' which however do not limit the validity of the methodologies and methods selected and applied in the research. As a result, Qualitative methodology and interpretative paradigm of inquiry were selected because of the nature of the research which requires the study of interaction between people within a construction environment (social setup) in order to understand how they execute client requirements information management. Inductive research approach was chosen because it was deemed most appropriate compared to the deductive approach. This is because no sufficient theory exists on client requirements information management in construction that would require a deductive approach. However, it must be confirmed that despite these methodologies and approaches being the chosen, a mixed method was applied to further drive the research for more validity.

As a result of the nature of the research and its purpose, case study was chosen as the primary research strategy of inquiry. The case studies were principally conducted using observations which were supplemented with other methods. The main factor for selecting case study was to enable an in-depth examination and analysis of the process of managing client requirements as applied in the context of construction projects. The selection of the cases was based on the purpose of the research, the data collection methods, available time to conduct the research, resources and accessibility to the cases' environment (i.e., in this case, accessing construction projects to conduct the study). An important factor considered was that any construction project would be suitable for the purpose of this research; in order to study how information about client requirements is managed. However, the study was to cover for all

the lifecycle phases which meant that any project selected should be able to provide for that coverage (i.e., starting from the preparation phase all through to the decommission phase). This was difficult to attain because of the limited time available in the research. Robson (2011) states that any research proposed to be done must be within the constraint of available time and resources. Consequently, the research design resulted to study different cases each at a different phase to cover all project lifecycle phases. Getting access to projects was very difficult; resulted in the research to use local knowledge and industry networks. Subsequently, a public organisation agreed for its building project to be used as a case, thus becoming the first case study (Case A) project of the research. This case was at transition from design to construction. It coincidentally happened that before the completion of that project, the same organisation initiated a second project and permitted the research to use that project too as a case (Case C). This was vital because it meant the research will then be able to study a case from the preparation phase which was missed in the first case. Similarly, a third project which was on-going was used as the second case (Case B). However, it was not followed until it reached the construction phase. The reason for this was that the research was mainly concentrated on Case C at that time; as its study commenced from the programming phase, and did not want to take risk of being distracted from the study as the project progresses from one phase to another. The research, constrained with time, meant that only these three projects could be used as cases. Time is an important factor when considering practicalities of conducting research. However, despite accessibility being a factor for their selection, other criteria were also considered as follows.

- Permission to attend and observe design and project meetings.
- Permission to access and study requirements sources and documents.
- Understanding that each project will involve varying architects and contractors. This was crucial to examine the influence and effects of external environment in the requirements management process.

Another particularly important and interesting factor for the selection of the second case (Case B) was because of the project's large number of external clients, each with their individual requirements for the facility. The difficulty associated with managing the requirements information of each of the different stakeholders for the same facility, was thought to be able to provide an excellent situation to (i) understand the requirements management process, and (ii) identify the inefficiencies and ineffectiveness of the process. These three cases were studied and are described in detail in Chapter 6.

Grounded theory was not used as a *strategy of inquiry* in this research because the primary focus was not to develop theory. According to Robson (2011), grounded theory seeks to generate a theory which relates to the particular situation forming the focus of the investigation. However, some element of grounded theory was used in the analysis of the data as described in Section 5.9.6.

Other research strategies reviewed in Section 5.5 but were not applied in this research for the following reasons.

- Survey: involves the use of a fixed design as a typical central feature which is theory driven; where the variables to be included in the study and the exact procedures to be followed are specified in advanced (Robson, 2011). Even if surveys are carried out as part of a non-experimental fixed design, they are not appropriate to carrying out exploratory work (ibid., p.242). Based on the nature of the research discussed earlier, survey was not considered suitable for use in this research.
- Experiment: commonly concerned with trying new things and seeing what happens, and involves the control and effective manipulation of variables by the experimenter (Fellows and Liu, 2008; Robson, 2011). This was not the purpose of the research reported in this Thesis, thus experimental strategy was not considered.
- Action research: focuses mainly to influence or change some aspect of the subject or whatever is the focus of the investigation (Robson,

2011). Even though the outcome of this research is expected to develop a better approach to managing information about client requirements, it is not focus on implementing a change during the research, thus it was not utilized.

- Ethnographic study: “seeks to capture, interpret and explain how a group, organization or community live, experience and make sense of their lives and their world” (Robson, 2011). This was not the focus of this research.

Qualitative methods (interviews, observations and collection of documents) have been used as techniques for the data collection of this research. In-depth case studies of construction projects were the strategy of inquiry. These case studies focused on client requirements information management and were conducted through the use of semi-participant observations. Interviews with selected stakeholders and individual organisations were held. A focus group comprising of construction experts and academics was also convened.

5.9.2 Review of Literature

Review of literature or commonly known as literature review is applied in research in order to educate a researcher on the topic by understanding what has been done in that domain in order to identify research gaps. Literature review provides an account of a topic and sources for the literature, which can lead to one or more research questions through illustration of major issues and refining the focus of the research (Gray, 2009). It is a prerequisite for doing substantive and thorough, sophisticated research (Boote and Beile, 2005).

Gray (2009) identifies three main purposes of literature review:

i. “demonstrate the key theories, arguments and controversies in the field;
ii. highlight the ways in which the research area has been investigated to date;

iii. identify inconsistencies and gaps in knowledge that are worthy of further investigation."

The research was able to accomplish this by identifying key words within the sphere of the topic to use in finding relevant literature. The sources of such literature included: books, journal papers, conference papers, white papers, reports, government publications amongst others. Scientific journal databases, library catalogues, conference proceedings and other library and online sources were used to access sources of materials. The keywords were divided into two main divisions: *primary* and *secondary* keywords. The primary keywords were generated within the main topic of the research (requirements management) and the secondary within all other domains relevant to the support of the main topic (i.e. process management, information management, collaborative working, etc.). A large amount of publications was retrieved, some irrelevant to the subject under study. Refinement was done according to the relevance of the information to the topic as a result of cumulating the most appropriate information to drive the research. It is important to note that the literature review did not entirely focused on requirements information management within construction but also other industries where the discipline of requirements information management is well established such as software engineering, manufacturing, aerospace and defence. As noted by Gray (2009), more than one body of literature (including both theoretical literature and empirical studies) may be associated with a subject area.

5.9.2.1 Learning from other Industries

Construction researchers have generally agreed that there are also lessons to be gained from the experience of other industries such as Manufacturing, Aerospace, Healthcare, Software Engineering and Business in applying IT capability within Construction. Over the last decade there has been a growing interest in how the construction and development industry can improve its performance by learning from other industries (Barrett and Sexton, 1999; Bresnen and Marshall, 2001; Fernie et al., 2003a). In the UK this interest has been prompted by Government-commissioned reports into the industry

(Latham, 1994; Egan, 1998; Fairclough, 2002), but also by the growing realisation that the construction process has synergies with processes in other industries. Nevertheless, project managers in the construction industry have traditionally been slow when it comes to learning from their counterparts in other industries (McGeorge and Palmer, 1997). This research utilised the experience and success of requirements management in such industries. This included learning how requirements management is applied in other industries such as manufacturing, software and aerospace. It was also studied how e-business processes and how organisational business processes can be integrated using internet technologies and how those can be applied in requirements management. This can help streamline the requirements management process and construction operations and to integrate those processes with stakeholders.

5.9.3 Population and Sampling

This research in order to be able to collect data firstly identified the population which will form the basis of the investigation. Consequently, because of the nature of the problem, the population was identified to be '*construction project stakeholders*' (i.e., all those involved in a construction project). Subsequently a sampling frame was developed using *snowball* and *purposive sampling* methods and the list comprised the following: *client, users, project managers, architect, M&E, structural engineers, facilities manager, cost consultants/quantity surveyors (QS), and contractors*. This sampling frame was divided into two groups namely: direct and indirect.

The direct group represented those who served as primary sources during the data collection and included the *client, project managers, architect, QS and contractors.* The indirect group represented those who were secondary sources and thus were not directly involved but their contributions were made through the direct group.

5.9.4 The Data Collection Process and Methods

5.9.4.1 Observations

The major and primary mechanism of data collection adopted in this research was based on observations of construction projects. During this period, project meetings, periodical progress meetings and design team meetings were organised to discuss the progress of the project attended by the client (or a representative), contractor, architectural designers, structural engineers, external project consultants and other stakeholders. The three projects used as case studies (further discussed in Chapter 6) all had budgets in excess of Fifteen Million Great Britain Pounds. Two of the buildings were to be occupied solely by the client organisation; the third was to be leased by the client to a number of different business organisations whose requirements were known to the client from the outset of the design. Observations were made during a two year period whilst the projects were under development. Audio recording of the proceedings were taken as well as the many hand written field notes, of which three samples (i.e., one from each case study) are attached in Appendix I, Appendix J and Appendix K. Sensitive personal and business information such as people's names, company names, etc in the field-notes have been redacted for confidentiality. The audio recordings as supplementary to the field-notes ensured that vital information was not lost as taking notes may not be sufficient to capture every detail and distractions during the meetings might have also caused some points to be missed. Certain parts of the field-notes were annotated with the corresponding length of the audio recording. This was beneficial during the analysis of the field-notes as exact reference were made to the tape which corresponded to the part being analysed. In order for accurate data to be collected, follow-up interviews with selected individuals lasting about half an hour were conducted by the researcher asking questions where particular point(s) were not clear. In order to avoid bias in the data collected, triangulation was done to validate the data collected from the case studies. The triangulation was done through follow-up face-to-face interviews as explained earlier with selected individuals,

which were conducted immediately after observation of each project meeting. These helped to clarify information which was not clear or misunderstood during the observations. The data collected was transcribed soon after the meetings while issues discussed were still fresh in the researcher's mind.

During the observations, the researcher was able to interact with the participants of the project meetings but at a scale that did not interfere with the progress of the meetings and without being too immersed in the context. "Being able to interact with research subjects enables the researcher to build rapport and make the subjects feel more comfortable being 'watched'" (Pickard, 2007). Observers can influence the situation being observed as subjects sometimes do not feel comfortable to participate as they would when not being observed. The observations helped to provide an understanding as to how requirements are gathered, stored, distributed and communicated between stakeholders, and how they are interpreted into later stages of project lifecycle phases. They also demonstrated how changes to client requirements are requested and handled through the authorisation mechanism and how the information generated from it is managed.

5.9.4.2 Interviews

Individual interviews were also conducted as supplementary data collection to discuss different issues on requirements elicitation, documentation, communication, and change management. Lifecycle management of the requirements was the focus of the interviews. Interviewees were selected based on individual's expertise and role within the case study projects. In total seven separate individual interviews were conducted comprising stakeholders from the case study projects: three client project managers; a construction manager; a project manager from the external consultant company; an architect and a facilities manager. Three of the interviews (conducted with two project managers and a construction manager) were pre-planned semi-structured interviews with the help of a questionnaire (Appendix A) to guide the interview. These lasted not more than an hour. The remaining four interviews were conducted as follow-up to the observations and were

randomly carried out depending on emergent issues observed during the meetings. Therefore, there were no pre-planned and no predetermined topics to be discussed. Those interviews were rather used as an engagement in establishing discourse with those selected to tell their own anecdote of the issues that came up. This was appropriate to gaining deeper understanding of the issues. The topics emerged from the observations and the outcome of those interviews supplemented the observational data. All interviews were audio recorded and transcribed which resulted in large amount of qualitative data (sample of which is shown in Appendix F) to facilitate the analysis of the data. Table 5.2 shows the roles and number of interviewees.

Table 5.2: Interviewees during the case studies observation

Role of Interviewees	No.	Company Represented
Project Manager	3	Client organisation
Architect	1	Architectural design company
Construction Manager	1	Two different contractor company
Facilities Manager	1	Client organisation
Project Manager (Consultant)	1	Consultant Company (Project Management)

5.9.4.3 Focus Group

Following the initial observations and interviews, additional information was needed which required further inquiry. As a result, there was the need to convene experts and industry practitioners to gather that information. Consequently, a focus group was decided to be the most appropriate. The sample of the focus group was selected through *snowball sampling* method. This was done with the assistance of the consultant project manager who directed the researcher to individuals who would have the required expertise and experience to provide the information needed. Consequently, the focus group included a project manager, two quantity surveyors and a senior academic. These experts were from a multi-national engineering consultancy

firm which specialises in project management. The participants were selected based on their experience and opinions on the management of client requirements in construction projects.

The conduct of the focus group was important to help the research explore the requirements management topic and to understand the associated industrial relevance; as well as to supplement the case studies. The focus group was held at the Regional Office of the industrial experts where they were joined by an academic and the researcher. This was a conducive environment for the experts and as they did not have to travel away from work. It was also a familiar location which contributed to their effectiveness during the discussions.

The researcher served as the facilitator during the conduct of the focus group. At the start, the facilitator thanked the participants for attending and introduced the purpose and rationale of the discussion. The participants also introduced themselves, describing their expertise, experience and roles within their organisation. Hardcopies of Powerpoint slides were distributed to the participants containing predetermined research points on the various topics to be discussed. These were used by the facilitator as a guide to the discussion. The facilitator then introduced the various topics (moving from one topic to another) and gave the participants the conversational space to response freely on the topics one after the other. Handwritten field-notes were taken by the facilitator and audio recording of the proceeding taken.

The focus group discussion lasted for an hour and twenty minutes. At the end, the facilitator summarised the topics discussed and the major points that were contributed by the participants. At this stage, participants were allowed to react to some of the points by further clarifications and comments. Finally, the participants were thanked for their attendance and contributions. They were reminded how the information generated will be used in the research. At this stage, it was also agreed that the notes be compiled and circulated to all the participants. This compilation was done and circulated, and is shown in Appendix G.

Initial analysis indicated an appreciation of the problem together with the realisation that further observation was needed to understand the problem and propose a solution. This is discussed in detailed in Section 6.2.1. Therefore, the subsequent phase of the research was to conduct further observations of construction projects in order to understand some of the issues raised from the focus group meeting, and to explore the requirements management process in more detail.

5.9.4.4 Questionnaire

A brief questionnaire on changes and their management (Appendix B) was designed and sent out to the three client project managers of the three case studies via Email as attachment. The three project managers were selected as the most suitable respondents because of their key roles in the management and administration of change orders. The key focus of the questionnaire was to collect further data on the change process and changes in the case study projects which could not be identified through the observations. Due to their busy schedules, the three project managers were not available to attend scheduled interviews to shed light on those issues. Consequently, a suitable alternative was to use a questionnaire.

Six questions were developed in the questionnaire and they focused on changes and the change process in the case study projects in order to clarify the following points.

- The total number of change orders that were requested during the course of the projects. This was relevant to determine the volume of change orders that were generated in those projects in order to establish the need for their effective management.
- The period it takes for a change order to go through the authorisation process. Information on this area can support the quest for effective and efficient management of the change management process in order to contribute to, and improve the swiftness and agility of the process.

- If delays were caused in the process and if so, what effect did they have on the timeliness and cost of the projects.
- The medium of communication used in the change request process which can be useful in correlating their effect on the entire effectiveness of the process.
- If an established mechanism existed in analysing the impact of changes which is important to support the call for a better approach to impact analysis.
- Understanding if rationale of changes were included in the change request information.

The questionnaire was distributed to all the three project managers as Email attachment which was a Word document. This allowed the respondents to easily complete the questionnaires electronically and returned as Email attachment too. A 100% respond rate was achieved and all three responses are shown in Appendix H.

5.9.4.5 Document Analysis

Document analysis of repositories including both soft and hard copies was conducted to shed light on current practice of how client requirements are documented and stored, communicated, distributed and changes requested. Brief documents and request for change forms/change orders (Appendix C) were analysed to understand the type of requirements information documented and requested as well as the change procedure and roles involved. Nonetheless, other project related documents such as monthly progress reports, changes to project schedule and programme, minutes, Emails and project manager instructions (PMI) (Appendix D) were also collected and analysed. Table 6.1 shows the different documents that were collected and analysed.

5.9.5 Triangulation for Data Validation

It is agreed that any particular research technique may have limitations which could eventually cast doubts on the validity of the data collected. It is therefore

fundamental that appropriate techniques are used to guarantee the validity of the data collected and analysed. This could sometimes mean combining two or more research techniques where viable. Triangulation is a research study approach where two or more research techniques are employed. As Dainty (2008) notes, “Qualitative and quantitative approaches may be employed to reduce or eliminate disadvantage of each individual approach whilst gaining the advantages of each.” Dainty (2008) also refers to triangulation as the application of quantitative research to corroborate qualitative research (or vice versa). It doesn’t only mean combining qualitative and quantitative methods but could be a combination of several qualitative methods, for example using focus group to gain an overview of ideas and get an insight into a problem which can be followed by individual interviews (Gray, 2009; Gibson and Brown, 2009; Flick, 2006; Corbin and Strauss, 2008). Other considerations of triangulation are the desire to validate or obtain various data on the same problem, such as combining interview and observation, then perhaps for the purpose of verification, adding another source of data (Corbin and Strauss, 2008). This approach is inherent to help neutralise biases of a single method.

During the observations conducted in this research, there were certain details not comprehensively understood which needed a secondary clarification. This research applied a triangulation approach by using follow-up interviews as a second method to validate the data collected through the observations. As a result, expert judgement was sought on areas that were unclear. This was accomplished by interviewing selected experts (*i.e.,* seeking *expert judgement*) to shed light on those areas. The follow-up interviews were not only relevant as a triangulation method but created an atmosphere where more data was generated in line with the observations. They also served as a mechanism for the researcher to authenticate the data collected as all those interviewed were participants in the meetings observed. The data was presented allowing the interviewee to comment on its completeness and provided rectifications were necessary.

5.9.6 Analysis and Evaluation

Thematic analysis method was used for the analysis of the data collected (Swenden, 2006; Boyatzis, 1998). It is regarded as one of the most common approaches to qualitative data analysis which often attracts a coding approach (Bryman, 2008). Coding involves the breaking down of data into separate pieces and regards the creation of categories and classification of data by grouping them together in a sort that can enable them to be regarded as the same (Charmaz, 2006). Themes are more or the less the same as codes and the process involves constructing themes and subthemes which are often generated after thorough reading of the transcription and field notes that make up the data (Gray, 2009; Bryman, 2008).

The data collected were thoroughly examined and categories established. Similarities in the data were identified which resulted in the grouping of similar data under different categories. These categories were further classified, coded and sub-divided into different key themes relevant to providing answers to the investigation. Table 5.4 shows a tabulation of the different themes under which the analysis was conducted. These themes formed the basis of the analysis in Sections 6.2 and 6.3 upon which the emerging theory was based. As an analysis method, grounded theory was also applied on the data in order to derive new ideas and theory for better approach to requirements management.

A critical aspect of this research was the mechanism to test and evaluate the Framework and prototype which included industrial input and assessment. It was thought to be relevant and also appropriate to involve industry experts and practitioners to interact with the tool so as to determine its relevancy to industry. The population of the evaluation was stakeholders of the case study projects. Subsequently, a sample of project managers (i.e., both client and consultant project managers) was generated. In order to plan for the focus group evaluation, invitations were sent out as Emails to all the three construction managers, three client project managers and the consultant

project manager of the case study projects. Out of the seven invitations, four responded expressing their willingness to attend. As a result, the focus group comprised of participants (three client project managers and the consultant project manager) from the case study projects (Table 5.3). This was convened at the offices of the participants to whom a demonstration of both the Framework and prototype was made. The reason for selecting these project managers was based on the fact that they were directly in charge of managing the client requirements in the case study projects and would be perfect to evaluate the applicability of the Framework and prototype system which was developed based on observations and theory generated from them.

Table 5.3: Participants at the evaluation

Participant role	Organisation
Client Project Manager A	Case Study A Project
Client Project Manager B	Case Study B Project
Client Project Manager C	Case Study C Project
Consultant Project Manager	Responsible for all case study projects

A questionnaire (Appendix E) was designed and developed to enable the participants of the focus group to give their feedback. The questionnaire was design into two parts. The first part centred on evaluation of the Framework and the second focused on the prototype. Each part contained open-ended statements with a likert-scale of 1-5 (*where 1 = Strongly Disagree, 2 = Disagree, 3 = Undecided, 4 = Agree and 5 = Strongly Agree*) on key criteria factors which facilitated the participants to gauge the Framework and prototype. Text area was left towards the end of the questionnaire for evaluators to make further comments and suggestions in free text as additional information to the evaluation process. All the participants completed the questionnaires which were used for the analysis coupled with the

discussions, and aided by the tape recording. A detailed description of the evaluation process is discussed in Section 8.7.2. Analysis of the evaluation results was statistically aided with graphs.

Table 5.4: Data analysis themes

Theme	Rationale
Storage (requirements information)	To understand the mechanisms for requirements capture and storage.
Access (requirements information)	To understand how different stakeholders access requirements information (i.e., how the information is distributed and shared).
Change request tools	To identify the different tools or techniques used for requesting requirement changes.
Communication of changes	To identify the different mechanism/channels of communicating changes.
Errors in changes	To find out if errors occur during the change process and to identify the sources of such errors.
Dependency checking	To understand how dependencies between requirements are traced and impact analysed.
Delays	To find out if delays are caused during the change request process and the causes for such delays.

5.10 Summary

This chapter presented a review of the various research techniques and philosophy in the quest to select the most appropriate for use in this research. Consequently, this research primarily adopted a qualitative research methodology and qualitative data collection methods. However, a mixed method approach was utilised for the data collection, analysis and evaluation. This approach followed a review of research philosophy in order to determine how best to design and execute the research. Interpretative and qualitative

methodology was selected because of the nature of the research. Case study method was used as the research strategy with observations, interviews, questionnaire, focus groups and document analysis as the data collection methods. Thematic analysis was used for the analysis of the data with some element of grounded theory to develop new ideas and theory; recommendations for better approach to requirements management, and defining implications for the Framework.

The methodology was also informed by various industries where requirements management has been successfully applied. Even though these are different industries, adoptions have been made in those areas (tools and techniques) deemed to suit the construction industry.

Methodically, the next phase of the research was to implement the research that was designed in this chapter. As a result, the case studies were conducted, data collected and analysed which are comprehensively presented and discussed in the following chapter.

Chapter 6. **Case Studies and Analysis of Requirements Management**

6.1 Introduction

The literature review conducted in Chapter 2 and 3 highlighted various difficulties encountered in managing information about client requirements. Research gaps were identified which constituted the design of a scientific approach to address and bridge gaps. Moving from *theory* to *practice*, this chapter presents the work conducted in understanding the real problem(s) from an industrial point-of-view in order to determine if there is any need for a solution to be generated as suggested in the theory. Consequently, management of requirements information was studied using three different case studies. These case studies were conducted on *'real-time'* (on-going) construction projects at different project stages. Studies on Case A began at the transition from design to construction and continued through to handover and early use/operation phase. Case B commenced during construction phase and continued through to completion and hand-over. The study on Case-C commenced during the late stages of preparation through to design, pre-construction, and ended at the initial stages of construction phase.

The findings of the case studies reported using two main approaches: narrative report and comparative structure. According to Yin (2003) and Robson (2002), the narrative report presents a detail account of the study supplemented with relevant tables, figures, and analysis and discussions as well as conclusions of the data; whilst in order to give a detail account of the cases, the comparative structure can be used to examine the cases from different perspective such as descriptive or explanatory.

All three case study projects were sponsored by the same client. The project management of all three projects was contracted to an engineering consulting company. A project manager was appointed from the consulting company

who represented the firm; and oversaw the project management of all three projects. As a result, the project management was based on the same method in all three projects. The tools and techniques for managing the requirements information were similar, as were the mechanism for handling requests for change. Consequently, the observations made on the case studies regarding requirements information management including the change management procedure yielded similar data. A focus group was also held to provide preliminary understanding of the study and to supplement data from the case study.

In order to discuss the results of the case studies, certain key themes (shown on Table 5.4) were identified to form the basis of the presentation and analysis of the data. However, because of the application of the same project management method by the client and project manager; and since the data collected from the case studies are based on the same issues, consequently similar findings emerged under the themes in the cases. It was found essential to group the emerging issues from all cases under the themes to enhance the interpretation and analysis of the data.

Subsequently, in presenting the results, it was deemed unnecessary to discuss the same issues repeatedly in each case. Thus, the approach is firstly to introduce each of the cases in terms of a project. Secondly, to generalise the results observed from each case under the factors that were selected to form the basis of data to be collected. Thus the method was to discuss the results based on those factors and present the analysis in themes for all the three cases as a whole. Critical analysis was made of the three cases on various areas of requirements information management as applied in those projects. A summary was also made with a discussion on the implications of the findings for the Framework.

6.1.1 Case A – University Department Building Project

Project A was the construction of a university building to bring together two departments to create a world class research and teaching facility in their areas of teaching and research. The new facility replaced an existing swimming pool, which was demolished by the client to make way for this project.

The design contained approximately 3,000m^2 of accommodation comprising laboratories and teaching space along with associated services, plant and circulation areas. The building was designed to have energy efficient structure with the concrete frame utilising a 400mm thick RC slab as a thermal mass integrated into the M&E design.

The contract value was £7.9 million and the construction period was from May 2007 to June 2008. The form of procurement was a two stage design and build process with a JCT 2005 contractors design as the contract type. The building was designed to have an internal floor area of 3,467m^2.

6.1.2 Case B – Public Building Project

This project was the new home for the national governing bodies (NGB's) of many sports. The scheme provides an innovative office environment enabling the NGB's to share information and produce innovative approaches to best practice. The scheme comprises four buildings with up to five storeys linked through glazed circulation spaces. The 'break-out' areas varied and include small scale sports facilities and an outdoor sprint track.

The cost of the programme was £12.5 million and the building was completed in December 2009. The procurement and contract type was traditional (design, bid and build) with JCT 2005. The building has an internal floor area of 3,467m^2.

6.1.3 Case C – University Department Building Project

This building project was to construct a new university department building to a cost of £14.2 million. The contract included the modelling, prototyping, visualization and display facilities as well as research and lecture spaces, computer suites, offices and a café, surrounded by hard and soft landscaping. The design for the centre involves extensive use of zinc cladding, roofing and curtain walling, and a concrete frame with exposed soffits throughout. The duration of this project is 65-weeks. Work commenced in March 2010 and the project was scheduled to be completed in June 2011. The contract type was a traditional (design, bid and build) form of contract under JCT 2005. The building has an area of 7,555m^2.

6.2 Case Studies and Focus Group Results

6.2.1 Results from the Focus Group

The methodological approach to conduct the focus group (*including how the participants were selected, who attended and for how long*) was discussed in Section 5.9.4.3 of the Research Methodology Chapter of this Thesis. As presented there, a focus group meeting was set up as a supplementary study with participants comprising a small number of industry experts from a multi-national engineering consultancy firm which specialises in project management. The meeting started with a brief outline of how requirements are documented to enable storage and retrieval; communication and distribution between all project stakeholders; how changes are managed and dependency analysed. Issues surrounding traceability, visibility and auditability of requirements changes were also outlined. A report was compiled (Appendix G) which detailed the outcome of the discussions on the various research topics.

The experts confirmed the importance of requirements management and outlined their current methods to ensure that client requirements were identified at the briefing stage of the project and any changes to these requirements monitored throughout the project. It was identified that, in all

their projects, details of requirements were included within the project execution plan. Changes to requirements were monitored through change control procedures, where changes are identified and recorded together with the cost and time implications. Other approaches, such as 'Value Management' were used to evaluate potential changes.

To record changes, common office software packages such as Microsoft Word, Outlook (for emailing), and Excel (especially for costing) were used. A risk register, where changes are forwarded and monitored, was also maintained. It was however observed that how changes were managed depended on the type of project, and client preference tools or systems to be used; sometimes clients were not ready to pay for the development and/or implementation of new systems.

The fact was acknowledged that any particular requirements system that may be suggested should consider project management protocols such as the Process Protocol and RIBA Plan of Work. This will ensure conformance to industry standards of construction project management. The experts believed that web based tools provided good facilities for managing requirements and represented the future platform for software based systems. Depending on client requirements, it was sometimes necessary to use a particular project management protocol which also depended on the choice of the client and the type of project procurement system.

6.2.2 Results from the Case Studies - Observations and Interviews

As described in Section 5.9.4.1, the main data collection method was through observations supplemented by interviews and questionnaire. During this period, data was collected from several sources using various methods which constituted to the understanding of the client requirements management process. Documents relevant to requirements information were also collected and examined. Table 6.1 shows the various types of documents collected and analysed. For the purpose of commercial sensitivity, some of these cannot be published in this Thesis; however, their analyses will be presented. The table

also indicates the types of information contained in those documents and the significance to their collection and analysis with respect to requirements management.

Table 6.1: The different documents collected and analysed

Types of documents	Information captured and examined	Significance
Brief	▪ The different requirement attributes ▪ Rationales and priorities of requirements ▪ Relationships between requirements	It was relevant to understand the different attributes used and why. It is also important to understand rationales of requirements which will help determine why they were generated and their priority in terms of implementation. Relationships between requirements will also help understand the link, dependency between requirements for traceability purposes.
Minutes	▪ Attendees ▪ Distribution ▪ Content (relating to request for change)	It was important to review minutes as they serve as reference materials on decisions made on changes during meetings. They also show the people who attended which is helpful to determine the different stakeholders who were involved in the process.
Change Order Forms	▪ Originator ▪ Change proposal ▪ (reason for change) Rationale ▪ Effect on cost and time (impact)	These forms are the primary carrier of change information. Thus it was crucial that they were examined and analysed thoroughly.
Emails	▪ Originator ▪ Distribution (cc) ▪ Content	Emails served as a valuable and desirable communication tool in all the cases observed. Their study was necessary to understand how exactly they were utilised and the content they carry.
Progress Reports	▪ Project status (in terms of requirements implemented and those out-standing)	These reports show the different stages a project was and describes the various level of completion. They were important to study to reveal how client requirements were implemented.
Project Manager Instructions (PMI)	▪ Description of instructions ▪ Cost and time effect	These instructions govern what work to be implemented following a change request. Thus it was necessary to study and determine their content in relation to the corresponding information on the change request forms.

6.2.2.1 Requirements Documentation, Storage and Communication

The key focus of these areas was to find out: (i) the storage mechanism of requirements information; (ii) if requirements were accessible to all parties; (iii) what was the access mechanism; (iv) how was requirements change information distributed and updated in all available instances of requirements.

Both literature and case studies show that in the construction industry client requirements management is currently manual and paper intensive. The case study projects (Case A, B and C) client requirements were elicited as a brief and documented in a text document using a word processor (e.g. Microsoft Word) with no central storage and accessibility. This document was distributed to various parties (the Project Management Board, Consultant Project Manager, Internal Project Manager, and the Architect) in different formats and media (e.g. hard copy, digital documents, etc). A large amount of the information (more than 90%) produced after the production of the brief was generated during meetings. This information was documented as minutes in text documents and disseminated in paper-based form to the relevant stakeholders. The architectural designer used this information to produce sketches and drawings. Drawings were then distributed to the relevant stakeholders again in paper-base. Because drawings were most often '*hard copies*', they were scanned before eventually being sent to a recipient. One of the primary mechanisms for communicating and distributing client requirements was through the use of *e-mail* with attachments of the brief and other documents such as minutes and drawings.

On very few occasions In Case C, drawings were uploaded to a project extranet for access by all stakeholders. However, even though this project extranet existed, it was *not commonly* used for accessing and communicating client requirement documents. Instead, the client, design and construction teams relied heavily on hard copies and e-mail messages with attachments for sending and receiving such documentation. Teams were aware of security

issues associated with sending documents as attachments and wanted to ensure that the information provided was not changed on receipt. Accordingly, word processed documents were frequently converted to Portable Document Format (PDF) before being sent to prevent distortion or change to the information occurs. CDs, DVDs and other electronic storage devices were used to store requirement documents and distribute to relevant stakeholders. Using hardcopies to communicate requirements and their related information was observed to have a negative impact on the effectiveness and progress of the projects and their management. The observations revealed how sometimes the change control forms detailing requested changes would not be in hand during project meetings for discussion and authorisation. This affected any other decisions that had to be made in relation to those changes under review.

The observations revealed the use of the telephone as a communication mechanism whereby amendments to requirements and sometimes queries were verbally made. This was seen as an easy way of communicating requirements but undoubtedly is very ineffective in ensuring auditability, traceability and visibility of requirements.

When orders were placed to suppliers, the relevant part of the specification with details of the specified drawings and their requirements were sent along. This was again through the use of Email or hard copy.

The architect commenced design and periodically, design meetings were held to review progress and check that the drawings fulfil the client requirements. During that process, suggestions were made by the Architect which resulted in additions of new requirements or amendments of existing ones. Those became changes to the requirements which then went through a request for change process.

6.2.2.2 Requirements Traceability for Dependency Checking and Impact Analysis

No recognisable system was observed to have been used for traceability and to provide dependency checking for impact analysis. This was further manifested by the respondents in the change process questionnaire (Appendix H). In one of the questions, respondents were asked:

Question: “How do you assess impact of the changes in relation to other requirements?” Two of the respondents stated:

Response 1: “*This is discussed at the Site and Design meetings prior to the preparation of the necessary paperwork, should it be agreed that it is a necessary change. Changes impacting on costs and programme are designed out so as not to, thus ensuring any sign off is a formality and does not delay the process.”*

Respondent 2: “*Request for changes are considered in term of the cost, programme and brief impact. Furthermore key parties including the client are consulted with regard to the impact of the change on the brief and the impact on other requirements.”*

Clearly, these responses did not indicate how impact on cost and time is assessed nor did it illustrate a defined tool for that purpose. In fact entirely, the documentation and storage mechanisms used did not in any way support traceability between requirements thus dependency checking was manually conducted. Impact analysis was done based on expert judgement by utilising individual expertise and experience of past projects to determine dependencies and traceability between requirements; and often discussed during design meetings.

During one of the meetings of Case Study C, extra toilets were added as a result of the maximum occupancy figure of the building which was not known to the meeting before hand. Consequently, this addition will impact on the

original building services requirements. However, this impact could not be analysed during the meeting as the M&E requested time to look into it.

6.2.2.3 Requirements Change Process and Management

As in every project and as it was observed, requirements in the projects were not static; they changed several times during design and construction. Similar observation was made by Bouchlaghem et al. (2000) who stated that "As projects progress, changes to the stored information base that has been built up during the project are inevitable." Observations reveal that changes to client requirements were initiated by different parties within the various case study projects and the following channels in Table 6.2 were identified to be used.

Table 6.2: Channels used for requirements change request

Change Request Channels	Description
Telephone	Requesting a change by calling and discussing the change but a formal change request accompanied with a change control form will have to be raised
Online Forms (eForms)	Using an internet based form to request a change (not used extensively in the case studies)
Email	Sending an Email with all change details and necessary supporting documents as attachments
Meetings	Requesting a change during design and or project progress meetings
Face-to-face(individually)	Meeting with an individual and verbally requesting a change but a formal change request accompanied with a change control form will have to be raised
Paper-based (hardcopy)	Using hardcopies of change order forms and sending them through the post

This was also confirmed in the interviews as shown in responses to question 5 of the interview questionnaire (Appendix A). In that question, respondents were asked:

Question: Requirements are constantly open to change throughout the lifecycle of a project. Different stakeholders may initiate a change through different channels such as meetings.

a. How are changes initiated and what medium of representation is used for this?
b. When changes are implemented, how is the information reflected to the initial requirements?
c. How are the changes communicated to all stakeholders?

Two respondents stated:

Respondent XX: "*A client can initiate a change by sending a request for change by an e-mail to myself (Project Manager) asking for a quotation as a result of the change. We respond by telling the client whether we can implement the change or not and we provide a quote for it. The External Project managers (ECH) will then be informed who will issue instructions to us on behalf of the client.*

We as the contractor can also request a change by going directly to the client and ECH detailing the change. The design team is copied the correspondence of the change requests and that will result in a drawing being revised by the Architect or Structural Engineer. That revised change drawing will then be sent for approval by the client and to all stakeholders."

Respondents XX*: "Both client and contractor can request for a change to the initial requirements and as said before, this should go through the normal changes process using hardcopy. We sign hardcopies and convert them to PDF files and send to other parties.*

Yes, let say if the colour of the chairs change, then the Architect will re-issue a drawing which will indicate that the colours have changed. They wouldn't necessarily go and change the specification.

In a more complicated project such as T5, the change request would be more complicated and may request a lot of signatories. That would be a good place to find out."

This manifested the various stakeholders can request a change which according to the second respondents goes through a change process. For example, in Case A, the client initiated changes in building space requirements, fittings, and electrical materials. Likewise, the contractor initiated changes to some materials due to market availability which all went through the normal change process. Whoever initiated a change, a change request form was filled and the authorisation process followed. Results from the change process questionnaire (Appendix H) also indicated the use of Email and hardcopies as the main medium used to communicate orders. Often, text documents are converted to PDF files before they are sent out as email attachments. These are tabulated as per respondent in Table 6.3.

Table 6.3: Medium used to communicate change orders in the case studies

Respondent	Medium used to communicate changes
Respondent A	▪ Email ▪ Hardcopy
Respondent B	▪ Email ▪ Hardcopy
Respondent C	▪ Email ▪ Digital document (PDF)

This change management process was paper based and authorisation sometimes took a long time before final approvals were granted. However before discussing the request for change process, it is vital to reflect on two different types of changes applied in the case study projects.

I. Requirements Changes

These were changes to the client requirements as defined in the brief or requirements document. Such changes were requested by the client to effect a change on an individual requirement of the building. An example of such changes was changing the lift of Case A project from a standard lift to an evacuation lift. The designer also requested changes to the requirements to meet design proposals and/or solutions.

II. Site Changes

These were change requests generated by on-site construction manager or designer relating to site constructability issues. Details of such change requests were documented on a request for information (RFI) form and sent to the designer to provide information on effects and or impact of those changes requested. An example of such changes was the removal of irrigation tanks onsite to enable development of a new car park. It must be pointed out that during the case studies; the research concentration was on requirement changes. However, any other changes which potentially had an impact or effect; or which resulted in a change to client requirements were also considered. As a result, the request for change process used in the case study projects will be presented and analysed.

III. Request for Change Process

There were two different requests for change processes that were observed in the case studies. There was the (i) pre and (ii) post contract award request for change processes. Both were studied thoroughly during the case studies. They both followed the same routine but their main difference is that a contractor is not involved in the pre-contract request for change. Most of the requests for change in the case studies were pre-contract change requests. This was because most changes relating to client requirements were generated and dealt with at the earlier phases (preparation, design and pre-construction). This does not mean that client requirements did not changed over the later phases. The research focused mainly on changes requested

during design and construction phases. Understanding the change process used no matter at which phase was sufficient enough to develop the change management component of the Framework and subsequently, the change management system.

IV. Description of the Request for change process

The client, contractor or any member of the project team can request a change by raising a '***request for change***' (RFC) form otherwise captioned and referred to as '*change order*' or '*change control*' shown in Appendix C by completing section 1 and 2. The form is made up of different sections (as shown on Table 6.4) which need to be completed by different parties depending on their roles.

Table 6.4: Different sections and parts of the RFC form

Section	Information captured/detailed
Section 1	Project details including: project name, Sponsor, project manager, originator of request, job no., change request no.; charge code and date of request.
Section 2, Part 1	Change proposal describing the changes, supporting documents and reason for the change.
Section 2, Part 2	Effect on cost
Section 2, Part 3	Effect on delivery timescale
Section 2, Part 4	Consequences of rejecting change request
Section 3	Change approval from those who may be affected by the change. Note: request will still need final approval.
Section 4	Final change request approval/rejection detailing name of authority, signature and date.

If the request is made during the construction phase, the ***Contractor*** completes ***sections 1 and 2***. The form is then sent to the consulting firm managing the project on behalf of the ***Client*** with all other supporting documents. The '***Quantity Surveyor***' otherwise referred to as the '***Cost Consultant***' and the ***'Consultant Project Manager'*** check the information for cost and time implication. If they consent to the information, the form is routed to the stakeholder(s) to whom the RFC is relevant. When the consulting firm receives approval from the stakeholder(s), '***Section 3***' would be completed by

their representative. When this is done, the RFC is then issued to the '***Client Project Manager***' for final authorisation. The '***Project Management Board***' is responsible for this final authorisation by approving or rejecting the RFC. This will be confirmed by the '***Client Project Manager***' to the consulting firm by completing '***Section 4***'. The ***'Consultant Project Manager'*** will then issue a '***Project Manager Instruction'*** (PMI) to the ***'Contractor'*** for implementation.

Otherwise if the RFC is a pre-contract (before contractor is appointed) request, the process remains the same except that the RFC can either be raised by the 'Designer' or the 'Client' who will complete '***Section 1'*** and '***Section 2-Part 1'***. The 'Consulting firm' will then complete '***Section 2-Parts 2, 3 and 4'*** and the process proceeds as described above.

No matter what the implications (negative or positive impact) are, the change request would then proceed to the client for approval and the change initiator is informed of the decision. It must be made clear that during an interview with some of the case study team members, it was clearly pointed out that the RFC process described and used were specific to the particular projects studied. They further highlighted that this process is more complicated than some of the other change process systems and processes used in other projects they had been involved in. It is also worth noting that this process is not necessarily representative of the whole construction industry. It is presented and used for analysis and demonstration purposes as the *de-facto* process used in the case studies.

6.3 Analysis and Discussion

The case studies highlighted that different techniques were applied in client requirements management in construction. Most of these take the traditional paper-based approach with a few modernised methods applied. The observations confirmed that different stakeholders had different interests in the client requirements at various phases of the construction projects. These included: clients, architectural designers, structural engineers, mechanical engineers, sub-contractors, suppliers, project managers (both contractor and

client) and end users. Other parties such as government bodies and environmental groups also had interests in the construction projects. All parties either in one way or the other participated in the process of managing requirements. The analyses of the case study data are concentrated on the themes defined in the research design and application (Table 5.4) of the methodology.

Observations confirmed requirements documentation, communication, changes and traceability form the basis of their management as discussed in current literature. However, the level at which this was done remains questionable if efficiency and quality of current practice is to be considered. The process of managing requirements involves eliciting, capturing and documenting them in a text document which details all the needs of the client which the project has to meet.

Once the initial design was developed in the early stages (RIBA Stage C), requirements documentation was not usually updated on the brief document in later phases and new and emerging requirements were not communicated to all other stakeholders at the right time. This created an atmosphere where different teams (e.g., the designer and M&E team) worked with different versions of requirements. This means any changes made could affect previous requirements leading to wrong decisions being made. The reason (*rationale*) for this was that the decisions on requirements and their changes were generally not included in client requirements. This research argues that decisions are an important part of requirements management and their '*rationale*' should be included in the documentation of requirements and related changes. A database management system could and should be used to manage the requirements. This will enable an information-centric orientation instead of the conventional document-centric orientation to the management of requirements information. Variable stores of data with individual stakeholder's requirements together with their parameters could be stored to enhance traceability and version control. Such a way of working would be much easier than a document base and requirements management

systems within construction firms should be able to provide collaborative working not only a standalone application system. Such systems would need to be web-based or enabled by the Internet to facilitate collaboration because of the various geographically disperse teams involved in the construction projects.

6.3.1 Key Observations of Client Requirements Information Management

According to results of the case studies, several challenges were identified to causing difficulties of client requirements information management. These were focused on the mechanisms for documentation, storage and access, sharing of the requirements information and provision of effective dependency checking and traceability.

A typical major problem was how to efficiently manage client requirement changes so that each member of the team is accessing the most up-to-date version of the requirements and to manage the change process so that requirement changes are updated in real time. Requirements were not always clear to all members of the project teams. On many occasions, further clarification was requested of particular requirements and the client project manager had to answer to those or refer back to the client users for clarification. This caused some delay in terms of decision making and programme progress. A particularly interesting episode occurred in *'Case C'* relating to requirements around the maximum occupancy of the building. This was not made clear in the brief and the design did not reflect the actual number. Further instructions and clarifications had to be made resulting in changes to the drawings. In *'Case B'*, requirements for wireless data access points were defined in the brief but their exact locations were not. IT personnel from the institution had to be consulted to define the locations for these data access points. This was confirmed during a project meeting when the consultant project manager stated that *"An Email has been submitted over the weekend; it should be in your inbox"* (consultant project manager).

A satellite mounting point was also specified but where on the building this needed to be fixed was not specified. Suggestions were made to place the mounting point on top of the roof in case the client wants to fix a satellite later in the future. If this suggestion was adopted and implemented, it would have been equally important to document that as a requirement with the rationale of mounting it on top of the roof. Sometimes, original client requirements are changed during the meetings as a result of design, material acquisition and or health and safety issues. There are situations when people cannot remember the rationales behind some of the decisions made which resulted in a change to the requirements. Recording what decisions were made during such changes is also an important factor for requirements change management. A scenario was observed during one of the project meetings of Case Study C when the architect suggested for the use of certain type of building material. However, the consultant project manager asked *if sustainability issues were incorporated in those suggestions*. This is an indication of the relevance of recording and documenting the rationale of decisions and suggestions made on requirements. In this particular case, the rationale would be useful to the facility managers if these suggested materials are used in the building.

Meeting observations followed by interviews with clients, contractors, and expert consultants showed that newly constructed buildings are typically handed over with operations and maintenance (O&M) manuals. These manuals detail the design of the building, the type of materials used, and how to maintain the building but not the client requirements. Although such manuals have proved to be very useful at handover they seldom cater for the lifecycle management of a building as they do not include the '***rationale***' (the reasons) for material selection. For example, in *'Case A'* where a particular type of glass material was used for the windows of a building, the requirements and their rationale for the selection of such glass material was not included in the O&M manuals.

Analysis of the type of requirements information required at each project phase highlighted how the nature of the information varies from phase-to-phase. One key issue identified is that there is no mapping of requirements information between the phases. This makes it extremely difficult to manage dependencies and traceability between them. As the initial client requirements are documented in the brief, the information needs to be stored in a purpose built repository which facilitates shared and distributive access. Consequently, all subsequent types of requirements and project information should be mapped to their origins within the program document. This will indicate traceability of dependencies between requirements at all phases through-life.

6.3.2 Critical Appraisal of the Observed Change Control Process

Situations were observed when a request was not approved in the first iteration and would require more information from the initiator before final approval is granted. A total of 260 change orders were processed in all the three cases as shown in Figure 6.1. This is a significant number and these change orders carried a vast amount of requirements information including the description of the changes and their rationale which is needed in the later phases of a building especially at operations. Thus, this indicates the importance of managing change orders of which processing could proof to be a challenge. Figure 6.1 shows the number of change orders for each individual case from the start of the project until completion. However, Case C project is still under construction at the time of writing this Thesis. The number of change requests indicated here for that project is the accumulation of all the requests up until the current stage. These numbers do not also take account of change orders during use/operation of the completed buildings of Case A and Case B.

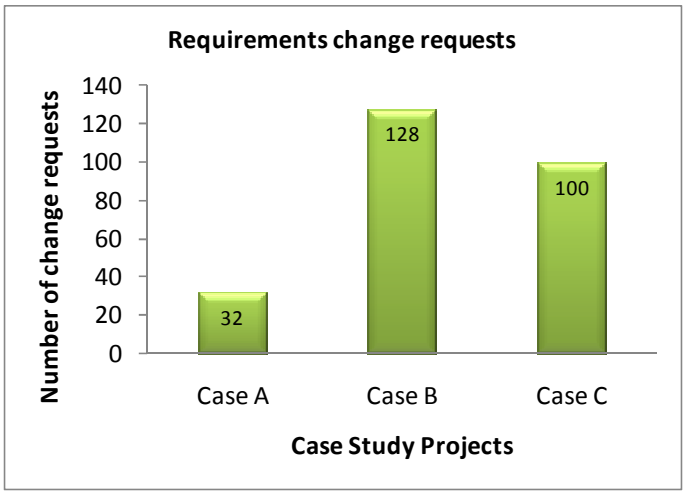


Figure 6.1: Number of change orders/change requests from the cases

It was observed that different stakeholders attended different project meetings during which decisions were made on changes to client requirements. In more complex projects such as Heathrow Airport Terminal 5, change requests could require a lot of different signatories for approval according to one of the project managers interviewed. Paper-based forms of approval were frequently ineffective. Vast amounts of information on such decisions were kept in personal memories during the meetings and eventually lost over time. Similar observations were made by Demian and Fruchter (2006) who indicate that "An experienced construction manager does not rely completely on published cost estimates, but keeps track of actual data from previous projects and uses that information to improve the accuracy of future cost estimates. The information is rarely stored in an external repository, but usually remains in the expert's head."

The projects' practice of reviewing change requests involves checking for dependent requirements and other components that would be affected by the proposed changes. This was carried out by manually checking through the brief and other related documents stored in different media and file formats, located in different places and in some cases, stored in various heterogeneous IT systems. The manual checking for dependencies was not only tedious and laborious but time consuming and error prone. With all pre-contract change orders, consultant project manager and his/her cost

consultant/quantity surveyor will review and provide time and cost implications. However, they would require information from the design team about impact the change will have on the design. As a result, both parties manually checked for dependency of the changing requirement from different sources for possible impact. This process as stated earlier was inefficient. Getting access to all the relevant information necessary for the dependency checking could be impossible. Sometimes, this process is delayed and even where possible, accurate checking is not likely due to human error that is likely to occur. A time and cost assessment generated from this exercise was not likely to be accurate and could eventually have negative impact on the entire project. An important observation made of the change order form (Appendix C) is that it doesn't include capture of the particular requirement that was changing. From the analysis, the 'change proposal' (a description of the propose change) is not enough for adequate dependency checking; and tracking either 'forward' or 'backward' traceability of the change. Thus it is the research's conviction that sufficient information that would pinpoint the exact requirement changing as a result of the propose change will be ideal to trace all other requirements and components that have dependency with it. Such information could be the requirement that is changing which can be represented in terms of the '***requirement Id***' (the unique identifier of the requirement). This information is not currently included on the change request forms.

6.3.3 Communication and Distribution of Change Information - Email

Email was the primary tool used in communicating a change request and its related information. This involved a change originator filling in the request for change form and attaching it to an Email. The recipient would download the attached form, print and process the request. The form would then be photocopied and hard copies distributed to the different people who are required to take action on the change requested. Sometimes, the form was scanned electronically and sent to all parties as an Email attachment. The design team upon receipt of the change notification and approval effect the change on the design by revising the appropriate drawings and attaching the

new drawings along with the change request form because drawings are also primarily used to communicate changes.

However, despite Email being the favourite choice and had been used hugely in all three case study projects, there were inefficiencies and ineptitudes associated with its use. It was observed that visibility and auditability of change the change process which is catalyst in any change management is virtually impossible to achieve with the use of Email applications as they were not designed for task management.

Ineffectiveness of the Email as a change communication tool also relates to access to the information when required. A scenario was observed when change request forms were sent for approval. The forms were printed and authorisation made, however they were left back and not brought to the meeting for discussion. There were times when Emails with attachments are sent out but some team members claimed not to have received the mail. Similarly, some claimed not to have received or been able to access the attachment. Requirements management requires task process management, traceability, visibility and an audit trail of requirements changes and their impacts. Email does not provide such functionality.

There were other technical issues relating to the use of Email that made it difficult to communicate and distribute changes effectively between stakeholders. In Case B, it was found out that the client organisation's IT policy limits the size of Email attachments one can send. As a result, there were some changes that needed drawings to be attached to support and also show the rationale of the changes to the client. However, because of that limitation, the Email was not the best tool to use in that particular incident and the project reverted to using hardcopies for that purpose.

6.3.4 Change Decisions and Causes of Delays

Brief documents from all three projects were studied and analysed thoroughly. There were situations where a decision was needed with respect to a particular requirement but it was difficult to ascertain how important or relevant

it was; a *rationale* and *priority* statement would have eased decision making. It was found that the *rationale* of client requirements and *priority* of requirements were not defined within the typical documents used. Priority of requirements indicate how important or its urgency to the project and can be set to *high, medium or low*. Similar observation was also made by Halbleib (2004).

Quite a number of changes decisions are made in meetings and are recorded in minutes. However, there are frequently other decisions made based on general agreements without adequately recording these in the minutes. The following comment was observed during one of the project meetings: *"Project Manager:* ***I am still waiting to get colour choice of the chairs. We can agree between us but will have to come back to decide which way to go****."* The architect responded by stating*: "****I would guess or assume the lab's chairs' colours would be white****."* Such decisions could eventually be lost in the process and impossible to trace again. Another issue was observed in Case C when the QS was delayed in ordering audio equipment because the requirements were not known. The costing was however done. This indicates that if requirements are not explicit, delays could be caused and assumptions made which could result in waste and/or re-work. This was further evident when an attendee started *"RFCs are wasting time and could delay Stage F design*."

Project decisions are mostly made at project management level which is normally channelled through business processes. For effective collaborative decision-making, the integration of project management, design and planning can assist the project manager to effectively collaborate with relevant personnel to collect necessary information with less iteration. Integrating business processes with design IT solutions will help both decision makers and designers collaborate effectively to reduce engineering flaws and meet productivity demands within shorter cycle times. Collaborative design can effectively assist designers to collaborate with people with different disciplines. The number of design iterations can be reduced by ensuring downstream concerns are addressed as early as possible. In most cases, information

transfer between parties involved in design and construction is manual and printed on hard copies. In certain situations, locating and accessing that information could be difficult. A great deal of these is product and building designs or contractual agreements. The level of project delay due to the lack of availability of such material information could hamper the desired operations of the project. This has been emphasised by Gyampoh-Vidogah et al. (2003) who state that “most information searching and transfer between project parties and clients are paper based,” providing constant source of delays. Connecting relevant project teams and clients with business processes will enable better information sharing and exchange thus will increase efficiency and effectiveness of project operations.

6.3.5 Updating Requirements Repository with Change Information

When there was a change to a particular requirement, it was virtually impossible to update all the instances of that requirement on all the copies. The most obvious way is to make newer copies of the requirements and re-distribute them. It was frequently observed that different versions of requirements were in circulation with teams and version control was difficult. Similar observations were also made by Gyampoh-Vidogah et al. (2003) in their work on implementing information management in construction: establishing problems, concepts and practice that “it is sometimes difficult to find the most recent version of engineering documents.” Design errors were observed to occur as a result of working with outdated sets of requirements information. It was clear that most of the changes discussed during these meetings were not made known to all the members after the meetings. It was however, observed that in some cases, the meeting would not progress on certain matters as the relevant documents were not available or some of the attendees would claim to not have received such documents. In a particular scenario, an attendee claimed to have received an Email on design related changes but did not see the attached document whilst others received the attachment. Telephone conversations are barely recorded in detail and make it difficult to trace change decisions. Because clients do not always define

clearly their requirements in some situations on certain components of the building, the design team assumed what is best or required by the client. Such decisions become new and emerging requirements that also need to be relayed back to the requirements or brief documents. An incident occurred when the RIBA Stage C design report had differences with the Stage C M&E report regarding fire evacuation strategy. The reason for this being that each was using a different version of the design information. The Architect had the most up-to-date information but the Mechanical Engineer did not as a previous version of the information was handed to him by his office prior to the meeting. As a result, all the advice given by the M&E report had to be revised. The representative had to call his office for clarification on this point before the meeting could progress. This shows that different versions of a requirement could be located at different places and used by different teams on different part of the project.

6.3.6 Distribution and Notification of Requirement Changes

It must be appreciated that several parties come together for project construction, operation and maintenance of buildings. The supply chain is distributed and requires collaborative endeavours. Up-to-date client requirements need to be accessible by all parties within the supply chain at all times and anywhere. If this is not the case, then it is highly likely that the team could be working on out-dated sets of requirements at a given time during the design, construction or facilities management process. This could cause errors and rework which potentially could have cost and time implications. The mechanism or tool used for notifications should be adequate enough to get to the intended people at the right time. Thus various platforms can be used for this purpose including a dedicated area within a change management system, Email, telephone and or mobile devices such as smart phones. Nonetheless, whichever tool is used, the process should be well documented and information traceable for visibility and audit purposes.

Improving the requirements change management process, procedures and activities remains a critical success factor for construction organisations for

improved delivery of facilities. The significance of a structured methodology for managing the change request process cannot be overemphasised. For that reason, establishing a robust change management mechanism supported by reliable and dynamic technology could be a catalyst to good requirements change management. Similar observations were made by Lee et al. (2003) in developing a web-based enterprise collaborative platform for networked enterprises; they indicated that “due to the complex workflow involving numerous operations, it would not be easy to monitor the smooth flow of so many activities.” Maciaszek (2007) on change management from a systems analysis and design perspective also buttress this point by stating that “strong management policies are needed to document *change request*, asses a *change impact* and effect the change.”

6.3.7 Integration between Requirements Management System and other Enterprise Systems

Many organisations have procurement systems for ordering materials during construction projects. The procurement of all materials is based on requirements set out in the brief. It was observed to be common for incorrectly ordered materials to cause delays in project execution. It would therefore be important to link the procurement system to the requirements management system to validate orders before they are placed. Such construction project requirements managements systems would have to be both product and process-oriented. Procurements systems sometimes go wrong because they are not directly linked with the requirements. A situation was observed where a change to the requirements of a lift was made through e-mail but recordings of this could not be established. An order was placed for the lift based on outdated requirement. This was noticed only when the lift was invoiced. A new order detailing the new requirements had to be sent causing a delay to the programme. Thus appropriate mechanisms need to be put in place for the control of changes and their subsequent communication.

Findings further indicated the inseparability of the building lifecycle phases. This means while focus can be made on managing requirements information

at individual phases, an integrated view should not be neglected, and must be adopted as the way forward. This integrated view was indicative by the bi-directional flow of information which is necessary in enabling and facilitating endeavours to better requirements information management. For example, at design phase, information may be required from construction phase to execute design related activities; similarly, at construction phase, design information will be required as illustrated in Figure 6.2. This bidirectional flow can be propagated across the lifecycle phases of a construction project as well as between different projects.

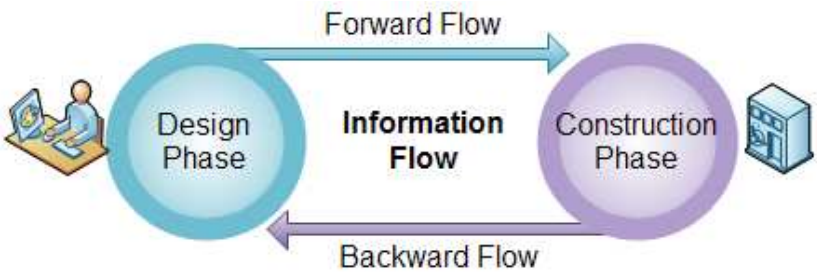


Figure 6.2: Bidirectional information flow between lifecycle phases

6.4 Summary and Implications for the Framework

This chapter has comprehensively detailed the three case studies conducted by this research. It also presented the results derived from those case studies as well as the complementary focus group, interviews and questionnaire. The findings were analysed according to various themes identified, which gave an all-inclusive picture of the industrial approach to client requirements information management from the perspective of the case study projects.

Both literature and case studies highlighted that management of information about client requirements in the construction industry is currently manual, paper intensive and inefficient. Client requirements information was documented using paper-based, printed on hardcopy are then archived along with other project documents. Sometimes, this information is transferred into electronic form using word processors or spreadsheets and later converted to PDF.

Within the case studies, each of the parties involved in the project work kept their own copy of the requirements or their associated documents such as drawings. This proves to be ineffective when changes are repeatedly made or considered. Clearly defining requirements is crucial but their management, especially making sure there is a centralised dedicated repository, is the best solution. Such a repository should be accessible to all those involved in the project with access rights. It was observed that requirements and their changes are communicated within a complex routine interaction between multiple clients who are based in different geographical locations having different stakes in the project.

The case studies also indicated that whilst request for changes have been carried out in projects, for it to be efficient and effective, the process must be adequately streamlined for a more robust coordination and control between people, and the systems used for information processing. Currently, dependency checking and analysis is manual and time consuming. This is because of the traditional paper base of documenting requirements which requires manual efforts to check those dependences. However, some advances have been made to document and store change requirements in databases but there is a lack of coordination between the formal change process and dependency checking thus lacking efficiency. This research therefore argues that the change management process should be integrated with the functionality of checking dependences.

Collaborative systems such as project extranets were not utilised in any of the case studies observed. The reasons given for this included: many projects are too small to warrant implementation of such systems; collaborative systems are not user friendly and demand a high level of IT support; project extranets collate too much un-necessary information. Thus it is important that a framework is established for client requirements information management and a system be developed to implement the Framework. The system must be simple to use to cater for the different skill sets of the users but include robust information management to support that process.

The literature and case studies also indicated that four characteristics of organisational management (*business process management, change management, information management and collaboration*) are essential enablers of requirements management due to the fact that they entail elements relevant to the management of requirements. Lack of their input towards the requirements management process could potentially jeopardise successful implementation and execution of any requirements management efforts. Therefore, a comprehensive and integrated approach that embeds principles of all four characteristics, need to be incorporated within the Framework to facilitate the requirements information management process as shown in Figure 6.3.

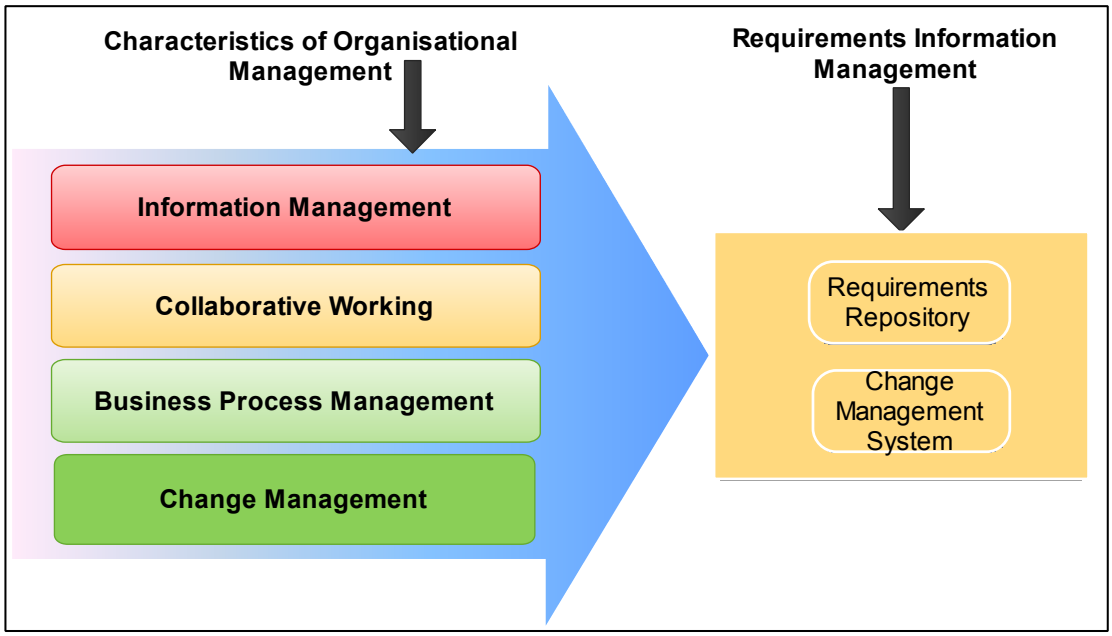


Figure 6.3: Relationship between three characteristics of organisational management and requirements information management

Chapter 7. **The eRIM Framework**

"For any company to operate in an efficient and effective way, it must be managed in a systematic manner where clear direction and control are intrinsic to everything that it does" (Alan Griffith, 2011)

7.1 Introduction

The results of the data collected from the case studies highlighted the importance of: managing client requirements information at each phase of a project and throughout the life of a building or facility; a centralised storage system; easy access to details of the requirements for all the project stakeholders; and efficient coordination and control and control of the requirements change process. This chapter discusses the developed Framework which defines a holistic approach to lifecycle client requirements information management and its constituent components.

Two types of requirements are defined for the purpose of discussing the Framework in this chapter and also in Chapter 8. These are *primary requirements and secondary requirements*. The initial client requirements stated in the brief are regarded as *primary requirements.* Room datasheets produced at the design phase are regarded as *secondary requirements* in this Thesis. Requirements vary in precision and detail as projects progress, therefore, this recognition was relevant to indicate the characteristic of that variation. These two types of requirements were also used to demonstrate how the Framework works but in practice, they are scalable.

It should be emphasized that client requirements management begins during the initiation and briefing stage of a project. However, the emphasis of the proposed Framework covers the stages from when the brief is produced, through design and construction and through-life of a building. The Electronic Requirements Information Management (eRIM) Framework was designed and developed to address the issues highlighted from the literature and case studies.

The approach behind the design and development of the Framework is based on both the requirements information management theory and empirical studies from the case studies. The following issues as shown in Figure 7.1 relating to requirements information management formed the basis for the development of the Framework. The rationale for the selection of these issues are presented and discussed.

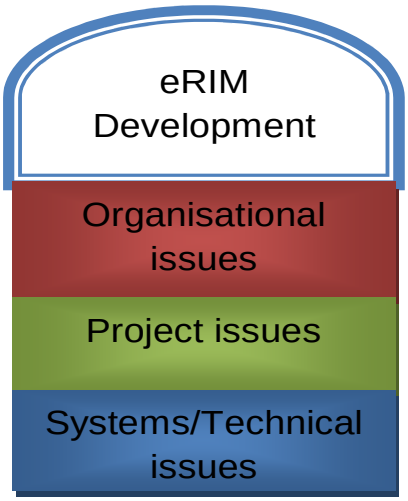


Figure 7.1: The three issues forming basis for eRIM Framework development

7.1.1 Organizational Issues

Within the construction industry, different companies, teams and expertise come together (in the form of client, contractor, sub-contractors, engineers, consultants, users, suppliers, etc) during a construction project working to fulfil the client requirements. As a result, the venture becomes collaborative requiring all stakeholders to interact and collaborate on matters of the project. This requires meeting relevant partners, creating, indexing, and archiving documents and information in a manner accessible to all stakeholders. Client requirements are an example of such information as discussed earlier in Chapter 2. Consequently, the need to facilitate the management and accessibility of those requirements becomes necessary. However, each of the teams may be operating from different geographical locations, utilizing their own information management system entirely isolated from the rest of the project team and having different processes from the rest. Thus the need to

define an approach to bring all stakeholders together in an integrated working environment becomes a necessity. Other organisational issues include social, cultural and policy within the different companies. The individual differences between the people involved to produce the products could affect success of project implementation. The cultural difference which could mean the different ways of working of the various companies could also impact the implementation process. Organisational policies defining the execution processes may not be generic across all companies, which without being streamlined could be difficult issues to manage. All these issues have effects on how requirements information can be managed across all participating companies.

7.1.2 Project Lifecycle Issues

A construction project comprises different lifecycle phases (*i.e., preparation, design, pre-construction, construction, use/operations and decommission*). Client requirements are implemented at each of the phases. Thus, this demands managing requirements across the phases and between all stakeholders and their constituent companies or institutions. However, the degree of precision and the detail nature of client requirements information vary in detail from one phase to another. There are also systems used at each phase for handling data and information used at that particular phase. Therefore, there is the need for a clear definition on how to maintain the relationship and integrate requirements information and processes at different phases.

7.1.3 Systems Issues

Generally, in construction projects, different computer systems are used in silos for managing project information. This includes requirements storage, retrieval and dissemination. Most of these systems are heterogeneous and are technically not integrated and interoperable. Information flow between these systems is difficult to attain. Therefore there is the need to define a systematic approach to make sure the systems are integrated and able to

share and exchange information between them, therefore providing an interoperable solution, enabling information access and exchange across heterogeneous systems.

7.1.4 Aim and Objectives of eRIM

The development of the Framework is one of the objectives of this research. Its aim is to specify an innovative integrated lifecycle approach for managing client requirements information in construction projects. This is hoped to help reduce operational cost and improve productivity in construction.

The specific objectives of the Framework were as follows.

- To define a structured approach to a web based centralized repository that can facilitate collaborative and distributed access to the client requirements. This will enable the different project stakeholders to seamlessly access requirements information from different locations through the internet.
- To define a mechanism for managing the relationships between requirements at all phases of a facility. This will facilitate *dependency checking* between requirements, which is crucial for impact analysis, and cost and time assessment.
- To improve information flow between all stakeholders across the whole lifecycle of a building. This is relevant to ensure that each stakeholder is abreast of developments especially with changes made to requirements. It will also help in making sure each of the project team members works with the most up-to-date requirements information.
- To enhance the requirements change management process by an efficient and effective coordination of the people and the systems. This is significant because of the many people involved in the routine change process and the amount of information handling and processing involved.
- To improve the current manual mechanism of dependency checking in order to facilitate impact analysis of the requirement changes. Because changes to a requirement can affect another depending on their

relation, it is appropriate that impact of changes are analysed by reviewing all dependencies before a change is authorised.

- To improve visibility and auditability of the requirements management process. Often, because of the many activities and people involved in the change process especially in large construction projects, it is difficult to determine the status of a change request, and to track its history. Therefore, it is wise to ensure visibility and auditability of changes.

7.2 Preface and Overview of eRIM

eRIM specifies a structured and controlled requirements information management process that registers client requirements after the production of the brief; throughout design and construction, and all through the life of the building. It ensures that details of client requirements are available at all times; enables the project manager to manage requirement changes effectively through a coordinated and controlled change management process and provides a history of previous changes to requirements. eRIM has been developed from a data/information-centric and process-oriented perspective with the concept of providing an ongoing view of client requirements. It places emphasis on collaborative working, process management, integration and interoperability, thus enabling information sharing and exchange between humans and systems (both homogeneous and heterogeneous); providing shared and collaborative access to requirements information over a centralised repository which remains up-to-date through-life. Similar features have been discussed by Arayici et al. (2006) as features in a proposed integrated project information system for use throughout the whole life-cycle of a project.

An overview of the eRIM Framework is shown in Figure 7.2. The basic system comprises: (i) a *requirements repository*, and (ii) a *change management system* which is business process management-oriented to manage the requirements change orders/requests and authorisation process. The Framework has a supporting scheme which defines requirements information

to be identified for each of the project/facility lifecycle phases. Because of the challenges of integrating different construction information management systems, the Framework also defined an integration procedure based on existing technologies. The information-centric concept from this research's perspective, is a paradigm shift from the management of requirements through paper-based and the associated electronic documents, to an approach were the content (*i.e., the information itself*) is managed through a well defined and structured format. The process-orientation connotes that requirements management should focus on the management (coordination and control) of the set of activities (business processes) which are performed when managing information about client requirements.

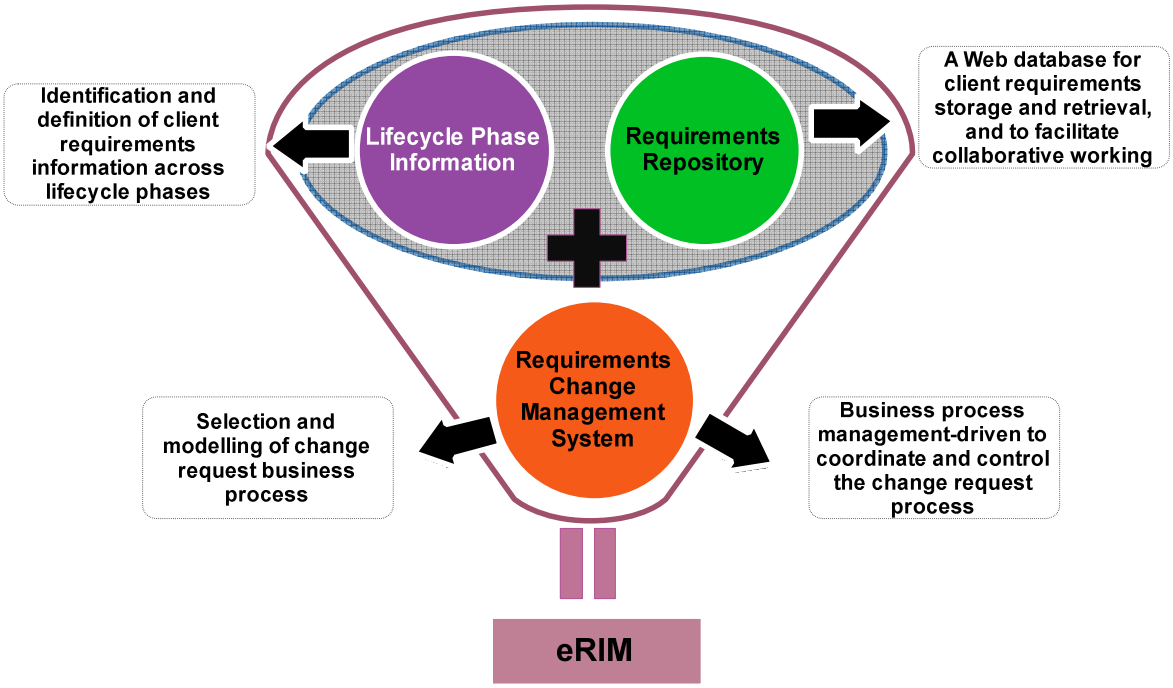


Figure 7.2: High-level view of eRIM Framework

7.3 Framework Development Process

This section discusses the various steps taken in the development process of the Framework for better management of information about client requirements in a construction project lifecycle. These steps were informed and guided by various factors which were applied in the process. These include:

- research gaps and problems (Section 1.2) identified through the review of literature;
- the research questions (Section 1.3) and how they can be tackled to help bridge the gaps and solve the problems;
- the implications for the Framework (Section 6.4) derived from the findings and analysis of the case studies results;
- tools and techniques identified for process management (e.g., BPMN for modelling, and BPEL for orchestration and automation) software service development (e.g., SOA), systems integration and interoperability (e.g., web services, SOAP).

The characteristics of construction projects which include collaboration and integrated teams; operations and maintenance of facilities were taken into account as well as the lifecycle processes associated with managing information about client requirements. Tools and techniques are adapted from other industries and similar or related work where appropriate. Several factors were taken into consideration as discussed in the implications for the Framework (Section 6.4). This section also discusses general factors relevant for efficient and effective management of information about client requirements within the development process and how the Framework can be used in practice.

In order to develop the eRIM Framework, it was initially essential to define the lifecycle phases of a building. Accordingly, two of the major and commonly used models of project lifecycle phases were considered and reviewed. These were the Plan of Work by the RIBA (2007) and the Process Protocol (Kagioglou et al., 1998). The review included determining the model that is more familiar and commonly used in industry. Consequently, the Plan of Work was adopted and its lifecycle phases chosen for eRIM. This decision was also supported through interviews and observations carried out in the case studies in which the Plan of Work was used throughout. Similar observations and choice was made by Thomson et al. (2008) when adopting project lifecycle by indicating that “consideration of various interpretations revealed that the RIBA

Outline Plan of Work 2007 provided the most recognisable interpretation, and this was supported by practitioners representing each of the project teams involved across the lifecycle during a series of interviews." Following the selection of project lifecycle model, familiarisation was made during the observations on how the client brief is used across each project phase and how it evolves into more detailed information in later phases. As a result, modelling the flow and transformation of requirements information across the lifecycle phases was required. These two models or maps define the activities at each phase, the information generated and used as well as the source and the resources utilised in that process including people and systems in project implementation and all through the life of a building. Consequently, process maps needed to be developed for each project phase. There are various process maps developed describing the project activities in construction such as those in the BIM Project Execution Planning Guide (The Computer Integrated Construction Research Group, 2009) and Cost Analysis of Inadequate Interoperability in the U.S. Capital facilities Industry (Gallaher et al., 2004). This research was careful not to 'reinvent the wheel' (by modeling these maps) but instead used those of the BIM Project Execution Planning Guide. They were used to demonstrate interaction between the project phases and eRIM Framework as if it were to be used in practice as shown on Figure 7.19 and Figure 7.20.

The literature review revealed the information intensity of the construction industry, where various types of documents are used in different project phases as carriers of that information. It was prudent to identify the documents and information and categorise them according to the phases where they are used. This was necessary in order to classify and determine the relationship between those documents and client requirements.

In order to define a central storage and access to client requirements, a study was conducted aimed at identifying the most appropriate mechanism for this definition.

Defining the request for change process was inevitable. As a result and to aid the development of eRIM, the requirement change management process as identified and observed in the case studies was modelled. The different stakeholders and the channels used to request changes were also identified.

BPMN was used as the modelling notation to model the requirements change process from a BPM perspective. Subsequently, because of this, the process maps (Figure 7.19 and Figure 7.20) developed by The Computer Integrated Construction Research Group (2009) were used to demonstrate the interaction between the activities of the project phases and eRIM. These process maps were modelled using BPMN. Thus this choice was appropriate in making sure there is uniformity between the modelling notations used to map the activities of the project phases and the requirements change management process. The development process is graphically represented in Figure 7.3.

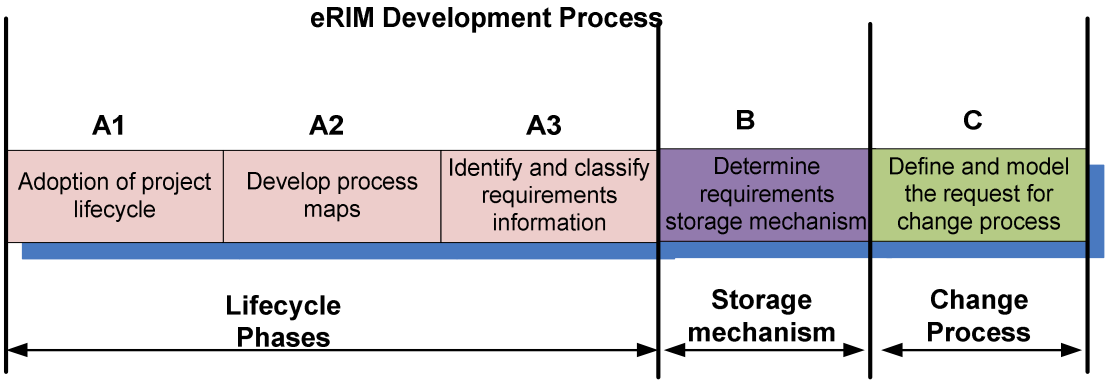


Figure 7.3: eRIM development process

7.4 Framework Components and Architecture

This section describes the development of the various components and architecture of the eRIM Framework. It also discusses how the components can be practically instituted and used.

7.4.1 Lifecycle Phases

The case studies highlighted changes in the detail of client requirements as the design is developed. Traditionally, these requirements are held in a

number of different documents. Client requirements must therefore be represented at each project phase in different levels of detail. The structure and format of the representation should follow the definitions according to standard representation. At the earliest phase, requirements could be represented in simple business language describing the business case and client needs of the project in a brief. The content and representation becomes more detailed in the later phases, for example in design, producing the specifications and room datasheets. eRIM accommodates this need by recognising project and facility lifecycle phases and types of documents at each phase. The relationship between the requirements information of the different phases must be identified and represented. No matter what type of information is defined at any particular phase, there will be some elements of client requirements which could relate back to requirements in the original brief. The project and facility lifecycle phases are shown in Figure 7.4. It must be noted that the RIBA Outline Plan of Work project stages conclude at 'use'. This research has separately recognised and included an additional stage, which is demolition/decommission in order to cover for the entire lifecycle of a building. Similar identification of lifecycle phases was made by Edum-Fotwe and Price (2009) by indicating that this would include all activities which would be deemed essential for executing the feasibility and business case, pre-design, design, build, operate, maintain and refurbish reuse and final decommission of a building.

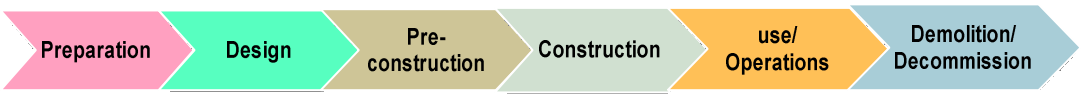


Figure 7.4: Facility Lifecycle Phases

eRIM classifies the lifecycle phases into two categories: (i) ***project lifecycle*** which covers all activities from preparation to end of construction (i.e. when the project is completed and the building handed over to the client. (ii) ***building/facility lifecycle*** entails all activities from use/operation of the building until its end-of-life (i.e. when the building is demolished or decommission and/or used for other purposes other than those for which it

was originally planned. Recognising the significance of managing requirements information across all phases, eRIM defines '***requirements information management***' to be conducted all through-life of a building encompassing both project and facility lifecycles. This according to eRIM means that the activities to manage client requirements should be integrated with those executed at each of the lifecycle phases. The philosophy is graphically represented in Figure 7.5. Kiviniemi et al. (2004) and Kiviniemi (2005) similarly conceptualised lifecycle management of requirements.

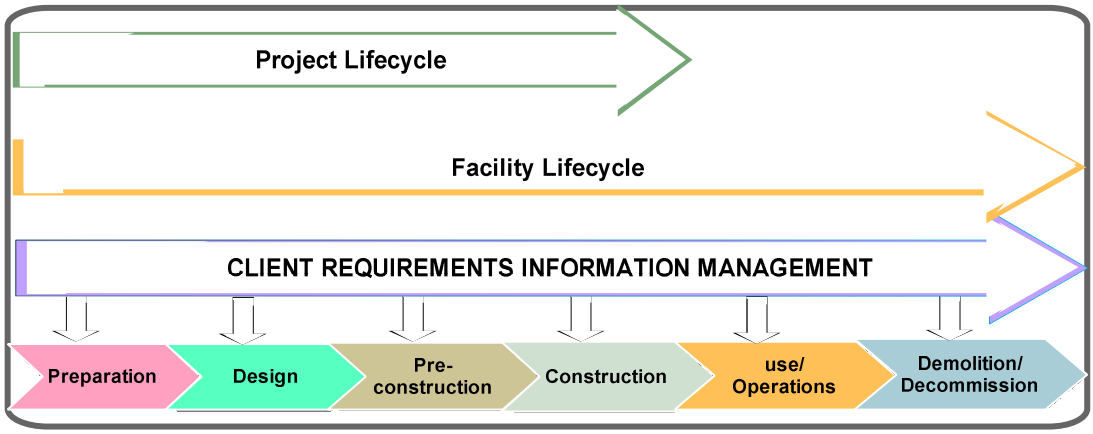


Figure 7.5: Indication of client requirements information management across lifecycle phases

Conventionally, there is lifecycle information in the form of *standard documents* that are generated and used at each phase. Each of those documents is a carrier of client requirements or is generated towards the implementation of the client requirements during construction and facilities management. Consequently, these documents need to be identified and categorised under each phase. eRIM defines a '***standard document layer***' for the specification of these documents. This research has identified some of these standard documents and information generated at each phase of the lifecycle. These are for the purpose of demonstration and are by no means exhaustive. East and Nisbet (2010) identify through COBie, commonly required information artifacts (Table 7.1) produced during the facility lifecycle mostly in paper form and are distributed between project teams; and form basis for discussion and sometimes demonstration.

Table 7.1: COBie2 Information Artifacts
Source: (East and Nisbet, 2010)

Phase	Deliverable	Author(s)
Initiation	Generic Functional Room Requirements	Owner
Initiation	Generic functional Adjacency Requirements	Owner
Initiation	Project Functional Description	Owner
Programming	Room Data Sheets	Architect
Programming	Blocking and Stacking Diagrams	Architect
Programming	Occupancy and Functional Zoning Diagrams	Architect
Design	Room Finish Schedules	Architect
Design	Product Schedules	Architect
Design	Named Equipment Schedules	Design Consultant
Design	Unnamed Product Schedules (e.g. values)	Design Consultant
Design	System Layout Diagrams	Design Consultant
Design	Product Performance Specifications	Specifier
Design	Contractor Submittal Requirements	Specifier
Design	Room Area Measurements	Architect
Design	Quantity Take-Off	Architect
Bid	Room Area measurements	Contractor/Sub
Bid	Quantity Take-Off	Contractor/Sub
Build	Product Submittals	Contractor/Sub
Build	Installed Equipment Invoices	Contractor/Sub
Build	Construction Inspections	Contractor/Sub
Build	As-Built Drawings	Contractor/Sub
Commissioning	Installed Equipment List	Commissioning Agent
Commissioning	Installed Valve tag List	Commissioning Agent
Commissioning	Replacement Parts List	Commissioning Agent
Commissioning	Equipment Layout Drawings	Commissioning Agent
Commissioning	Preventative Maintenance Schedules	Commissioning Agent
Commissioning	Troubleshooting Schedules	Commissioning Agent
Maintenance	Corrective Maintenance Work Orders	Maintainer
Maintenance	As-Operated Plans	Maintainer
Operations	Facility occupancy Reports	Operator
Operations	Asset Management Reports	Operator
Operations	Safety and Hazard Inspections Reports	Operator
Operations	Renovation and Upgrade Plans	Operator/Designer

Following the identification of the documents at the 'standard document layer', it is prudent that the information is adequately stored in a manner to support collaborative and distributed access. In order to facilitate the storage, requirements information within those documents has to be identified and extracted into the repository. A '***requirements information layer***', is defined which will serve as a funnel between the 'standard document layer' and the repository. This would potentially mean storing any information relevant to the

client requirements in the documents. This layer also requires structuring the information with clearly defined attributes for each lifecycle phase. At this layer, relationships between requirements should be identified and specific attributes should be established to serve as traceability links between related requirements across the lifecycle (as shown in Figure 7.6).

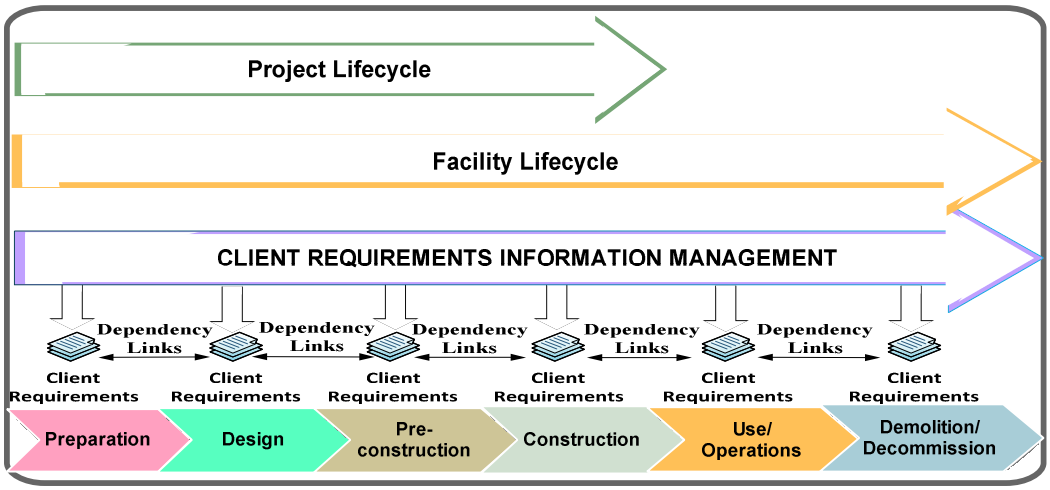


Figure 7.6: Requirements dependency links across the lifecycle phases

The *standard document layer* and the *requirements information layer* are demonstrated within the lifecycle phases and presented in Figure 7.7.

Figure 7.7 gives a representation of the entire lifecycle phases with layers and example documents used therein. The procedure for creating the lifecycle phases requirements management elements and all related entities described earlier as the first component of eRIM is summarised below and a graphical representation is also presented in Figure 7.8.

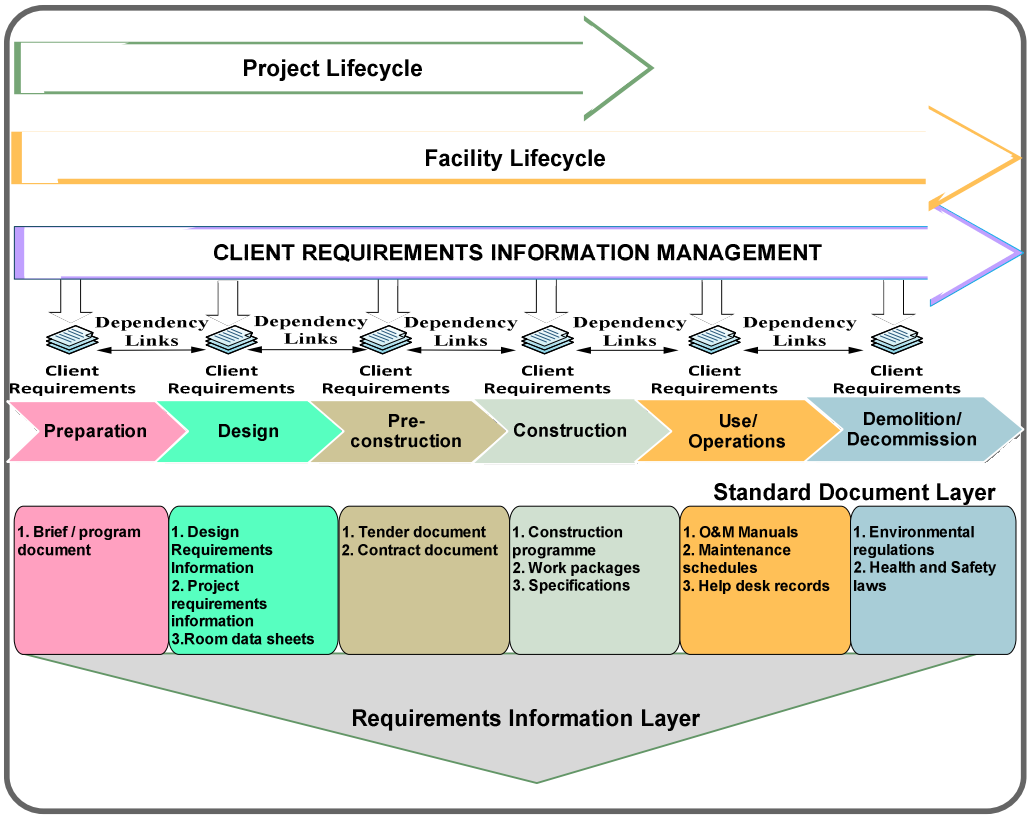


Figure 7.7: Lifecycle phases showing standard document and requirements information layers

This demands the following activities.

- Identification of standard construction documents at the 'standard document layer'.
- Identification of client requirements information at the 'requirements information layer'.
- Structuring and formatting of the identified requirements information in an appropriate format according to the database schema of the repository to enable storage and to facilitate the drive for compatibility between systems and teams.
- Identification of requirements attributes to be used as a 'mapper' to the program document (The mapper is a requirement identifier that links related requirements which is essential for traceability across the lifecycle).

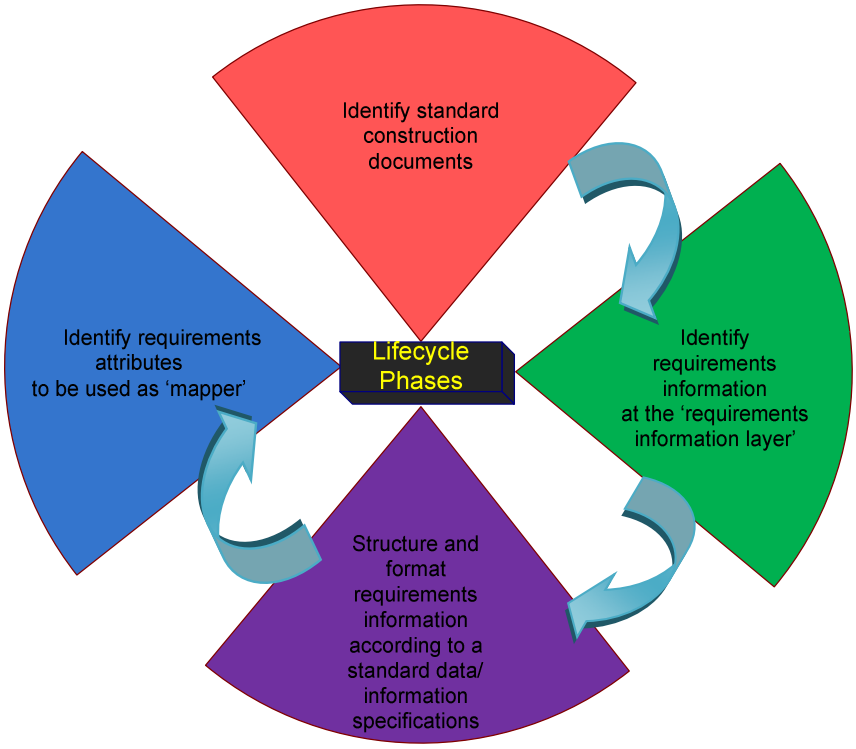


Figure 7.8: Lifecycle requirements identification and structuring

7.4.2 Requirements Repository

Client Requirements, as defined at each project phase, should be stored in the repository (Figure 7.9) within a separate requirements library module designed for that phase. Dependent requirements should be mapped between modules to provide traceability between requirements necessary for impact analysis of changes. New requirements should be added into the repository no matter the identified media (online form, telephone, Email, paper form, verbal instructions through face-to-face or at meetings) used for its creation. Alternatively, information on requirements can be recorded in an external document which can then be directly imported into the repository (*Currently, this extraction and importation into the database is manual*). Such external documents need to be specifically structured and formatted according to the data schema of the individual modules of the repository. In order to automate this manual input of information in the database, this research suggests that the system used to document the initial documents at each phase be integrated with the repository. This can be based on W*eb Services*. In this

way, information on those documents held in the source computer systems can seamlessly send the information to the database by invoking the web services developed for that purpose. Another proposition by this research is that multiple web services should be developed, which will be used at various phases to enable interaction with the repository on requirements management activities.

The database schema should support detailed requirements information storage and should include attributes such as requirement type, description, rationale and priority. The schema should support standard data/information specifications to define construction related information. This will be catalyst to facilitating requirements information flow between various phases and systems. Therefore, this research recommends that structures and formats of standard specifications for information exchange should be adhered to facilitate this process. *Rationale*, information on why a particular requirement is needed, is considered a key attribute. It is also essential and relevant to understanding changes and their impact and can mitigate from people making incorrect assumptions on requirements. *Priority* indicates its importance or urgency to the development of the project.

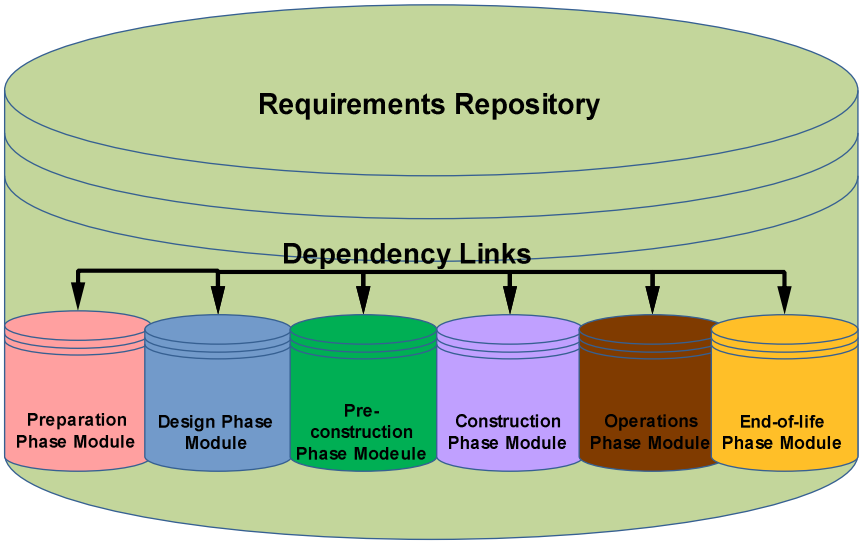


Figure 7.9: client requirements repository illustrating modules for each phase

The repository should provide up-to-date and real-time requirements information, as a centralised storage, which can be accessed concurrently by distributed teams at different locations. Project team members, subject to roles and authorisation, should be able to log-in to the repository and create/view/edit requirements. Different business processes and systems are used at various phases of a project to facilitate activities of those individual phases. E.g. a *material procurement system* is used to *order construction materials* (i.e., a business process). Such systems carry data and information associated with requirements yet they stand independently.

The process of materials procurement is based on requirements set out in the brief. It is common for incorrectly ordered materials to cause delays in project execution as observed in the lift episode during case study A. It would therefore be important to integrate the procurement system and the material procurement process with the requirements management system via web services to *validate orders* (i.e., to check for compliance) before they are placed. This means lifecycle business processes related to requirements management should be identified and *modelled using BPMN*, then transformed into BPEL and deployed in the process engine/BPEL engine for execution. The individual tasks within the processes that are performed to interact with the requirements repository by checking for compliance should also be identified. Consequently, those tasks should be designed and developed as services which the process models will invoke to perform the processes. This means all the requirements related processes (BPMN Layer) within the lifecycle phases (Lifecycle Layer) will be interacting with the repository (Data Layer) via the web services (Web Services Layer) using *SOAP as the communication and messaging protocol*. The processes themselves can also be packaged as services, and can be invoked and used by other processes internally or externally. This will facilitate an integrated business process requirements management across the lifecycle phases. Figure 7.10 illustrates this philosophy of the Framework based on the SOA architecture presented by Juric and Pant (2008).

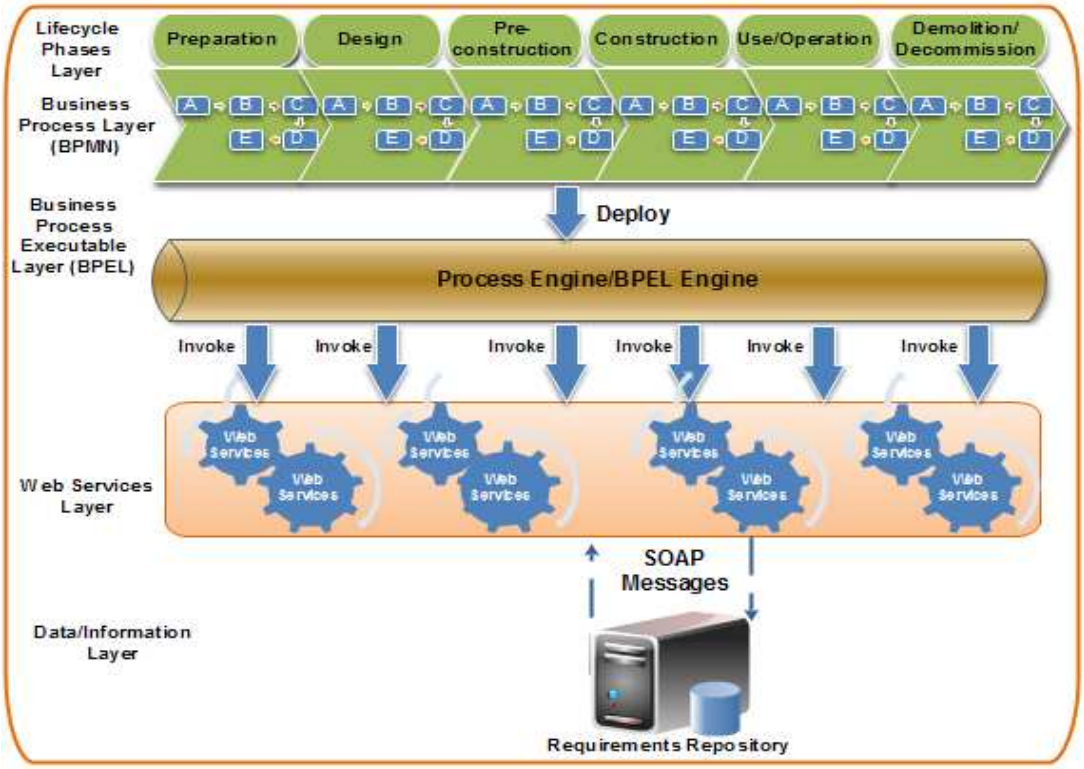


Figure 7.10: The SOA architecture model of the eRIM Framework

In the previously described scenario, the integration between the procurement system for material ordering at pre-construction phase with the repository has been demonstrated according to steps A, B and C in Figure 7.11. Steps A and B illustrated compliance validation checking and the associated response through web services. Steps C then places the order if compliance with the requirements was met. eRIM Framework's proposition is that business processes and systems used at all lifecycle phases should be integrated with the requirements repository as shown in Figure 7.11 with the case of the pre-construction phase.

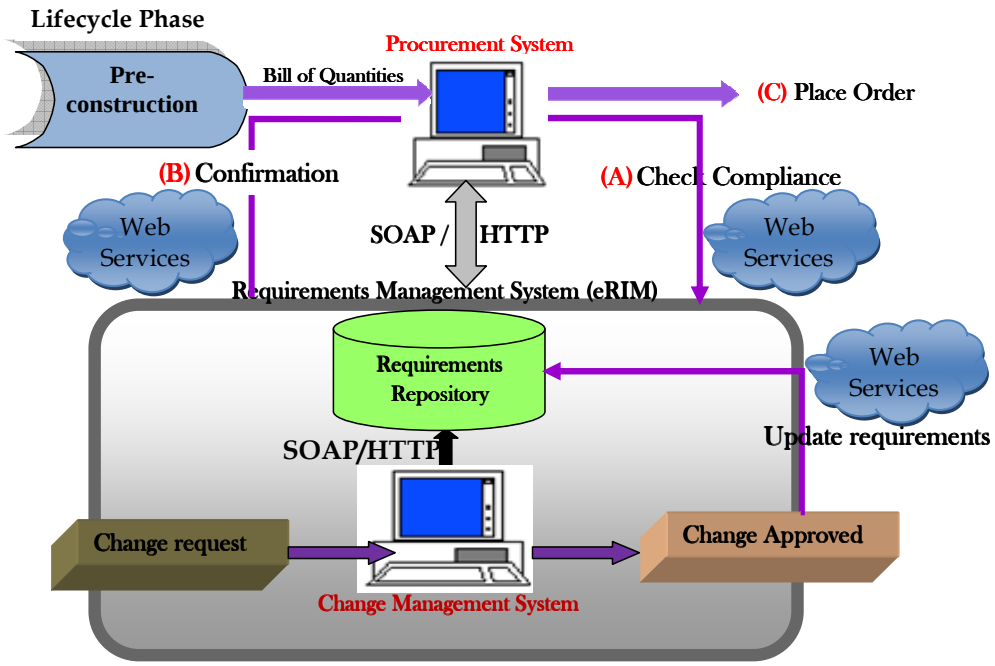


Figure 7.11: Integration between eRIM and a procurement system

Accordingly, this will enable the *constant checking of compliance* with requirements to validate any requirements information carried in those systems in accomplishing activities at the phases in which they are used. With this example, the material procurement system can be integrated with the requirements management system to check order information against the requirements for compliance (Jallow et al, 2008). The order checking can be based on the *web services* that will perform steps A, B and C as discussed earlier. This is vital in the effort to reduce the purchase of materials that do not meet requirement specifications. This can contribute to waste reduction due to wrong inventory by ensuring the right orders are made in the first place, and also reacting to changing requirements after the orders are placed. In the end, this integration will help streamline the procurement processes with the requirements management processes and to add value to the entire construction process. Similar integration of other lifecycle phases can also be instituted. The following activities should be performed in addition to those of the lifecycle phases when implementing and using the repository.

- Design and develop database schema according to requirements attributes.
- Implement database to support collaborative access by distributed teams.
- Storage of the information within the repository which is essential for consistency, accuracy and completeness of requirements information. The information should be structured or should be based on standard data/information specifications for storing construction related information. Such standards include the IFCs data schema.
- Integrate the repository with other systems used at various project phases using service oriented technology and web services.

7.4.2.1 Dependency Links

In order to provide efficient and effective traceability between requirements within the repository, dependency links need to be indicated between dependent requirements for traceability purposes. A dependency may occur between primary requirements or between a primary requirement and a bottom-level requirement (i.e., secondary requirement). Figure 7.12 illustrates links between a primary requirement and a number of secondary requirements.

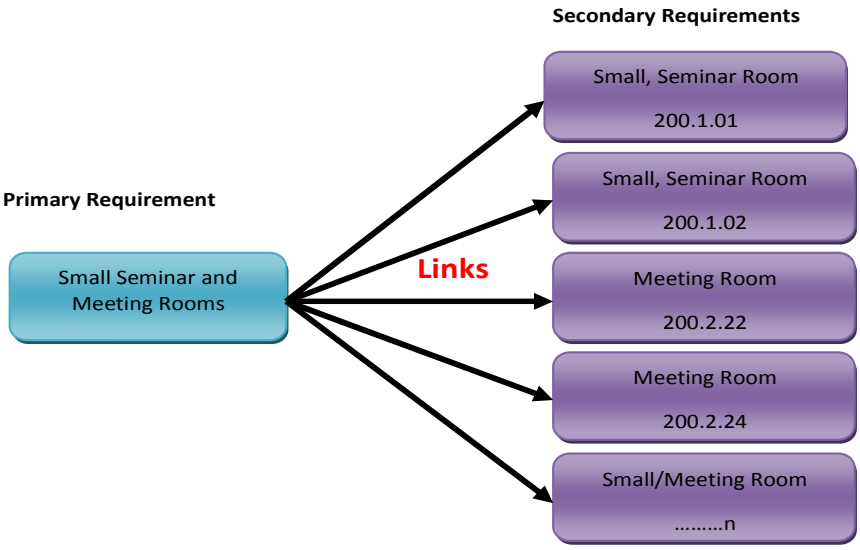


Figure 7.12: Illustration of links between requirements

eRIM specifies three types of dependency links that can exist, namely: *no dependency, strong dependency and weak dependency*. The links are represented by arrow lines (i.e., solid and dotted) with the arrowhead pointing at the direction of the impact.

- A *strong dependency* exists where there is *maximum constraint* between two or more primary requirements or between a primary requirement and a secondary requirement. A strong dependency link is represented by a *solid arrow line*. Where a strong dependency exists, a change in one of the requirements will have an impact on the depending requirement(s).
- A *weak dependency* exists where there is *minimum constraint* between primary requirements or between a primary requirement and a secondary requirement. A weak dependency link is represented by a *dotted arrow line*. Where a weak dependency exists, a change in one of the requirements will have an impact on the depending requirement(s). However, this impact may be very minimal or not occur at all.
- A *no dependency* exists where there is *no direct dependency* between requirements and no representation is made in this instance.

For example, a dependency link between two primary requirements, e.g., ‘Requirement A’ and ‘Requirement B’ as illustrated in Figure 7.13 could be strong or weak in either direction. However, a link from a primary requirement to a secondary requirement(s) will be a ‘strong link’. In this case, the direction of the arrowhead pointing towards the secondary requirement(s) will be impacted when there is a change. Similarly, a link from the secondary requirement(s) to a primary requirement will be a ‘weak link’ as demonstrated in Figure 7.14 and Figure 7.15. In this case, the direction of the arrowhead points towards the primary requirement, which may have minimal impact or none at all when there is a change in the secondary requirement. Secondary requirements as defined in this Thesis are represented in ‘room data sheets’ as illustrated in Figure 7.15.

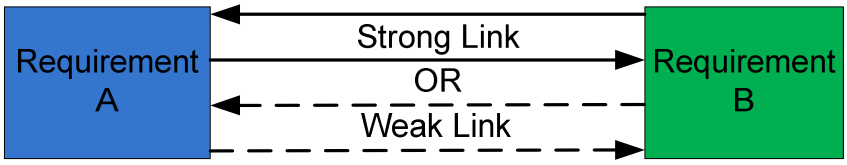


Figure 7.13: Links between two primary requirements

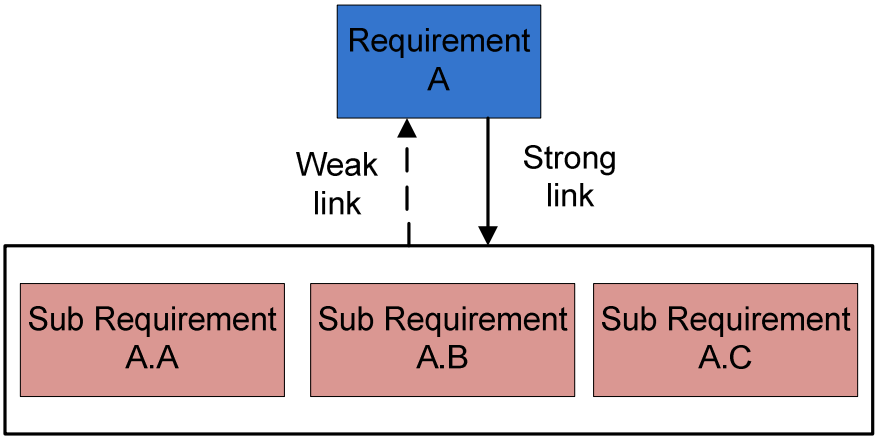


Figure 7.14: Links between a primary requirement and secondary requirements

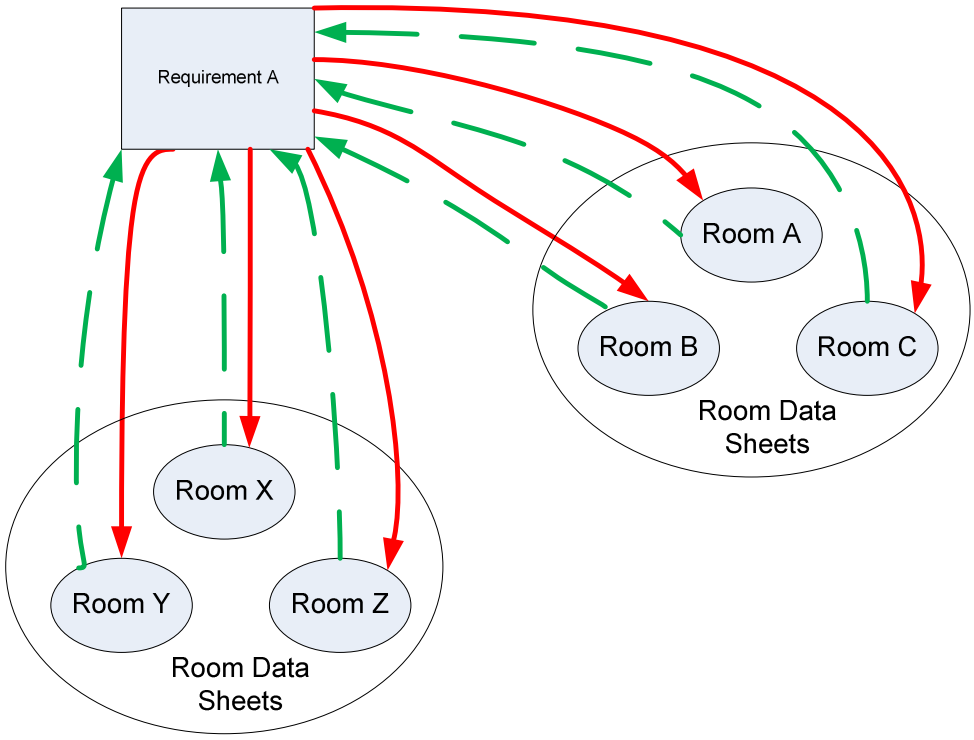


Figure 7.15: Links between a primary requirement and room data sheets

These dependencies can be further propagated between requirements, secondary and further down with tertiary requirements across the lifecycle phases, forming an integrated network of dependency links.

7.4.3 Requirements Change Management System

Change management is an integral and essential component of the Framework. Requirement changes should be executed under a coordinated approach to streamline the change process and assist in real-time capture of the change information. Different construction organisations may have different change management procedures or protocols in terms of execution. eRIM accommodates for these differences. Change may be requested through different channels shown in Table 6.2: Face-to-face (individually), team meetings, telephone, Email, paper-based (hardcopy) and on-line forms. However, no matter which channel is used to request a change, a formal change request process is followed and a change control form completed as observed in the case studies. The information should also be processed through the change management system. This means change information should not be added into the repository through the web database directly.

Requirement change management is regarded as a process-oriented activity and this research adopted a business process management (BPM) approach to manage all changes ensuring the synchronisation of process activities and to integrate different processes, people and systems together with the information required to provide coordination and visibility. Process-orientation is vital to support collaborative working and information flow and facilitates integration of processes across projects lifecycle. In his work on a data-centric, process-oriented model for effective collaborative working, Bacon (2009) echoes that “without putting process at the heart of collaborative working, the adoption of a technology solution, be it an extranet or a BIM, is unlikely to deliver value to the collaborating team or to the client.” A change request will be routed accordingly during the change management process as defined by the workflow with activities and tasks performed by both people and systems. Because the BPM system is integrated with the repository, requirements

information can be made available from the repository through the integration layer which can be used to analyse the impact of a requested change. This is dependency checking. The '*requirements dependency checker*' searches the repository for all related requirements (i.e., both primary and secondary requirements) to the one proposed in the change request. This enables the user to assess the cost and time impact that could be caused as a result of the proposed changes. Once the authorisation is complete, the system updates the repository with the change information using the '*requirements updater*' without any manual input. The update is done in such a way that the change information is added as a *new version* of the changing requirement whilst keeping the original for historical purposes. The change process system then communicates that information to the initiator, and all stakeholders who may be affected by the change through Email notifications. The initiator will also get the information on the user notification section of the system. Table 7.2 shows the different criteria that the change management system has to meet as defined by eRIM Framework with the description and rationale of each criterion. The system is capable of capturing real-time process data across the authorisation activities. This data is then written to the repository in the 'change' database module which holds all change history. This module is also linked to the requirements module thus making it possible to trace all changes for each individual requirement.

Table 7.2: Criteria of the change management system

Criteria	Description	Rationale
Change Process Coordination	Streamlining, coordinating and controlling the change request process.	Important to make sure the different people involved in the change process are integrated and that the process is visible and auditable.
Dependency Checking	To check for dependency between the changing requirement and other requirements (primary, secondary or tertiary requirements).	Important to trace relationships between requirements and other components which is crucial for impact analysis.
Requirements Update	Updating the requirements repository once the authorisation process is complete.	Important to make sure requirements are updated during the project development process so that people work with the most up to date requirements and capture the change history.
Change Notification	Communication of change information to the change initiator and all those who may be affected by the change through Email and on the notification section of the system.	Important to make sure all those concern are informed of changes on requirements at the right time with the right information.

Figure 7.16 shows a high-level graphical representation of the request for change process that would require implementation into an automated change management system. The first activity '*Request Change*' requires a change initiator to identify any changes and fill in a change request form. The various parts and information to be filled depends on who the initiator is and the type of change requested as described in Section 6.2.2.3 of Chapter 6 (Case Studies). This request can be initiated using any of the identified channels tabulated in Table 6.2. This form is sent for authorisation and is received by the relevant authority who then starts the necessary processing. The '*Process Change Request*' task involves various sub-activities which require different participants to review the changes requested and decide either to approve or reject the changes as modelled in Figure 7.17. This would include *checking*

for dependencies of the changing requirement in order to determine the impact of both cost and time implications. It also involves *assessment of effect on both time and budget*. Once the approval process is completed, two highly important tasks ('*update change' and 'communicate change*') should be executed. '*Update change*' requires updating the repository with the most-up-to-date information generated from the change process. '*Communicate change*' requires that information to be communicated to all stakeholders especially to those whom the change is relevant. This could be done through Email notifications. It is important to note that only the key steps of the change management process are shown on the architecture of the Framework (Figure 7.16) for illustration purpose.

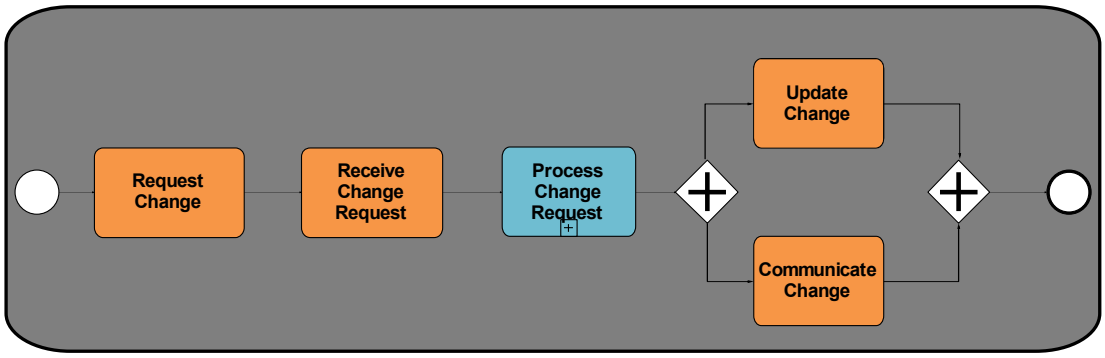


Figure 7.16: Request for change process showing high-level view of the core activities.

During full implementation, these would require expanded modelling using BPMN showing all the activities of the process including the sub activities grouped as '*process change request'*; information flow and stakeholder interactions across functional units, roles and other systems (both internal and external). The sub-process of 'process change request' task is illustrated in Figure 7.17.

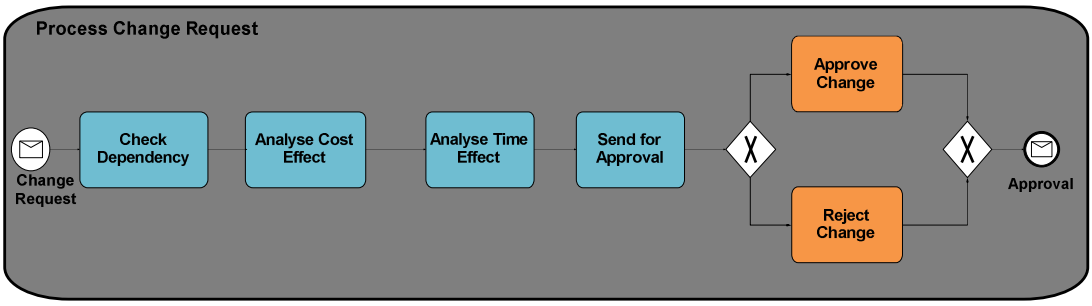


Figure 7.17: The sub-process for 'process change request'

In order to implement and use the change management system in practice, the following activities need to be undertaken.

- Develop a process map of the requirements change process: it is recommended for this to be developed using Business Process Management Notation (BPMN).
- Automate the process model into an executable process. E.g. transform the BPMN model into Business Process Execution Language for web services (BPEL4WS): a Business Process Management Suite/System can be employed for this.
- Deploy the executable process by publishing the BPEL into a process engine/process server for execution.
- Define and develop the integration between the change system and the repository using SOA and Web Services technology.

The eRIM Framework showing all the constituent components and their interrelation is depicted in Figure 7.18.

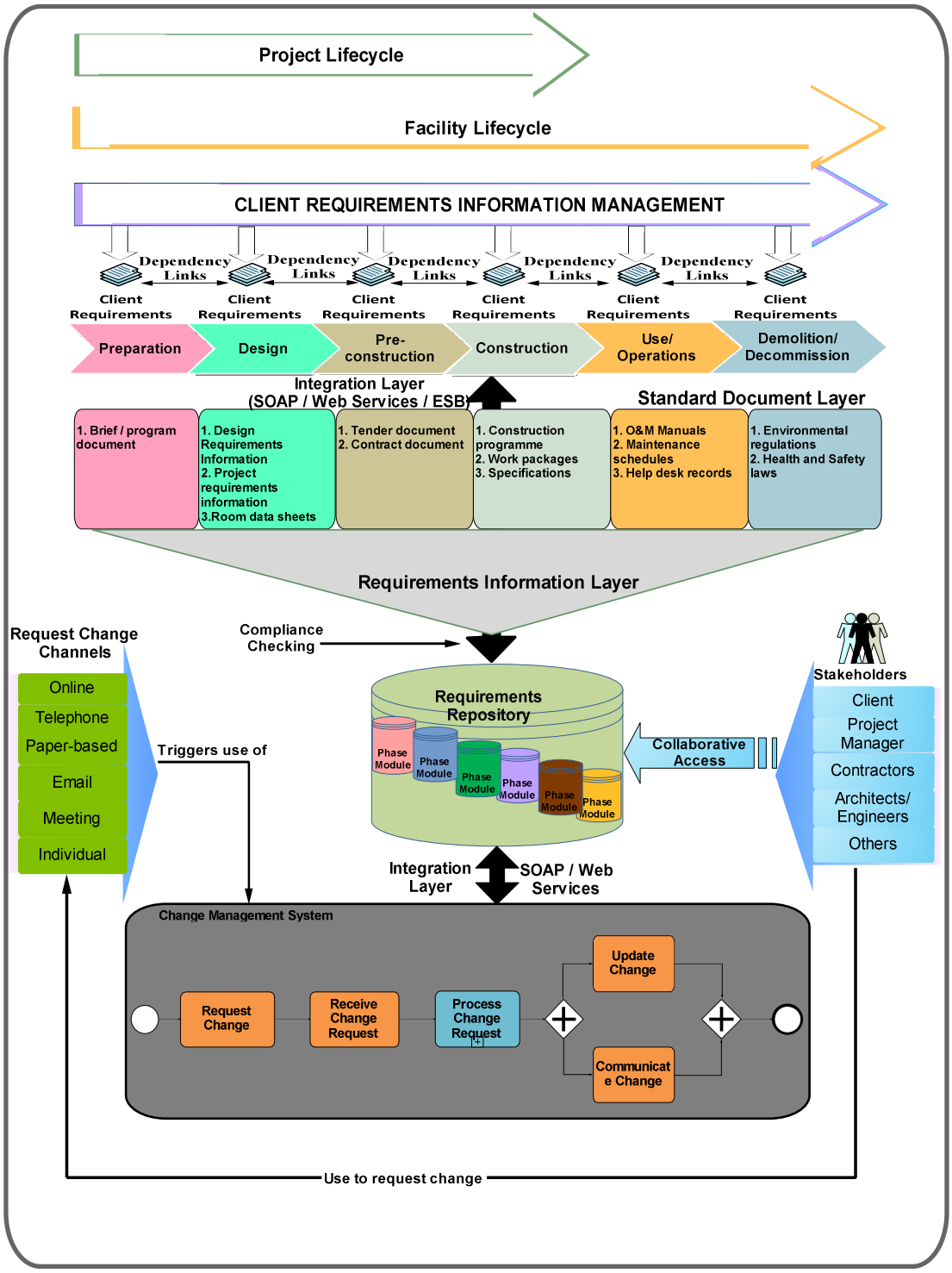


Figure 7.18: The architecture of the innovative and integrated eRIM Framework showing all the constituent components

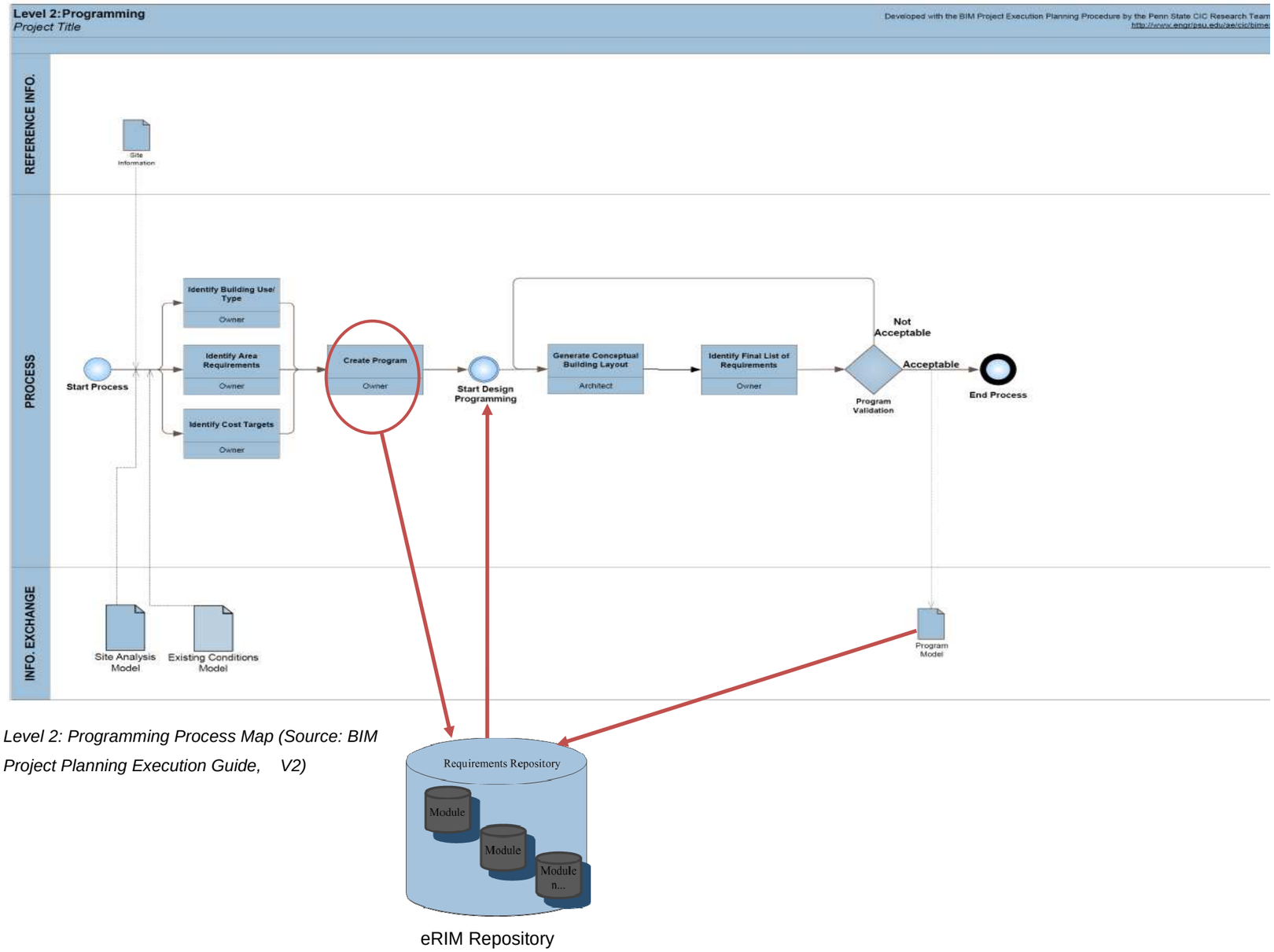
7.4.4 Requirements Management Roles

This research identified that personnel from several functional areas within a construction project are currently responsible for capturing and managing the client requirements. The client, architect, consultants, project manager (PM), quantity surveyors (QS) and cost consultants (CC) play key roles in managing the client's requirements. The designer and contractor play a major role because they focus on transforming customer needs, expectations and constraints into design solutions and supporting them throughout the construction process. With the several parties involved, it becomes cumbersome to identify who is responsible for the management of the requirements. In other areas of the construction process, specific role(s) are created to be responsible for specific management tasks and activities. Within other product development sectors such as manufacturing, aerospace and software, '*Requirements Managers*' are hired specifically to be responsible for customer requirements (Schmidt and Souza, 2007). Within the construction industry, there is currently no standard role responsible for specifically managing client requirements. Given the difficulty of managing client requirements, it is recommended that introduction of 'Requirements Manager' role be incorporated within the project team which is important in contributing towards successful projects. Similar recommendation was made by Lee and Egbu (2008) who state that the appointment of capable expert consultants is important to ensure that client's project requirements are fully met.

7.5 Interaction between Project Phases and the Requirements Repository

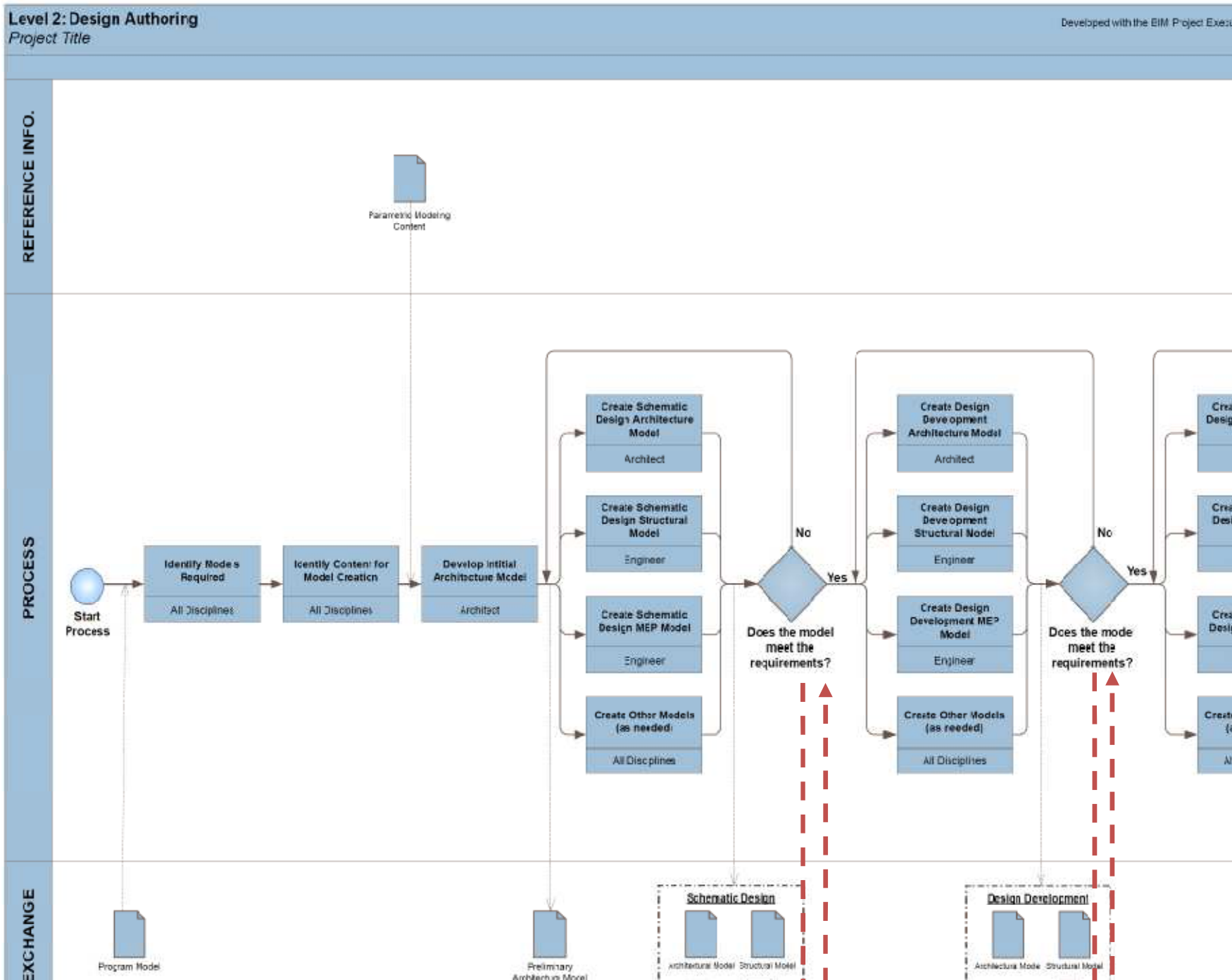
Multiple construction process activities take place during a project and through-life of a building during which a large amount of information is produced containing client requirements. One important aspect of project management is the focus on the management of client requirements. These are made up of large amount of information that is needed throughout a project by different stakeholders in multiple and distributed locations. The eRIM Framework defines an integrated and centralise repository of

requirements through an information management system to support the construction management process. The main driver for this is the fact that requirements are documented and archived using paper copies and manual processes. This proves to be laborious and error prone; inefficient and ineffective for sharing and distributing information in a distributed environment. This research identifies the various stages of the construction process at which to capture the information and store it within the repository and also to retrieve requirements information to be used during the construction activities. The process maps defined in the BIM Project Planning Execution Guide (The Computer Integrated Construction Research Group, 2009) are used for demonstration purposes; and to show how eRIM Framework can be used in practice. Figure 7.19 demonstrates how some *programming activities* as defined by BIM Project Execution Planning Guide can interact and be integrated with eRIM. It shows program document being archived in eRIM repository which can then later be accessed by designer when the design process begins. This access can be facilitated through Web Services as earlier discussed in Section 7.4.2. It clearly shows eRIM serving as a requirements model to archive requirements information and also as an access point. In Figure 7.20 interactions between *design authoring activities* as defined by BIM Project Execution Planning Guide with eRIM is demonstrated. Dotted lines between decision points within the lifecycle activities and eRIM indicate requirements compliance checking. For example, in order to determine if design meets requirements, the process needs to check the requirements information within eRIM which will provide feedback. Similarly, these interaction points need to be defined at any level within the project phases where there is the need to either store or access requirements.



Level 2: Programming Process Map (Source: BIM Project Planning Execution Guide, V2)

Figure 7.19: Interaction between project programming activities and eRIM Repository


Level 2: Design Authoring
Project Title
Developed with the BIM Project Exec
REFERENCE INFO.
PROCESS
EXCHANGE
Parametric Modeling Content
Start Process
Identify Models Required
All Disciplines
Identify Content for Model Creation
All Disciplines
Develop Initial Architecture Model
Architect
Create Schematic Design Architecture Model
Architect
Create Schematic Design Structural Model
Engineer
Create Schematic Design MEP Model
Engineer
Create Other Models (as needed)
All Disciplines
No
Yes
Does the model meet the requirements?
Create Design Development Architecture Model
Architect
Create Design Development Structural Model
Engineer
Create Design Development MEP Model
Engineer
Create Other Models (as needed)
All Disciplines
No
Yes
Does the model meet the requirements?
Program Model
Preliminary Architecture Model
Schematic Design
Architectural Model
Structural Model
Design Development
Architectural Model
Structural Model

7.6 Summary

In this chapter, the Electronic Requirements Information Management (eRIM) Framework was presented and described. It defines a lifecycle approach to managing information about client requirements. The Framework is *information-centric*, *process and service-oriented* and comprises two main components; a *requirements repository* and *change management system*. Based on the combination of the advantages of web database systems and business process management, the Framework expands the scale of traditional client requirements management to include a lifecycle approach from a process management perspective. This approach identifies requirements at each phase of the project. Requirements information derived from each phase is stored in the repository with related requirements mapped using a unique identifier. This ensures traceability between requirements which is crucial in enabling dependency checking to facilitate impact analysis when considering change requests. The change management system provides clear control and coordination of the change request process and contributes towards historical knowledge on all changes that occurred during a building lifecycle.

The expected benefits of eRIM are to contribute towards enhancement of an integrated project team (client, contractors, users, constructors, suppliers, etc) and processes (from programming, design, construction all the way to operation and demolition or decommissioning). This could contribute to waste reduction and improve the quality of built facilitates. The applicability of the Framework was conducted through the implementation of the prototype and evaluated through a focus group as discussed in Section 8.7. The Framework formed the basis for the design, development, implementation and evaluation of the prototype system which will be discussed in the next chapter of the Thesis. The prototype was developed based on the IT tools and technologies identified and reviewed in Chapter 4 of this Thesis.

Chapter 8. **Prototype Development and Evaluation**

8.1 Introduction

This chapter presents in detail the development of the prototype system and the technologies utilised for that purpose. The integrated requirements information management system based on the eRIM Framework was developed as a prototype. It was developed to implement and operationalise the eRIM Framework as a proof-of-concept. This chapter will first present an outline of the development process including the technology and the system architecture and infrastructure used in the development. Secondly, the Chapter reports on the evaluation which included initial test runs and an industrial evaluation through a focus group to demonstrate its applicability. A description of its operation (*i.e., how the system functions when being operated by users*) is also presented. The benefits and limitations of the prototype have also been discussed.

8.2 Aim and Objectives of the Prototype System

The development of the prototype is one of the objectives of this research. Its aim is to implement and operationalise the Framework. The client requirements information management process must be practiced with a broad understanding that it falls within a larger context of project information which must be effectively documented and efficiently managed. Analysis of the case studies indicated that an integrated and centralised storage of client requirements information and a change management system were needed for a better approach to requirements management. A web database system was designed and developed to serve as an integrated repository of client requirements and to enable collaborative, distributed and shared access through the Internet. A BPM system was developed to serve as the change management system.

According to McNurlin et al. (2008), a live '*work-in-progress'* system that may be implemented as an actual production system of some variant is referred to as a software prototype. The main aim of developing the prototype system

was to implement the eRIM Framework formulated to define a better approach to client requirements information management. The prototype also demonstrates how the techniques of requirements information management as defined could be transformed and implemented into a computer-based information management system. In order to achieve the implementation of such a system, the following objectives were identified.

- Develop and implement a web database system to serve as the client requirements information repository. This system will contribute towards facilitating collaborative and distributed access to client requirements information in a construction project.
- Facilitate the efficient and effective management of request for change by implementing a change management system based on BPM.
- Facilitate seamless information sharing/exchange between the web database and change management systems through integration and interoperability of the two.
- Serve as a *decision support tool* of requirement changes and impact analysis of cost and time.
- Provide distribute requirements related work management between teams in different geographical locations.
- Enhance auditability and history of all requirements and facilitate compliance, performance measurement and management relating to requirements management activities.

It has already been discussed that eRIM defines a lifecycle approach to management of client requirements information. However, as a prototype system serving as a proof-of-concept of eRIM Framework, it did not implement management of requirements information at all lifecycle phases. Nevertheless, the implementation covers the two earlier lifecycle phases: *preparation and design*. It is anticipated that the implementation and demonstration of managing requirements information at those two phases would be sufficient to prove the concept defined in eRIM Framework.

8.3 System Architecture and Development

8.3.1 System Development Environment

Based on analysis of available tools and technologies, it was decided that open source software and technologies be used as the environment for the development of the prototype. This choice was based on the ideology of cutting down costs especially with limited budget as observed by Hartmann and Hartmann (2010). Developer support was also another major reason for the selection of open source software development environment because of the many support groups and forums available online. Since the prototype was to implement the Framework, it did not require the use of expensive and complex technology. As a result, MySQL (a free database management system based on structured query language (SQL) for database manipulation) was used as the Relational Database Management System (RDBMS), Apache as the web server to provide Hypertext Transmission Protocol (HTTP) services to enable access through the Internet and *Hypertext Pre-processor (PHP)* as the web scripting language to develop the web interface as shown on Figure 8.1.

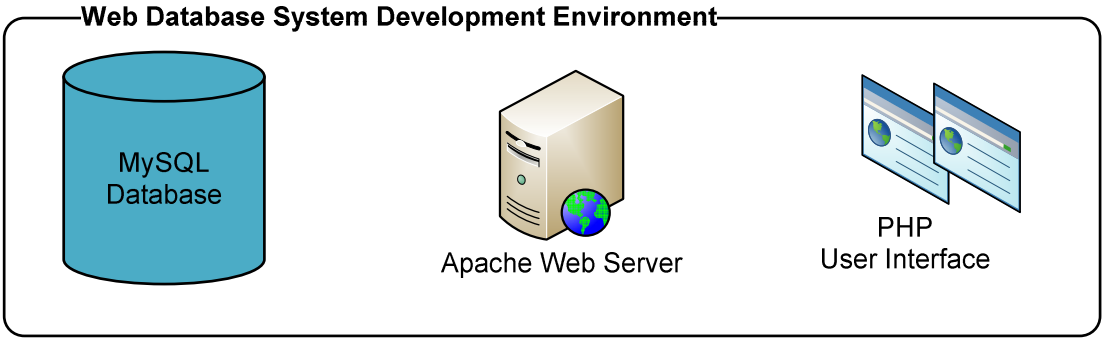


Figure 8.1: Components of the development environment for the web database system

A change management system was developed to provide cohesive coordination and control of the change request process. Open source was again the preferred development environment. A review was conducted of selected open source BPMSs in Section 4.1.6 and consequently, *'Intalio Works'* BPMS, comprising a designer/modeller & Server was used as the BPMS to develop the CMS. Intalio BPMS is designed around the open source

Eclipse BPMN Modeler, Apache ODE BPEL engine, and Tempo WS-Human Task Service (Intalio Inc., 2010). It has two different editions (Community and Enterprise) with the former offered completely free though with limited features. However, the features offered in the community edition were sufficient for the development of the CMS as a prototype. The Intalio process designer which is powered by Eclipse is an integrated development environment. It supports the work of, and can be used by business analysts, software engineers, and system administrators; to model business-level processes, their binding onto external systems and user interfaces, and their deployment onto the BPMS Server for execution (Intalio Inc., 2010). Figure 8.2 shows the different technology components discussed earlier that comprised the prototype system.

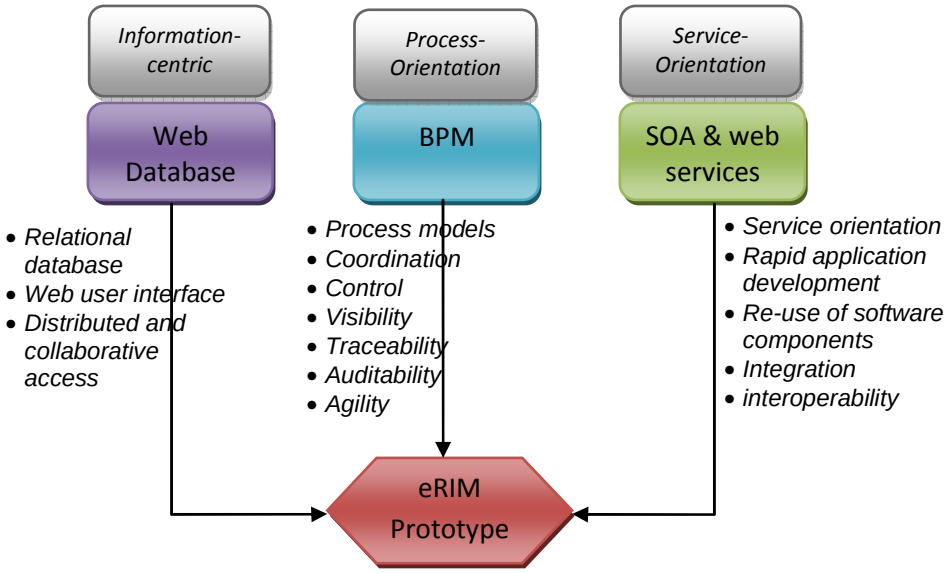


Figure 8.2: Components of eRIM Prototype System

Systems integration and interoperability are key intended features of the prototype. Consequently, this was implemented through service orientation and the use of web services technology. Information flow (access, share/exchange and document) was achieved through SOAP message request and response mechanisms.

8.4 Systems Analysis, Design and Development

8.4.1 End User Requirements

8.4.1.1 Business Rules

In order to establish the end user requirements of the system, it was crucial to identify the core business processes of requirements management process and to understand the business requirements of the system. “A business rule is a statement that defines or constrains some aspect of the business (Von Halle, 2002).” According to Atzeni et al. (1999), business rules are amongst the tools information systems analysts use to describe properties of an application that otherwise cannot be directly articulated with a conceptual model. Logical database designers are often concerned with identifying data entities, relationships and attributes and the constraints on the data (sometimes called business rules) to be stored in the database (Connolly and Begg, 2010). They describe the main characteristics of the data and constitute a form of documentation of a conceptual schema (Connolly and Begg, 2010; Von Halle, 2002; Atzeni et al., 1999). Database entities, attributes and relationships as well as their integrity constraints are described by the conceptual schema. Identification of business rules is crucial in database design and to create data models. Consequently, the business rules were defined which explicitly helped identification of the different actors, their relationships and a conceptual view of the interactions between them. They were established through observation of the requirements management process, examination of requirements and their related documents such as brief and change order forms amongst others as well as interviews with clients (or their representatives) and project managers. Some of the business rules that were derived for the purpose of developing the prototype system for the two lifecycle phases (preparation and design) are as follows.

- Client initiates a construction project
- Client appoints contractors for the project
- A project is made up of different phases
- A Phase has sets of requirements

- A project comprises of many different stakeholders and team members
- A Client states his/her requirements
- Primary requirements can have several secondary requirements
- Requirements are assigned priorities
- Every requirement has a rationale
- A team member can add/edit/view a requirements information (depending on the role)
- Requirements are transformed into design information
- Every requirement can change several times
- A client, designer or contractor can *request* a requirement change
- A request for change goes through an authorisation process
- Changes are approved by the client or client representative

Based on the business rules of the system, a *schema* (Figure 8.5) of the database was developed. However, only those business rules relevant for the implementation of the prototype were used. A use case diagram (Figure 8.3) was developed. Use case diagrams play an important role in systems analysis and design as they represent the interaction between users and the intended information system to be developed (Maciaszek, 2007; Hoffer et al., 2007; Shelly, 2006) and are a principal visualization technique for behavioral model of systems (Maciaszek, 2007). Use case diagrams have two major elements (actors and cases). The actors represent users of the information system with specific roles describing how they interact with the system. The intended goals of the users or the activity they perform on the system are the cases (Maciaszek, 2007; Hoffer et al., 2007; Shelly, 2006). The use case diagram demonstrated the functional requirements of the prototype system.

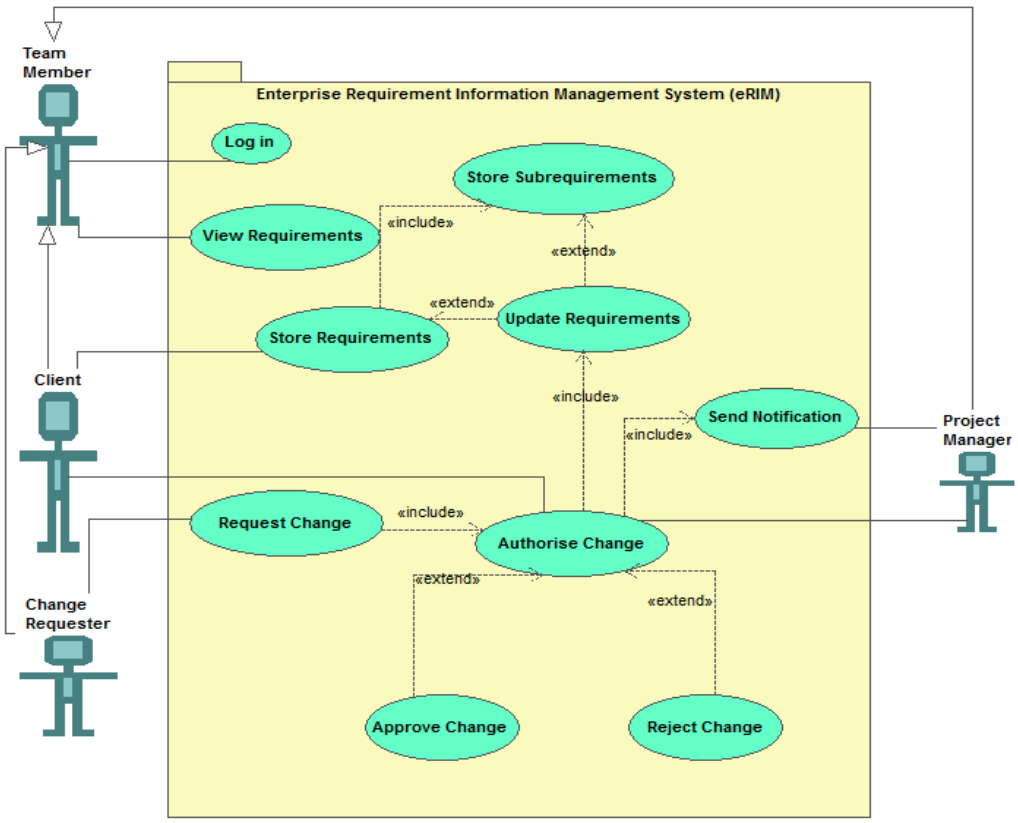


Figure 8.3: Use case diagram of eRIM prototype system

8.4.2 Requirements Repository – Web Database System

As discussed earlier, a MySQL database was developed to serve as the requirements repository. Analysis of the client requirements management business rules helped better understanding of the user requirements of the web database. This resulted in the development of the database schema (Figure 8.5) and the production of the database including tables (to store requirements information), queries (to manipulate the data), and forms (to enable user interaction with the database). For the purpose of this prototype, only the tables and views necessary to process requirements information at the preparation and design phases of a construction project are implemented and demonstrated. These tables were created using MySQL scripts, an example of which is shown in Figure 8.4.

```
CREATE TABLE IF NOT EXISTS `primary_requirement` (
  `requirement_id` int(5) unsigned NOT NULL AUTO_INCREMENT,
  `space_type` varchar(100) CHARACTER SET utf8 NOT NULL,
  `description` varchar(500) CHARACTER SET utf8 NOT NULL,
  `estimated_number` int(3) DEFAULT NULL,
  `rationale` varchar(100) NOT NULL,
  `priority` varchar(10) DEFAULT NULL,
  `project_id` int(5) unsigned NOT NULL,
  `related_requirementID` int(5) unsigned DEFAULT NULL,
  `phase_id` int(5) unsigned NOT NULL,
  PRIMARY KEY (`requirement_id`),
  KEY `project_id` (`project_id`),
  KEY `phase_id` (`phase_id`),
  KEY `related_requirement` (`related_requirementID`),
  CONSTRAINT `FK1_ProjectID` FOREIGN KEY (`project_id`) REFERENCES `project` (
`project_id`) ON DELETE CASCADE ON UPDATE CASCADE,
  CONSTRAINT `FK2_RelatedReq` FOREIGN KEY (`related_requirementID`) REFERENCES
`primary_requirement` (`requirement_id`) ON DELETE CASCADE ON UPDATE CASCADE,
  CONSTRAINT `FK3_phaseId` FOREIGN KEY (`phase_id`) REFERENCES `phase` (`phase_id`) ON
 DELETE CASCADE ON UPDATE CASCADE
) ENGINE=InnoDB AUTO_INCREMENT=15 DEFAULT CHARSET=latin1;
```

Figure 8.4: MySQL table (primary_requirement) creation

Several different tables are developed amongst which are: '***primary_requirement***' to hold the initial brief information at the preparation phase, '***secondary_requirement***' to hold requirements information at the design phase such as individual room data sheets. Since requirements are open to changes during the project development and all through life, another table '***changes***' was also developed to hold all requirements change information. Users of the web database system are registered and held on a table '***team_member***'. This table holds information about users such as name, authentication information (username and password), Email address and project role. The 'Email' address field is necessary for automatically sending notifications. The '***project***' table holds information on an individual project whose requirements will be managed. As can be seen in Figure 8.4, the attributes of the requirements table include '*rationale*' and '*priority*'. These have been discussed in the analysis (Section 6.3.4), that they were not initially included in the briefs of the case study projects. Following critical analysis of the briefs and understanding the requirements for better requirements management, this research identifies the essence to include these two attributes about requirements. As a result, they were included and implemented in the prototype.

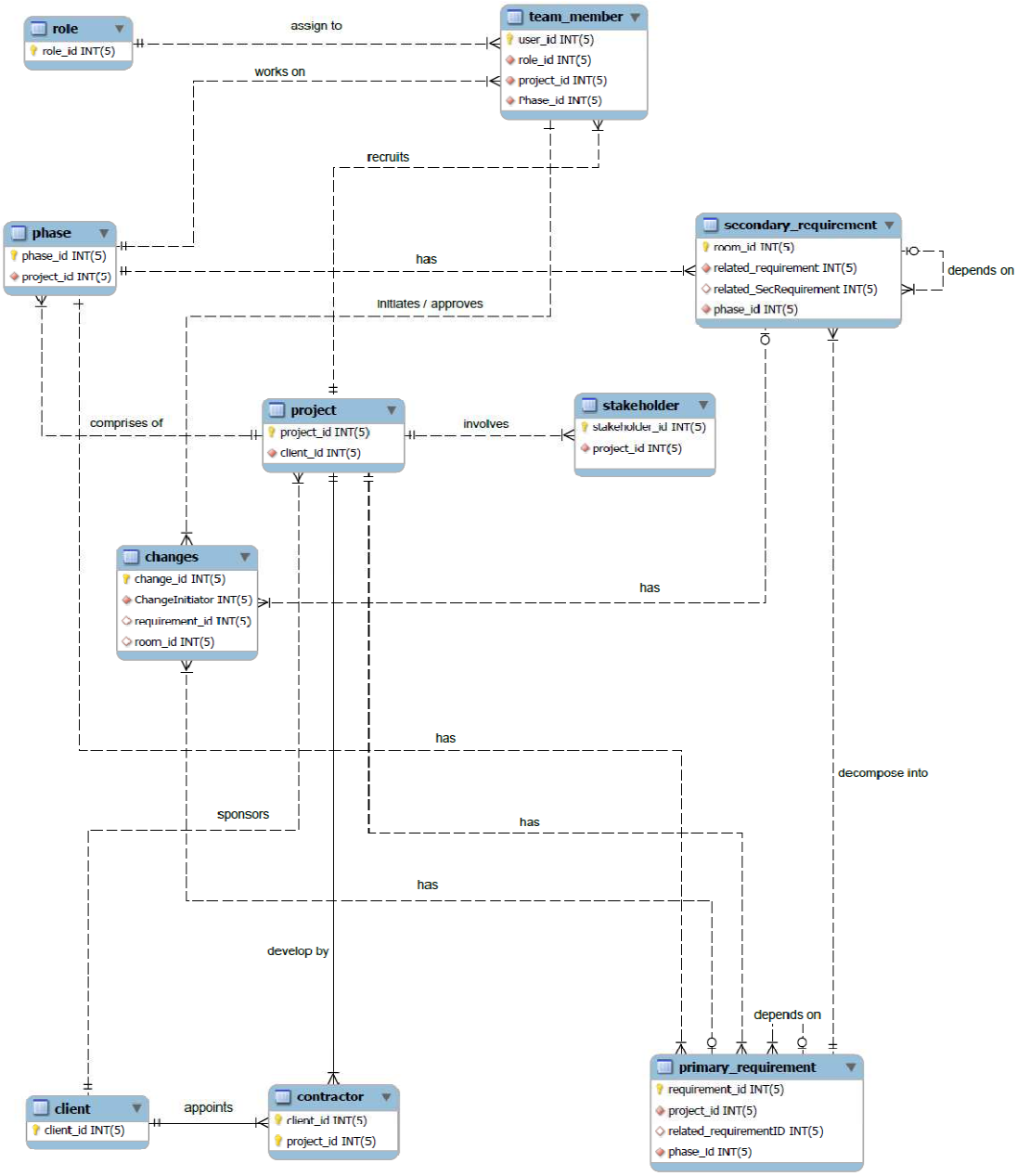


Figure 8.5: Entity relationship diagram (ERD) of eRIM database using the crow's foot notation

MySQL Workbench, an integrated tool for database design and modelling amongst other, was used to produce the ERD (Figure 8.5). The tables on the model show only the 'key attributes' (i.e., primary and foreign keys) for simplicity of reading the model. Using the MySQL Workbench output, the relationships (i.e., Identifying and nonidentifying) between the tables are

indicated with *solid* and *dotted lines* respectively (Oracle, 2011). The solid line is used where a foreign key in a table forms part of the primary key of that table. For example in the relationship between the *'project table'* and the *'contractor table'*, the foreign key *'project_id'* in the *'contractor table'* forms part of its primary key. A dotted line indicates a relationship where a foreign key of a table does not form part of the primary key of that table. For example, the foreign key *'role_id'* in the *'team_member'* table does not form part of its primary key.

In order to provide traceability between requirements and room data sheets, two approaches were developed. These are relations and dependencies between the primary requirements and secondary requirements. Relations between a secondary requirement and a primary requirement exist where a secondary requirement is fulfilling that particular primary requirement. For example in Case C, *small seminar rooms* were defined as a primary requirement in the initial brief. Subsequently, several small seminar rooms of different sizes were designed and specified in room data sheets during the design phase. In this case, traceability was developed between the small rooms in the room data sheets (secondary requirements) and the particular primary requirement in the brief which specified for small seminar rooms. This traceability was implemented by creating a link between the two tables ('primary_requirement' and 'secondary_requirement'). This is a catalyst for creating traceability between related primary requirements and room data sheets. Accordingly, a unique identifier was used as a 'mapper' linking each requirement to the room data sheets. The mapper is a 'primary key' which uniquely identifies a requirement. In this way, both forward and backward traceability can be provided between requirements information at each project phase. All changes to the requirements are stored in a separate table (*changes*) which is also linked to the 'primary_requirement' and 'secondary_requirements' tables. Dependency links were created between individual primary requirements where there is dependency, and between primary requirements and secondary requirements. Figure 8.6 shows a view

of dependency between a primary requirement and a secondary_requirement to demonstrate how the two are linked.

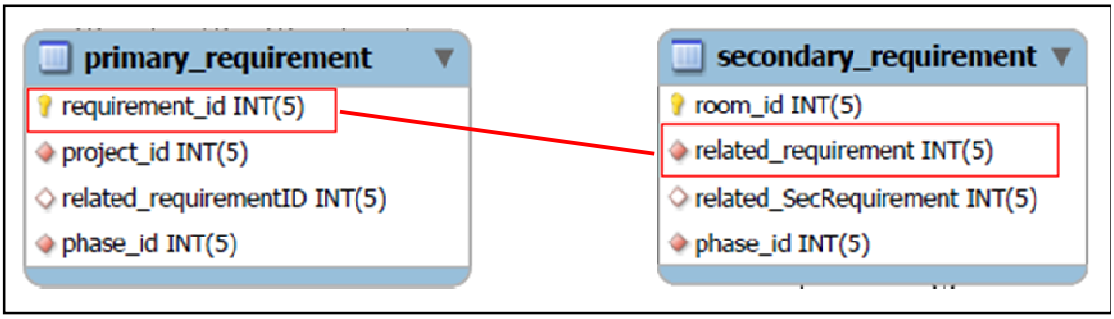


Figure 8.6: Dependency link between primary requirements and secondary requirements

Web based forms were developed in the user interface to enable users to add, view and update information to any table. Password protection was used to control access. Each user is granted access rights depending on roles which determine how an individual interacts with the system such as add, view, edit, delete, request change, authorise change, etc.

8.4.3 Change Management System

Three key criteria for an effective and efficient requirements change management system were identified.

i. The ability to perform dependency checking of changing requirements.
ii. Facilitation of cost and time impact assessment of changes.
iii. Update requirements information within the repository after the authorisation process.
iv. Communication and dissemination of the change information within the change management system and also as Email notifications to all those concerned.

These criteria have been met by the prototype system and are incorporated and implemented as features within the CMS.

8.4.3.1 The Process Model/Map

The change management system was developed using Intalio BPMS. The development started by modelling the change request process of the case studies described in this research. The inbuilt process designer (Intalio Designer) within the BPMS was used as the modelling tool which is based on BPMN. General consultation was done with the project managers to determine the structure of the project organisations and the activities of the requirements management process. This also included consultation on the various actors, tasks and information sources of the change request process. The process map described the activities, tasks, steps, resources, participants/actors (both humans and system) and information flow of the change request process. The process map was then transformed into an executable BPEL process; deployed and executed through the process engine/server.

Two different types of pools exist: ***'executable and Non-executable'***. As shown on the process model (Figure 8.14 and 8.15), six pools namely: ***'PMB', 'ChangeInitiator'***, ***'Consultants'***, ***'ChangeProcess'***, ***'Stakeholders', 'Database'*** were developed. Each of the pools represents a participant with specific functionality within the entire request for change process as follows.

- PMB': this is a pool representing members of the Project Management Board (PMB) who do the final review and authorisation of a change request.
- 'ChangeInitiator': this is a pool representing any participant within the request for change process who can request for a change. This can be a client, designer, contractor or any other project team member. Subsequently, any task within this pool can be performed by any person whose role can request a change.
- Consultants': this is a pool representing any participant from the consulting firm within the request for change process who reviews

change requests and analyse impact on time and cost on behalf of the client.

- ‘ChangeProcess’: this is the nerve centre of the process (i.e., it handles the request for change process activities that are performed by the process engine) and controls the interactions of tasks between different pools. In other words, this pool is an automated pool containing the activities that the process engine handles. BPEL codes will be produced from this pool and is referred to as an ‘executable pool’. Tasks in this pool are performed automatically by the process engine.
- Stakeholders’: this is a pool representing any participant within the request for change process from the client organisation, who reviews change requests and make the initial authorisation.
- ‘Database’: this is an automated pool in which tasks are performed by system participants. All the tasks within this pool are automated and performed by the developed web services as tasks within process steps that interact with the requirements repository. Such tasks include checking for dependency, sending Email notifications and updating the repository with change information. These tasks are invoked and performed automatically by the process engine without any human intervention.

The tasks developed in the process model (Figure 8.14 and 8.15) are modeled in rectangular shapes; named according to the task they represent and are placed within the pool in which they are to be performed. Those that are performed by the ‘process pool’ (i.e., the ChangeProcess) are blank shapes without any decorations in them whilst those performed by the other pools (PMB, ChangeInitiator, Consultants, Stakeholders and Database) have decorations/annotations. These give a lot of information and indicate what type of service operation is being invoked. In some cases, they indicate if a task is automated (i.e., if it is a task to be invoked and performed by a system) or not; some annotations could also indicate tasks which humans perform by completing a form (carrying information) attached to it. Tasks are also linked between pools with ‘dotted-lines’ showing how they interact

through information flow between them. Tasks are also linked together within a pool with a 'solid line' which shows the 'process flow' and not data/information flow. The following annotations in Table 8.1 are used in the process model as described according to Intalio Inc. Two gateways have been used within the process model (i.e., the 'AND' gateway and the 'OR' gateway). The 'AND' gateway which can be used for a 'parallel split' and 'join' was used where the process needs to branch into two or more parallel tasks each of which executes concurrently and where convergence of two or more tasks is required respectively. In a different approach, the 'OR' gateway was used where a decision was to be made in order to decide the process flow.

Table 8.1: Annotations and their descriptions as used in the process model

Annotation	Description
	Means that the task first sends a message (green arrow) and can optionally receive an answer (blue arrow); it invokes a request-response operation.
	Represents a WSDL operation (request and response) that is bound to a defined endpoint.
	Indicates messages of type 'request'.
	Indicates messages of type 'response'.
	Indicates a process people form attached to the task as a service.
	Indicates an 'AND' gateway where forking and joining can take place.
	Indicates an 'OR' gateway where decisions can take place.

8.4.3.2 Forms

Web-based forms were created to enable input and display of information during process execution. These forms could also be used as services on the process model. The following forms were created using the modeler in Figure 8.7 is displayed.

- RequestChange: used by a change initiator to request a change by filling in the required information.
- Dependency: used in the process to display the requirementID and space type of the changing requirement.
- Dependents: used to show all requirements information relating to the changing requirement.
- Notification: used by the process to convey results of the change request to the initiator.
- ImpactonCost: used by an authorise person to review, assess and indicate cost impact of a change request.
- ImpactonTime: used by an authorise person to review, assess and indicate time impact of a change request.
- FMApproval: used by an authorised person from Facilities Management (FM) to review and authorise a change request.
- FMNotification: used by the process to convey results of the approval from FM approver.
- FinalApproval: used by an authorise person on behalf of the Project Management Board (PMB) to review and provide the final authorisation of a change request.

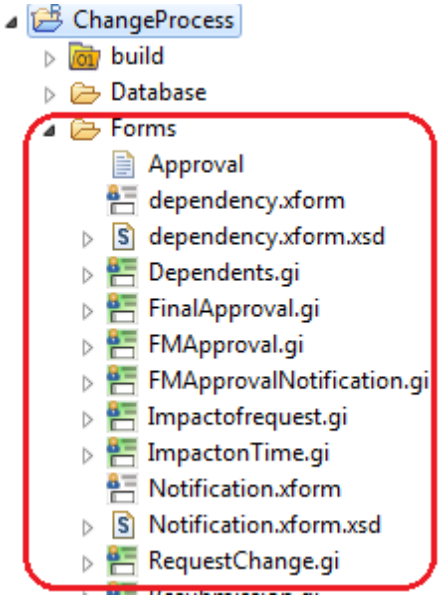


Figure 8.7: The process explorer showing the form folder with the forms

8.4.3.3 Services

As discussed earlier in Section 7.4.3, eRIM recommended the use of SOA philosophy and Web Services technology to system development and integration. The change request process was broken into tasks that can be implemented as services. Consequently four web database operations were developed as *services* and transformed into web services in order to be invoked and consumed within the change management system. The services were internal web services, thus they were not published into a UDDI because both the database and the change management system are internal applications. The change management system which needed to consume the web services knew their location and interfaces, and can consume them directly without having to search or ask a service provider for them. The services were *primary_requirement, primary_secondary requirement, requirements updater, Email.* They were initially scripted as SQL statements and then transformed into *web services* described in the WSDL files by the BPMS. It is important to note that the *primary_requirement* and *primary_secondary requirement* services are together form a composite service referred to as *Dependency Checker*. Therefore, both the two will be

discussed as dependency checker. These services perform different functions and are described as follows.

- Dependency checker: this is a composite service to be invoked within the BPM application at the '*check dependency*' task to enable an authorised person to review and assess the cost and time impact of a change request. The two services of the Dependency checker are shown on the *Database Pool* change process as '*primary_requirement service*' and '*primary_secondary requirement service.*' They are automatic tasks consumed by the sub-process called *Check Dependency* and performed within the 'database pool'. They enable the authorising agent to check dependencies of the requirement to be changed with other requirements in the repository. This will facilitate and enhance evaluation of the change and the assessment of cost and time impact as the dependency checker will reveal if any other requirement will be affected if the change is implemented. Once the services are consumed and dependency check completed, the process continues to the next task without the user realising if an external system (the requirements repository) has been utilised. These two services are implemented in the process model as shown in Figure 8.8.

  The *primary_requirement service*: this service as part of the dependency checker selects all primary requirements related to the changing requirement from the primary_requirement table of the database and feeds back that information to the change process.

  The *primary_secondary requirement service*: this service as part of the dependency checker selects all secondary requirements related to the changing requirement from the secondary_requirement table of the database and feeds back that information to the change process.

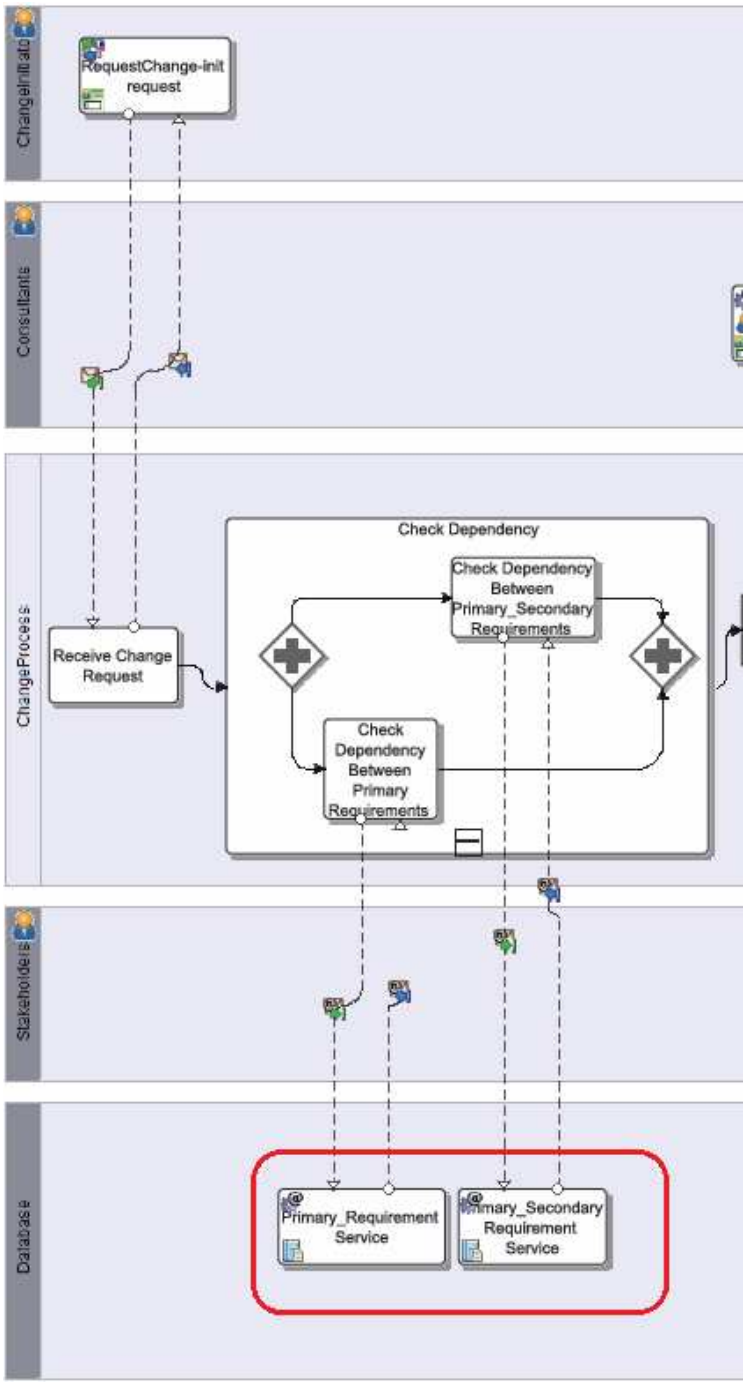


Figure 8.8: Dependency checker services mapped on the process model

Without the dependency checker, the cost and time impact assessors would need to check the repository manually for the dependencies. Similarly, without a requirements repository which takes a data/information-centric approach, the process would have required paper documents to be reviewed manually to check for any

dependencies. This could be cumbersome, manually intensive and time consuming. In some cases, no dependency would be noticed because of the inefficiency of going through large documents similar to document centric systems as in project extranets. An example of one of the dependency checking services (i.e., *the service which checks for dependencies between primary requirements and secondary requirements*), was developed as an SQL *select* statement with a wildcard (?) as a parameter (shown in Figure 8.9) to represent the changing requirement id. This statement was transformed into a web services as described in the WSDL file (Figure 8.10).

```
SELECT r.requirement_id AS "Requirement ID", r.space_type AS "Space Type",r2.* FROM
 primary_requirement AS r, secondary_requirement AS r2 WHERE r.requirement_id = ? AND
 r2.related_requirement = ?
```

Figure 8.9: The select SQL statement that queries the repository using a parameter value

```
 1: <wsdl:definitions targetNamespace="urn:abkaja.com:connectors:database:changeprocess:select
    service"
 2: xmlns:tns="urn:abkaja.com:connectors:database:changeprocess:selectservice"
 3: xmlns:soap="http://schemas.xmlsoap.org/wsdl/soap/" xmlns:wsdl="http://schemas.xmlsoap.org/
    wsdl/"
 4: xmlns:xsd="http://www.w3.org/2001/XMLSchema" xmlns:ns="urn:intalio.com:connectors:database
    :changeprocess:selectservice"
 5: >
 6:     <wsdl:types>
 7:         <xsd:schema>
 8:             <xsd:import schemaLocation="select.xsd" namespace="urn:abkaja.com:connectors:d
    atabase:changeprocess:selectservice"/>
 9:         </xsd:schema>
10:     </wsdl:types>
11:     <wsdl:message name="selectInput">
12:         <wsdl:part name="parameters" element="ns:selectParameterSet"/>
13:     </wsdl:message>
14:     <wsdl:message name="selectOutput">
15:         <wsdl:part name-"parameters" element-"ns:selectResultSet"/>
16:     </wsdl:message>
17:     <wsdl:message name="selectFault">
18:         <wsdl:part name="fault" element="ns:selectFault"/>
19:     </wsdl:message>
20:     <wsdl:portType name="selectPort">
21:         <wsdl:operation name="select">
22:             <wsdl:input message="tns:selectInput"/>
23:             <wsdl:output message="tns:selectOutput"/>
24:             <wsdl:fault message="tns:selectFault" name="nsselectFault"/>
25:         </wsdl:operation>
26:     </wsdl:portType>
27:     <wsdl:binding name="selectPortSoapBinding" type="tns:selectPort">
28:         <soap:binding style="document" transport="http://schemas.xmlsoap.org/soap/http"/>
29:         <wsdl:operation name="select">
30:             <soap:operation style="document" soapAction="urn:abkaja:connector:jdbc:query:s
    elect"/>
31:             <wsdl:input>
32:                 <soap:body namespace="urn:intalio.com:connectors:database:changeprocess:se
    lectservice" use="literal"/>
33:             </wsdl:input>
34:             <wsdl:output>
35:                 <soap:body namespace="urn:abkaja.com:connectors:database:changeprocess:sel
    ectservice" use="literal"/>
36:             </wsdl:output>
37:             <wsdl:fault name="nsselectFault">
38:                 <soap:body namespace="urn:abkaja.com:connectors:database:changeprocess:sel
    ectservice" use="literal"/>
39:             </wsdl:fault>
40:         </wsdl:operation>
41:     </wsdl:binding>
42:     <wsdl:service name="selectService">
43:         <wsdl:port binding="tns:selectPortSoapBinding" name="selectPort">
44:             <soap:address location="http://localhost:8080/ode/processes/ChangeProcess/Data
    base/select"/>
45:         </wsdl:port>
46:     </wsdl:service>
47: </wsdl:definitions>
```

Figure 8.10: The WSDL file of the select web service

The use of the wildcard is valuable so that the statement is dynamic and will work for any requirement. The dependency checker service queries the database by sending a SOAP message and returns the result as XML document. This would contain several data fields of the from the *primary_requirement* and *secondary_requirement* tables.

However, only a few of these fields are required for dependency checking and assessment purposes. As a result, data transformation was required to select only the required data fields for use on the 'dependents form'. Consequently, an XSLT file ('requirements.xsl') (Figure 8.11) was created to perform this transformation. According to W3C (1999), XSLT (a stylesheet language for XML) was designed for use as part of XSL, for transforming XML documents into other XML documents.

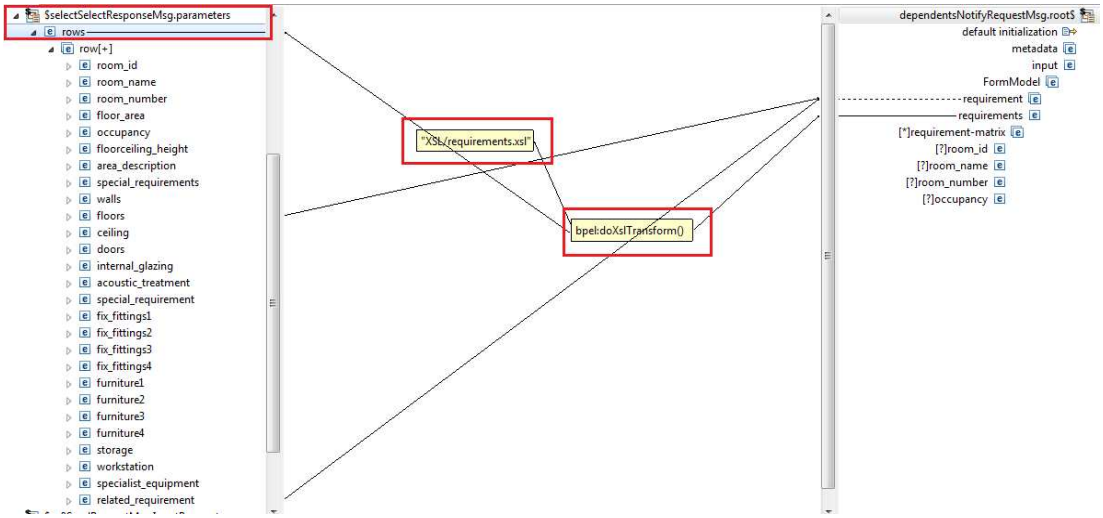


Figure 8.11: The mapper showing operators with XPath expressions

- Requirements updater: this is a service to be invoked within the process application immediately after a change is 'approved'. This is shown on the change process as '*update change information'* and is an automatic task. It enables the changing requirement information to be updated in the repository in real-time with the most recent information in the change request. Without this service, a user would have to input the changes manually in order to update the requirements with a new version in the database. This is implemented on the process model as shown on Figure 8.12.

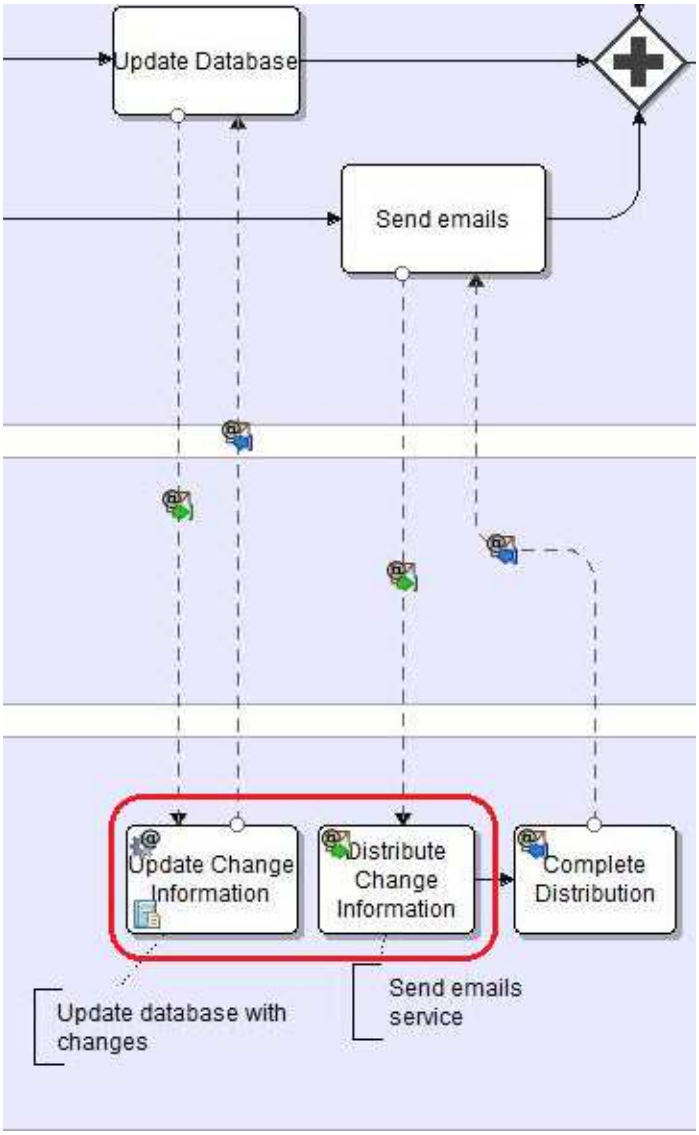


Figure 8.12: Requirements updater and Email notification services mapped on the process model

In some cases, no immediate update is made if a manual process was used thus creating a delay in updating information. Consequences of this are data inconsistency and invalidity in that a superseded requirement would still be in the database which could be used by other people. In a manual paper base system of requirements change management, having to update this change is virtually impossible on all instances of the original requirement as different instances would be located at different places. The service that sends the user emails

shown in Figure 8.12 was a service within the process engine and this research only made use of it.

- UserEmails: depending on the requirement that is changed and updated, a notification will be sent via Email to all those who may be affected by the changes. This service to be invoked within the process application enables the selection of the Email contacts of users from the repository. This is shown on the change process as *Retrieve Email Contacts* and is an automatic task. Without this service, the contacts will be selected manually. This is service is shown in Figure 8.13.

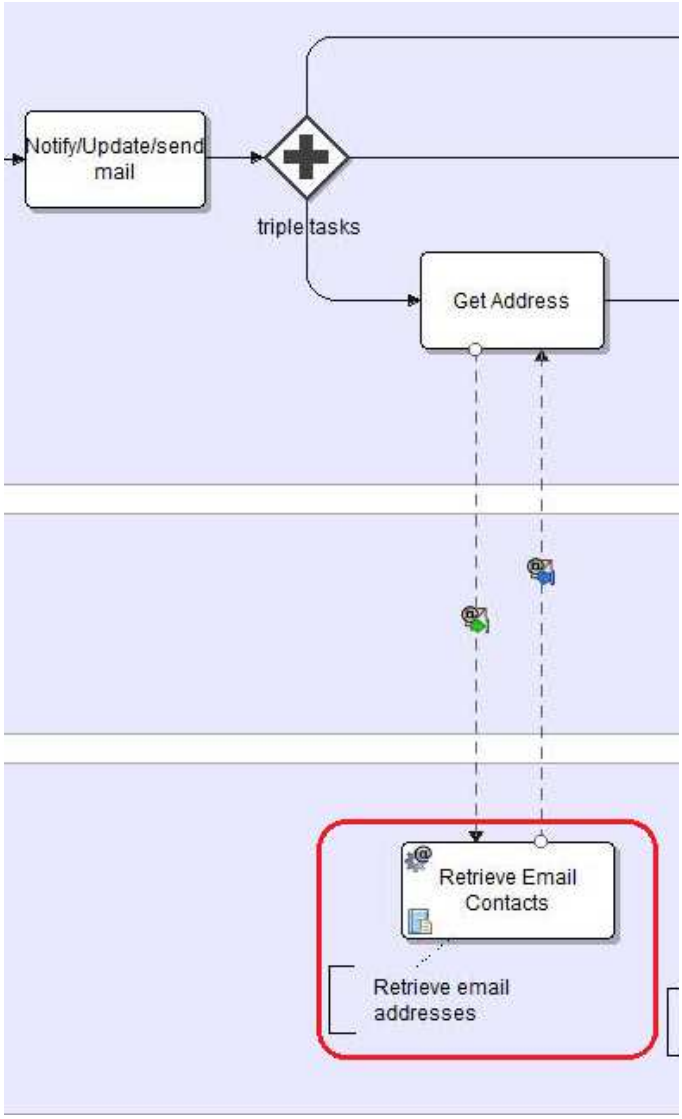


Figure 8.13: userEmails Service mapped on the process model

8.4.3.4 Process Deployment

Following the development of the process model (Figure 8.14 and 8.15) and all the required elements, it was deployed on the process engine for implementation and execution. The process engine is responsible for creating process instances and controlling the execution. This includes responsibility for scheduling and task management as well as routing and calling services. Once deployed, the process is ready for execution by logging onto the user interface framework to access the process execution.

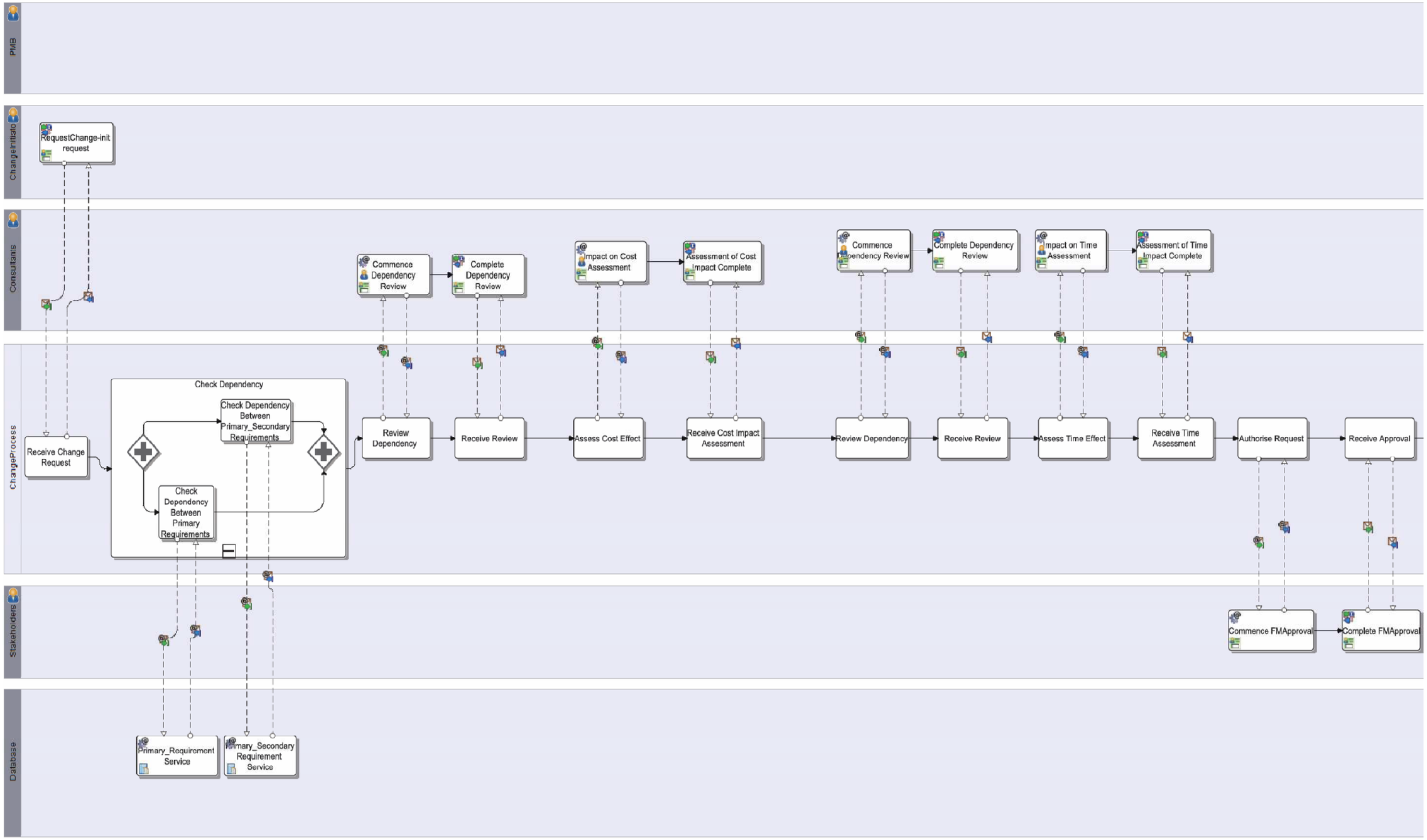
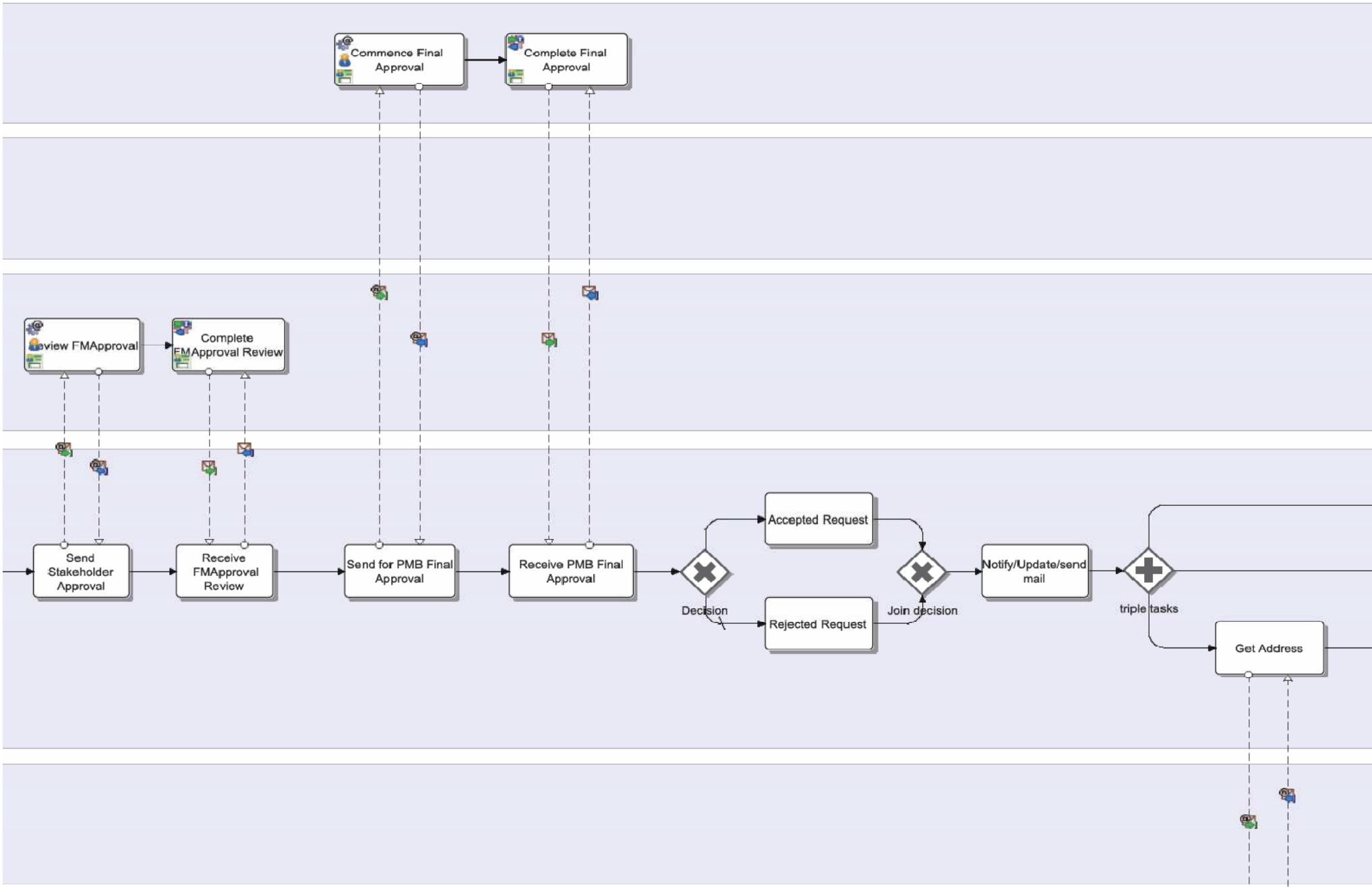


Figure 8.14: The Change Request Process Model - PART A


Commence Final Approval
Complete Final Approval
eview FMApproval
Complete FMApproval Review
Send Stakeholder Approval
Receive FMApproval Review
Send for PMB Final Approval
Receive PMB Final Approval
Decision
Accepted Request
Rejected Request
Join decision
Notify/Update/send mail
triple tasks
Get Address

8.5 System Operation and Evaluations

8.5.1 System Operation

8.5.1.1 Web Database System

Using their credentials (i.e., username and password), every user will be required to 'log-in' for authentication and to access the functionality of the web database system. Once this is done, users can navigate the system through the menu and perform various tasks depending on their role(s). This includes adding new primary and secondary requirements to the repository using web forms. During this process, dependency information (i.e., dependencies between: primary requirements; primary requirements and secondary requirements or between secondary requirements) would require to be completed on the forms (E.g., as shown in Figure 8.18). Users can also view and edit the information.

Change information can be stored on the repository but not directly through the web database system. This can be done only through the change management system following the change request process. This is important so that no change information is input onto the system without the request following the formal change request process using the change management system. It is also important to note that no change information can be deleted from the system once it has been stored. This is crucial for auditability and historical purposes.

8.5.1.2 Change Management System

Business processes can be run through the user interface by completing web forms. In principle, users interact and perform tasks assigned to them through the user interface; access process notifications and can initiate a process. On the main window of the user interface are three key links which are relevant for process execution. These are: '***tasks***', '***notifications***' and '***processes***'.

- ***Tasks***: will list any task assigned to and required to be performed by a user.
- ***Notifications***: will list process notifications which a user needs to be aware of.
- ***Processes***: will list all business processes which a user can access and execute. E.g., the requirements change process.

A user logs into the user interface and clicks on the '***processes***' link which opens a window displaying the '***requirements change request***'. By clicking on this link, the user is presented with the change request form which is used to initiate a change request. This form is filled and routed to the next activity in the process to be carried out either by a human or automatically (by a system). If the activity is a human workflow, the task will be listed under the ***'tasks'*** list when a user logs in. The process proceeds and before changes can be authorized, dependency of the proposed change has to be evaluated as a decision making task. This requires checking the database for all related requirements.

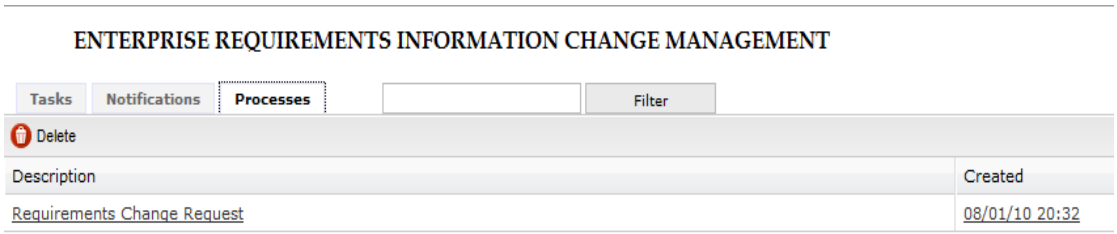


Figure 8.16: Change Management System (process) user interface

8.5.1.3 Dependency Checking

As a result, the 'Dependency checker', which is a SQL operation service, was invoked and consumed by the '***check dependency***' task of the change process. The '***dependency checker***' as web services then sends a SOAP message and queries the database based on the SQL parameters. The database returned query results which are then sent back as a SOAP response to the process. This information as an XML document is transformed using XSLT into a new XML document and displayed in a format

specified by the change management system, indicating the changing requirement and all other dependent requirements from the database as shown on Figure 8.17. The reviewing authority will be able to use this information to help assess and determine the 'cost' and 'time' effect of the change. The process proceeds until a decision on the change is reached.

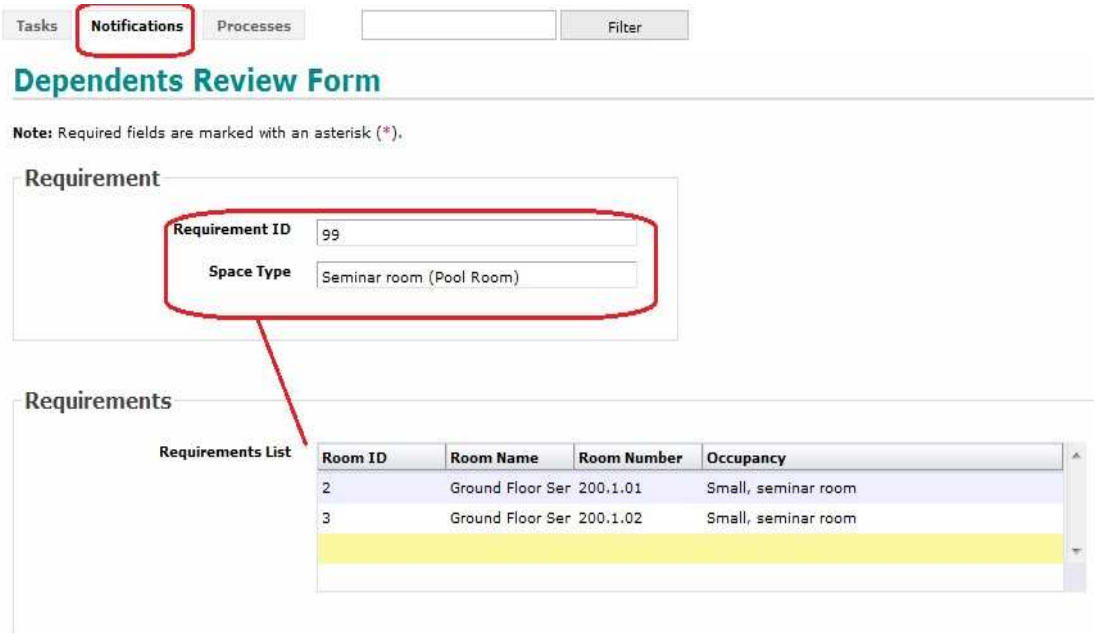


Figure 8.17: Dependency checking information

However, the 'dependency checker' query will only work if the right information is initially entered on Section 2, Part 1 of the 'ChangeRequest' form as described in Section 6.2.2.3 (IV). Particular and important information that should be completed on the form is the 'requirement Id' as highlighted in Figure 8.18. This is the primary identification attribute used as dependency link, and to query the database for related information (i.e., all dependent requirements) to the one requested in the change.

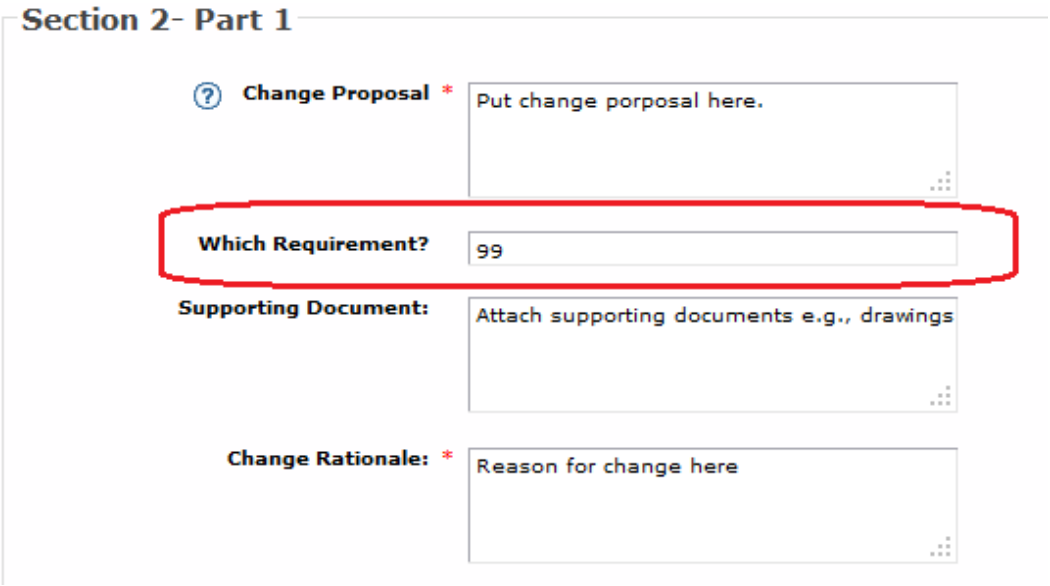


Figure 8.18: The ChangeRequest form showing the ID of the changing requirement

8.5.1.4 Notifications

Following the approval of a change request, the relevant team members receive Email notifications containing details of the changes. The '***send emails***' task of the change process invokes a built-in or an embedded web service (for sending Emails) within the server and consumes the '***send***' operation to distribute Email notifications. In order to implement this functionality, a dummy list of emails was created for test purposes.

Another notification is also sent to the change initiator into his '***Notifications***' box within the change management system. Once the person logs-in and clicks-on the '***Notifications***' link, another link called '***Change notification***' will be displayed which when clicked-on will render the notification form with all the necessary change information including the change proposal, and outcome of the authorisation.

8.5.1.5 Updating Requirements Repository

Simultaneously, as the notification is sent to the initiator of the request and notification Emails distributed, the database is also updated with the changes using the '***update database***' task of the process which is a system task performed by invoking and consuming a web service. The task invokes the '***insert***' web service which has been generated as a SQL command and transformed into a web service to insert data into a specific database table. This information is also sent as a SOAP message to the database which is then written to the 'change' table of the database. At the same time, the change request initiator is also notified of the decision on the change on the process user interface.

8.6 Integrated Portal

A single portal enables central log-in to different web-based systems. eRIM was designed with this intent (eRIM portal) to serve as the 'central access point' to both systems (repository and change management system), thus eradicating the need to switch between the two systems components. With the correct authentication, both systems can be accessed using the single log-in portal. Because Intalio BPMS supports Liferay, an open source enterprise portal, it was intended to be used to develop the portal. It must be stipulated that this aspect (i.e., the integrated portal) of the prototype was not fully implemented due to limitation of the community version of Intalio BPMS. Funding restrictions meant the research could only use the community version but an enterprise edition should be considered for further development of the system especially if commercial deployment is envisaged.

To facilitate integration and interoperation between the two systems (web database and change management systems), web services (*'dependency checker', 'requirements updater', 'Get requirements' and 'user emails'*) were developed as application services that perform specific individual tasks within the database. The WSDL documents of these Web Services were published to the internet and made it possible to reuse them as software components or

services in other systems. A MySQL database connection was established to enable the invoked web services to interact with the web database system. Figure 8.19 shows a graphical presentation of the system architecture.

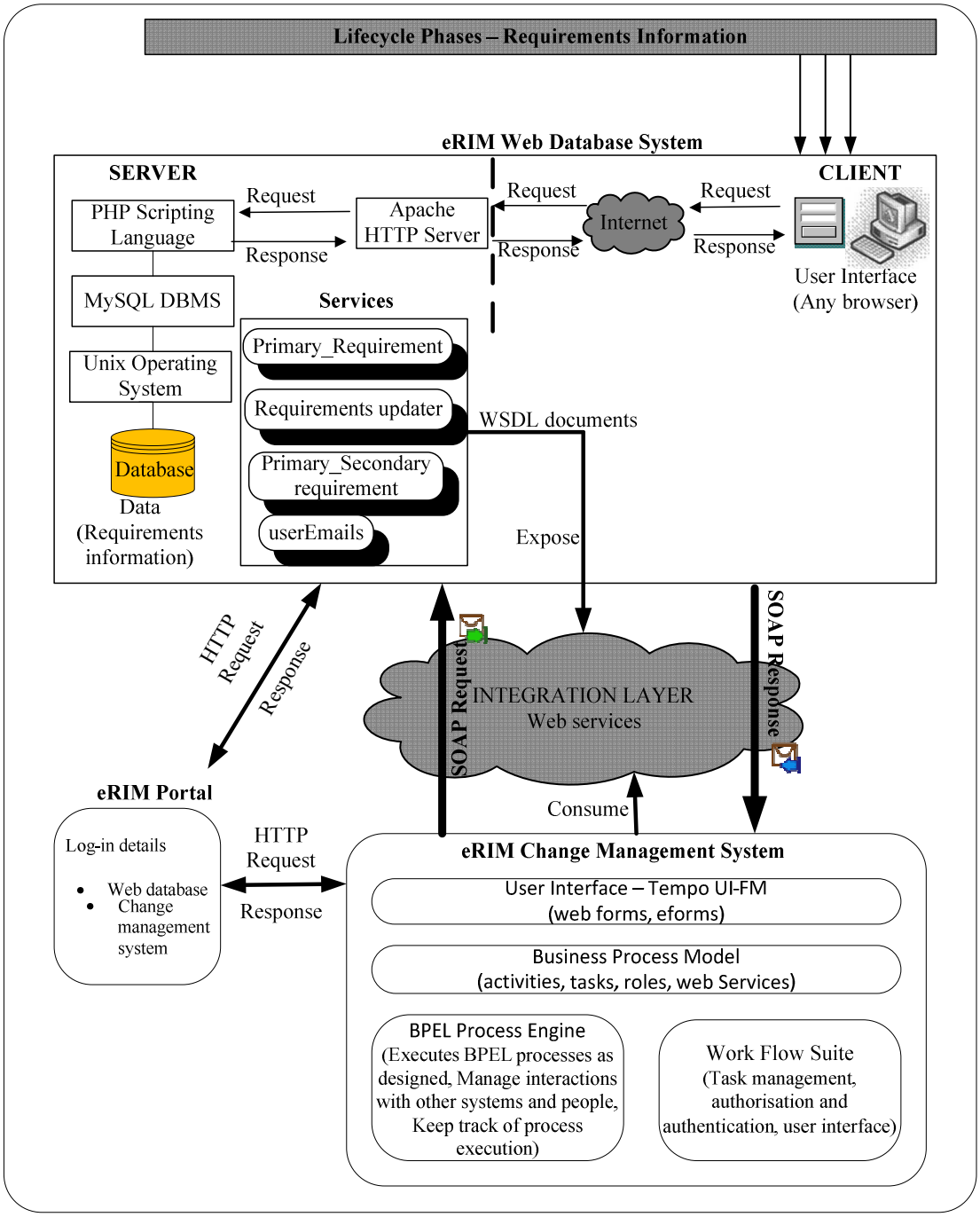


Figure 8.19: Architecture of eRIM prototype system

8.7 Framework and Prototype System Evaluation

8.7.1 Pilot Testing

Preliminary tests of the functionality of the system were carried out as the system was being developed from module-to-module. After the development of each module, tests were carried with the contribution of 'peer review' researchers. Three peers were selected for this initial test. They were selected based on their experience on systems development and construction project management. Data from a pre-contract requirements information management scenario of Case C were used to initially test the functionality and potentials of the system. Peers were given access to the system under supervision and instructed what to do. After each test, peers discussed the functionality and suggestions were made to improve the system. However, initial results were indicative for more tests to be carried out. Consequently, an industrial evaluation was deemed relevant for that purpose which resulted in the planned and conduct of focus group evaluation. The data is restricted due to its commercial sensitivity.

8.7.2 Focus Group Evaluation

Subsequent to the pilot test, a focus group comprising experts and practitioners was convened for the industrial evaluations. Participants were drawn from the construction projects used as the case studies and included four project managers. The reason for selecting project managers is that they were the main people administratively responsible for the management of client requirements and charged with their implementation on behalf of the client. Therefore, since the Framework and prototype were aimed at improving the requirements management process, it was considered fitting for them to provide evaluation in order to determine how the Framework and prototype system can affect the current mechanism of requirements information management of which they are heavily involved. A structured evaluation

process (as shown in Figure 8.20) was designed and followed during the evaluation process.

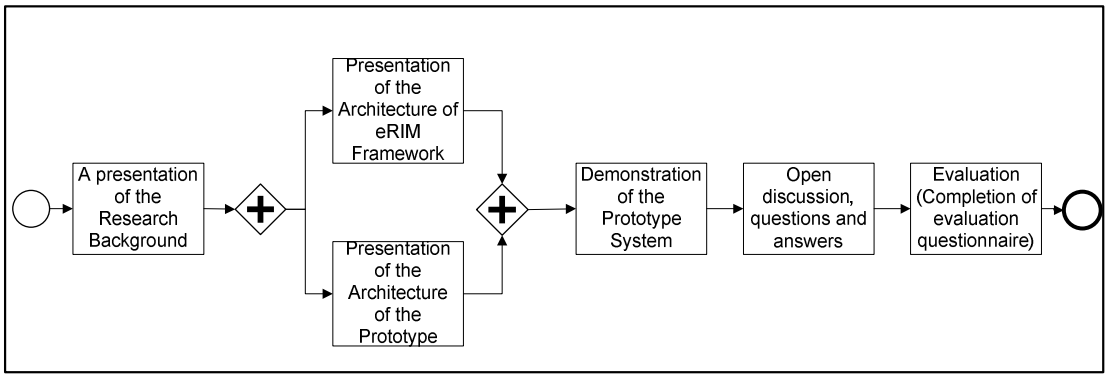


Figure 8.20: The evaluation process

At the beginning, a presentation was made outlining the research problems, aim and objectives including a detail description of anticipated deliverables. The research methodology was also described in order to give an insight on how the proposed solution was reached. Following this, the eRIM Framework was presented and all components described in detail. Discussion was also carried out on how the components solve the defined problems in an integrated manner. A presentation of the architecture of the prototype system too was conducted with a detailed description of its constituents and their relationships.

The major part of the evaluation was the demonstration of the software prototype developed as a means of implementing the theoretical Framework. This process followed the following four activities.

i. A demonstration of the web data-base component of the prototype system serving as the requirements repository was performed. This was conducted taking the participants through the functionalities of the web database showing the user interface, the menu, data entry and presentation forms and test data. The demonstration also showed how to insert data in the database and how to perform links

between requirements for traceability purposes and searches were also demonstrated.

ii. A demonstration of change management system responsible for coordinating and controlling the request for change process was performed. This included how a user logs into the user interface and start a process. It also included how various users can log in and access their various functionalities through the task, notification and processes links of the user interface. The demonstration also included presentation of how the change control form is routed between the various participants and the task that each role/participant performs on the form. The automated mechanism of checking for dependencies and how the information is presented to a user was illustrated. Also demonstrated was how notifications are sent to stakeholders and also how the repository is updated with change information.

iii. Following the demonstration of the prototype system, the floor was opened for participants to discuss freely and comment on the presentations (including the presentations on the architectures of the Framework and prototype systems as well as the operations of the system). Questions and answers were also made during the course of the discussions.

iv. The questionnaire (Appendix E) that was designed for the evaluation; which was distributed at the start of the evaluation, was then completed by the participants. As stated in the Methodology, this questionnaire had various statements each with a likert-scale for participants to rate according to their opinion factoring their experiences.

The evaluation results were captured from the questionnaires that were completed by the participants. A quantitative approach was used to present

the data which were then analysed and discussed. The questionnaire also included a portion which captured qualitative data (free text) from the participants, which was also analysed qualitatively. Two types of evaluations namely: formative and summative and were considered for use in the evaluation of the Framework and prototype. According to Clarke (1999) and Gray (2009), formative evaluation is applied in research in order to provide feedback to those trying to make something (could be a system or process) better; whilst summative evaluation is used to establish how effective a process, system, project or programme is and to provide judgement on it. Consequently, based on these two reviews, both were deemed necessary to use in this evaluation. Therefore the triangulation method was used for the collection of evaluation data, presentation and analysis of the data. It must be noted that the evaluation did not include participants' interaction with the prototype because the aim was not for a *usability* evaluation. It was mainly aimed at evaluating the applicability of the Framework in managing information about client requirements and how an information system can be implemented to operationalise the key features of the Framework.

8.7.3 Evaluation Results and Analysis

8.7.3.1 Results of Part 1

In the first part of the questionnaire, participants/evaluators were asked to rate their perception towards ***client requirements management process*** according to the statements given which were induced through the observations of the case studies. In tabulating the quantitative data, each of the evaluation statements is presented followed by the statistical data through graphs as follows.

- Statement (i): *Lack of lifecycle client requirements management could affect successful completion of building projects.*

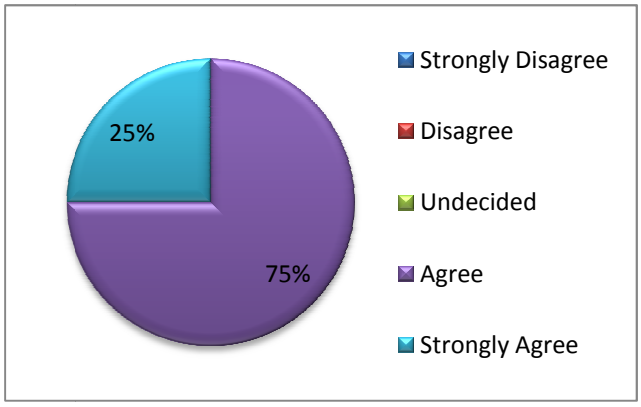


Figure 8.21: Evaluators' response to Part 1, Statement (i) of the questionnaire

The results indicated that all evaluators either agreed or strongly agreed with the statement. This supports the research's position that it is important to take a lifecycle approach to managing client requirements information in order to provide improve the process and deliver successful built facilities. It also reaffirms the claim that current practice does not adopt a lifecycle approach which needs a paradigm shift.

- Statement (ii): *There is need to improve the current manual and paper-based process in managing client requirements information for better efficiency and effectiveness.*

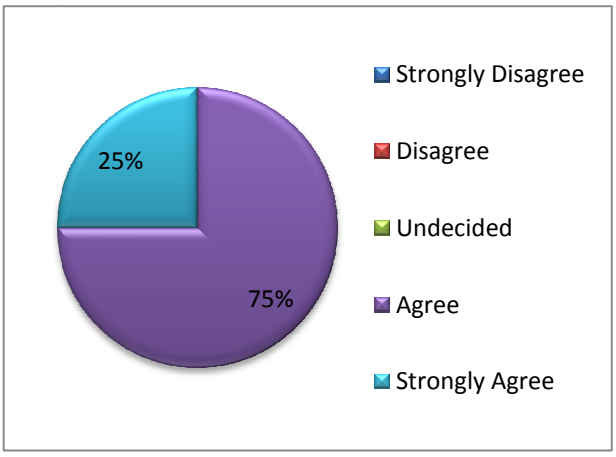


Figure 8.22; Evaluators' response to Part 1, Statement (ii) of the questionnaire

As the Framework and prototype system were developed with the aim of improving the current requirements information management process which is hugely manual and paper intensive, all evaluators agreed with eRIM that the process needs improvement. However, reference was made to the fact that paper has been largely used to manage construction information specifically to facilitate the communication of the design which is preferred on paper because of the large-scale/size of drawings. Discussions also supported the results that automating the process will enhance the management process for efficiency and effectiveness.

- Statement (iii): *Lack of a centralised storage and access of client requirements could affect their effective management.*

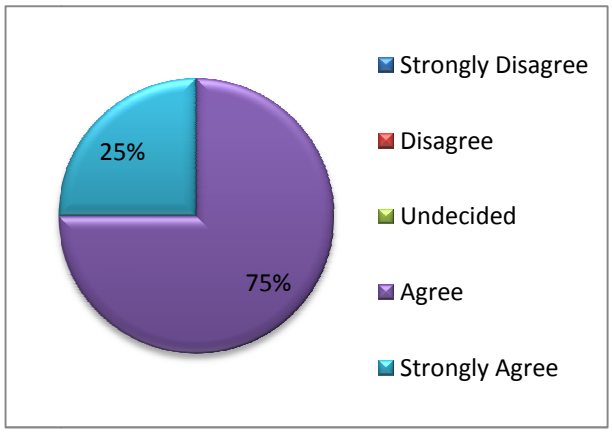


Figure 8.23: Evaluators' response to Part 1, Statement (iii) of the questionnaire

Evaluators were also in the same opinion (as most agreed) according to the results that the keeping requirements information in different locations and versions could be detrimental to the management of client requirements. It was identified that storing them at a central location which can be accessed by all those involved in the project depending on their roles could improve the process. This was in contour to eRIM that a central repository of requirements that can be accessed collaboratively and distributed no matter the geographical location of an individual could potentially improve the requirements management process.

- Statement (iv): *Traceability between requirements is very important in the management of client requirements information management.*

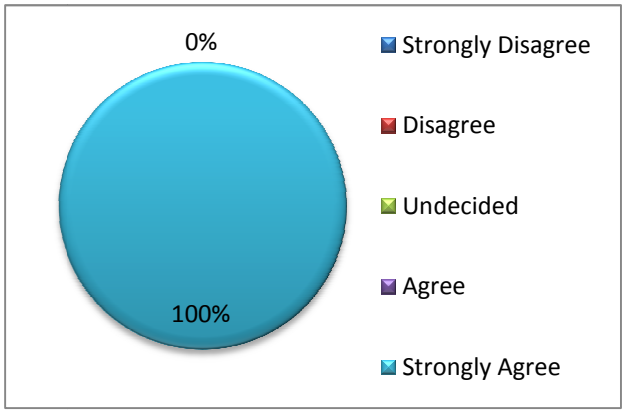


Figure 8.24: Evaluators' response to Part 1, Statement (iv) of the questionnaire

Traceability between requirements is crucial factor to the management of client requirements information. A requirement could be traceable either forward or backward or bi-directional describing its life including all changes associated with it. Because requirements may be dependent on one another, traceability could be vital in helping to trace those dependencies. All evaluators *strongly agreed* with this statement and emphasized that traceability is an important factor of requirements management.

- Statement (v): *Lack of proper coordination and control of the request for change process could affect the proper management of client requirements information.*

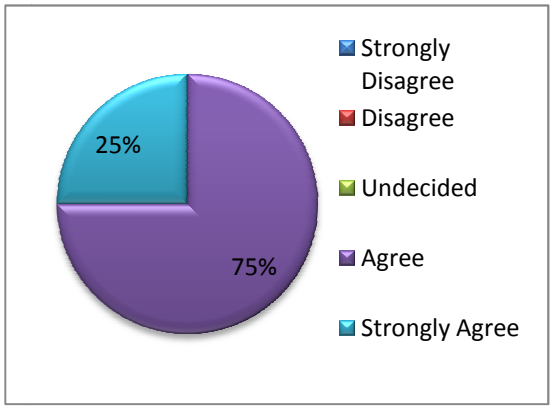


Figure 8.25: Evaluators' response to Part 1, Statement (v) of the questionnaire

A routine and repetitive process, request for change involves a large number of people and information with different sources. The process could sometimes be challenging if not properly and adequately managed, and could affect the proper management of requirements. This was recognized and buttressed within eRIM that a mechanism needs to be defined that will aid this process by better coordination and control. Evaluators agreed and supported this statement. Some commented that delays are sometimes caused during the process and needs improvement.

- Statement (vi): *Impact analysis is relevant for effective client requirements information management.*

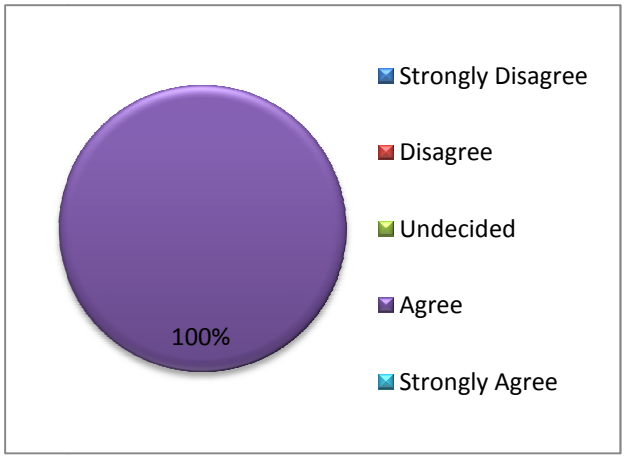


Figure 8.26: Evaluators' response to Part 1, Statement (vi) of the questionnaire

When a requirement changes, it is likely that another will be affected by that change. In order to know this, analysis needs to be carried out during a change request and before implementation of any changes. Impact analysis can facilitate this process utilizing dependency and traceability information between requirements. This in mind, there was a general consensus between the evaluators according to the results (as a 100% agreement) was achieved thus emphasising the relevancy of impact analysis for effective client requirements information management which has been defined within eRIM.

8.7.3.2 Results of Part 2

In the second part of the questionnaire, participants/evaluators were asked to rate their perception of ***the potential of the electronic requirements information management (eRIM) Framework and the prototype system for effective management of information about client requirements in the construction sector***. In tabulating the quantitative data, each of the evaluation statements is presented followed by the statistical data through graphs as follows.

- Statement (i): *eRIM clearly presents client requirements management problem in construction.*

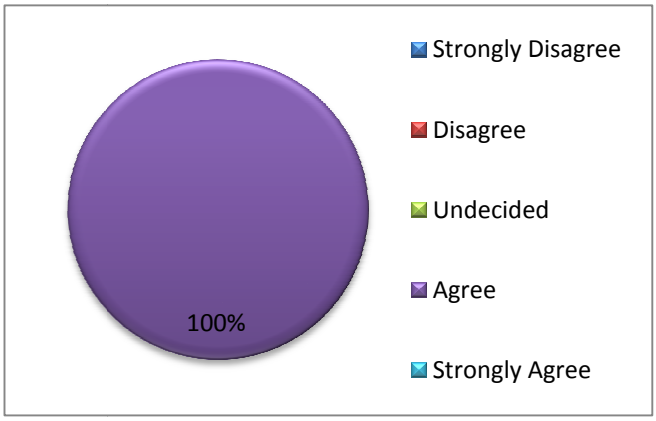


Figure 8.27: Evaluators' response to Part 2, Statement (i) of the questionnaire

Amongst the problems this research tried to solve included the lack of a lifecycle approach and a centralised repository for managing client requirements information management and the inefficient and effective coordination and control of the change process. The evaluators unanimously agreed (with 100%) that this has been sufficiently represented by eRIM.

- Statement (ii): *eRIM clearly defines a solution to client requirements information management problem.*

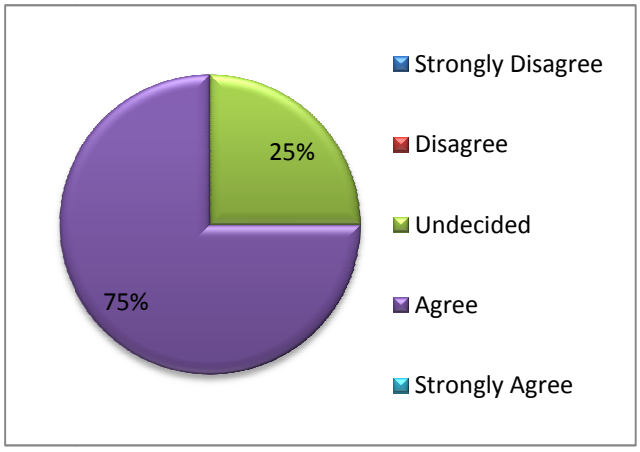


Figure 8.28: Evaluators' response to Part 2, Statement (ii) of the questionnaire

eRIM specifies a structured and controlled requirements management process that registers client requirements after the production of the brief; design and construction and all through the life of the building. It ensures that details of client requirements are available at all times; provides a history of previous changes to requirements and enables the project manager to manage requirement changes effectively through a coordinated and controlled change management process. Most of the evaluators agreed that a solution has been defined with only one of them undecided. The reason for the indecision was that the nature of the dependency links between requirements within the repository needs to be determined to establish how they should be implemented. But the evaluator was convinced that once that is ascertained, eRIM would solve the stated problem.

It is important to state that the mechanism and nature of the dependency links are issues identified by the research that need further investigation. However, it is clear that the concept had been adequately defined and it is a matter of implementation and not what is required to be implemented that needs further study.

- Statement (iii): *The integrated and centralised web database system will facilitate collaborative and distributed access to client requirements information management.*

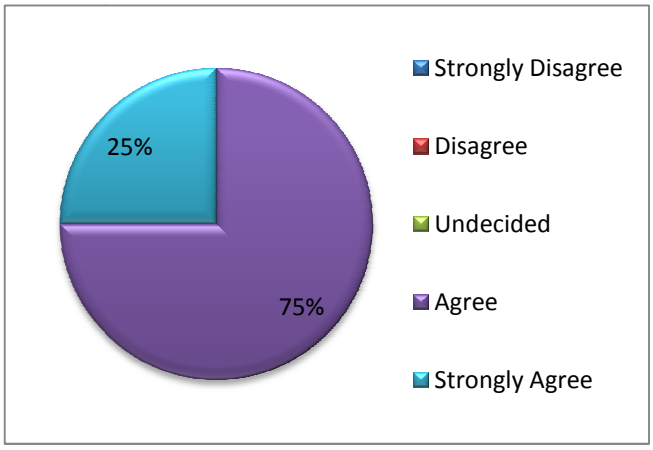


Figure 8.29: Evaluators' response to Part 2, Statement (iii) of the questionnaire

The web database system serves as a central repository for client requirements information. This system can be accessed by project stakeholders through a web interface over the internet no matter of individual's location (i.e., at anytime and anywhere) depending on roles and access authorisation rights. The centralised repository approach will ensure that everybody works with the same and most up-to-date version of the requirements. Evaluators have (according to the results) agreed that this approach and the system will facilitate an improved collaborative access. Discussions to this effect were made that sometimes different team may work on different versions of requirements information which could potentially result in defects resulting to re-work.

- Statement (iv): *The dependency links defined in the prototype will enhance traceability between requirements.*

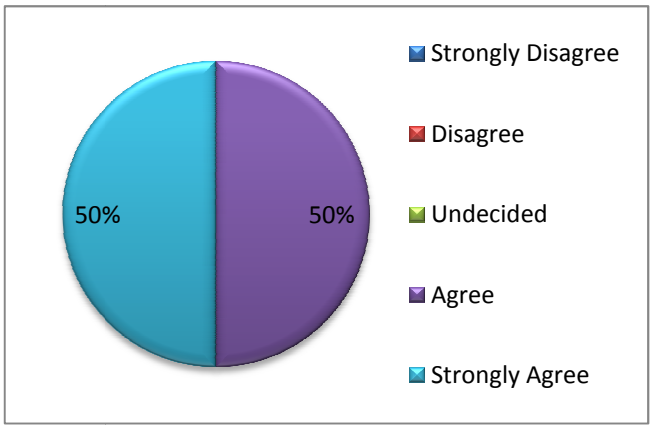


Figure 8.30: Evaluators' response to Part 2, Statement (iv) of the questionnaire

As stated earlier, traceability is crucial in requirements information management which according to eRIM can be facilitated by defining dependency links between related requirements. Evaluators (half-and-half) strongly agreed and agreed to this statement but emphasized the need for proper implementation of the dependency links. This is however regarded as an important development because currently the mechanism of checking for dependency during changes is manual and not efficient and could result in errors. Therefore, the facility of automated checking for dependencies as implemented in the prototype system will hugely enhance the change process.

- Statement (v): *The change management system will improve the manual and paper-based request for changes process.*

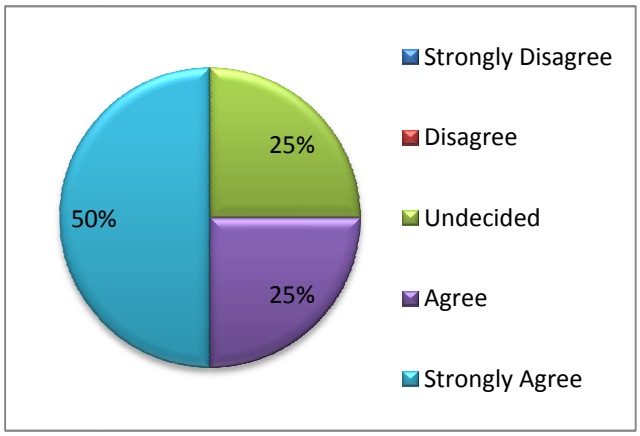


Figure 8.31: Evaluators' response to Part 2, Statement (v) of the questionnaire

Greater number of the evaluators had either agreed or strongly agreed to this statement with a single participant undecided. This according to the participant is based on the fact that the change management system entirely depends on the manner on how the requirements are initially stored within the repository. Although, it was agreed during the discussions, that automation of the changes process implemented by the system was an improvement and a desired feature.

- Statement (vi): *The change management system will provide better integration between people and systems.*

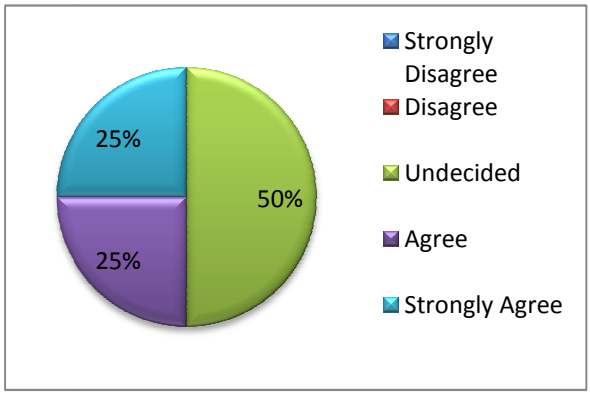


Figure 8.32: Evaluators' response to Part 2, Statement (vi) of the questionnaire

Integration between the people involved in the change management process, and the systems is important if efficient and effective change management is to be achieved. This helps to streamline the process and facilitates collaboration and effective information sharing. However, achieving integration is a major problem because of the different locations people work from, different systems infrastructure and data structures. Consequently, the eRIM prototype was designed and developed to facilitate seamless integration by developing services which can be provided and consumed over the internet using SOAP and delivered through the change management business process. This means integration can be achieved independent of location as people can access services through the web front end and of any system infrastructure. However, the evaluation results indicated a split (i.e. 50% were undecided if the change management will provide better integration whilst the other 50% agreed). However, during the discussions, participants indicated that though the functionality of the change management system indeed provides integration and interoperability between systems, it would entirely depend on how the repository was designed and developed with clearly defined dependency links. A comment made by an evaluator stated: *"The services of the system will rely on how the change management system links back to the briefing requirements and the various stakeholders of the project."*

It was evident that the system meets its criteria of providing an automated coordination and control of the change management process which it was set out to achieve.

- Statement (vii): *The change management system provides an improved dependency checking functionality for impact analysis.*

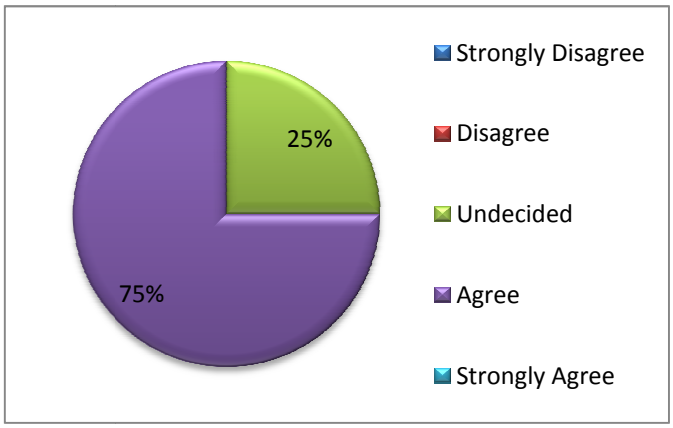


Figure 8.33: Evaluators' response to Part 2, Statement (vii) of the questionnaire

Although majority of the evaluators agreed that dependency checking can be improved with the use of the change management system because of the dependency checker service, one of them was worried that this would entire depend on how the dependency links are created in the repository. However, during the discussions, all evaluators consented that if the links are properly defined then the system would be helpful to improve the manual checking of dependencies during a changes process.

- Statement (viii): *The change management system provides a better facility to updating requirements information.*

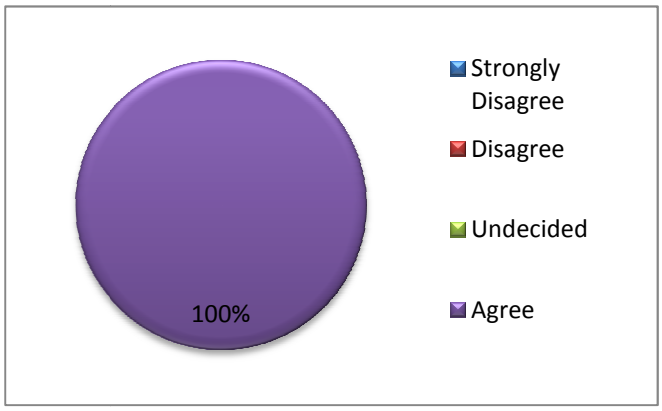


Figure 8.34: Evaluators' response to Part 2, Statement (viii) of the questionnaire

Generally, updating client requirements information in the original brief after a change is authorised was virtually not carried out in the case studies. In most cases, the design is updated with changes and not the original brief document. It was also virtually impossible to update all the different versions of the requirements that may be with different people at different locations. The change management system integrated with the requirements repository has the capability to update client requirements information using a web service 'requirements updater'. Without this web service and the central repository, it will require manual input of change information to the brief document and also in all other requirements documents held by the different parties. Evaluators generally agree that this functionality within the change management system provides a better approach to updating requirements information.

- Statement (ix): *The change management system provides an improved and efficient communication of requirements changes through the Email notification functionality.*

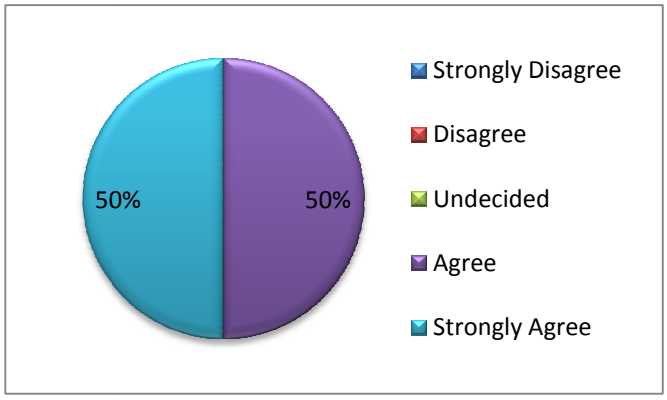


Figure 8.35: Evaluators' response to Part 2, Statement (ix) of the questionnaire

Communicating requirements and change information to all stakeholders is an important aspect of construction project management. Specifically, notifying those teams a change may affect on time is crucial to reducing waste and rework. The prototype system uses a web service to send notifications to different people who need to be informed of the changes

real time. These notifications were sent as *Email notifications* which were regarded as a desirable way of communicating information. The results indicated that all evaluators either strongly agreed or agreed to the fact that the system will improve and provide efficient and effective communication through *Email notifications*. However, a comment made by this particular evaluator to support his opinion was: *"The system would need to ensure that all the inter-relationships are provided to ensure any change is notified to team members."* This means that in order for the system to identify who needs to be informed of the changes, the relationships between the people and the requirements have to be sufficiently defined.

- Statement (x): *In general the prototype system will contribute towards effective and efficient project management in construction.*

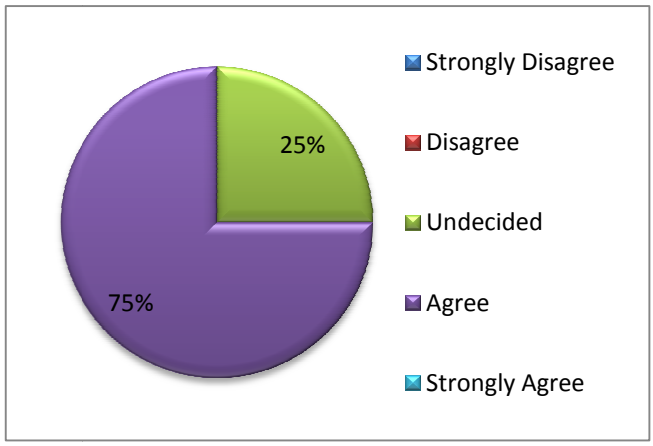


Figure 8.36: Evaluators' response to Part 2, Statement (x) of the questionnaire

Construction project management is employed to ensure that client requirements are transformed into a completed facility that meets those requirements. This involves multiple processes and activities amongst different parties. A key aspect of this process is to ensure that the requirements are adequately managed including their documentation, communication and changes associated with them. eRIM Framework was

developed for that purpose and the prototype system implemented that concept into an information system. The majority of the evaluators agreed that the prototype will contribute towards efficient and effective project management with only one undecided. As a result, from the perspective of the case studies conducted and the evaluation, the eRIM prototype can help significantly in project management.

- Statement (xi): *If I had the prototype system in my day-to-day work, I would use it extensively for requirements and change management.*

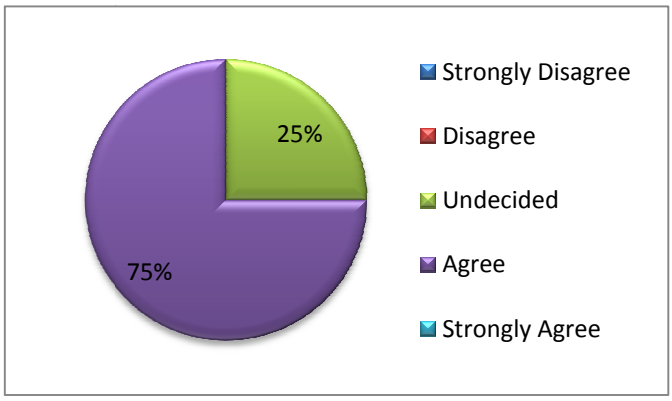


Figure 8.37: Evaluators' response to Part 2, Statement (xi) of the questionnaire

The aim of the eRIM Framework and prototype system is to specify a better approach to requirements information management to help construction organisations reduce operational cost and time in product and service delivery; whilst increasing performance and productivity, and realising high quality of built facilities. eRIM Framework specifies how to perform and implement this process. The prototype system is aimed at implementing a support IT tool that can be used to facilitate the management process. Thus, most of the evaluators indicated interest in using the prototype system in their day-to-day work (i.e., for client requirements information management) if available. One of the evaluators was undecided but this was not related to the functionality of the system but rather on implementation issues. During the discussions, another evaluator observed that the prototype is working fine and has

demonstrated the key features but would rather want to see the system operate in a real life project: *"Although I have seen the prototype system in operation I would like to see it working in practice on a real life project."* It is important to remember that the prototype was not meant to be a working system, rather to implement and test the operational procedure of the Framework which it was able meet.

8.7.3.3 General Observations

Important observations, comments and suggestions on the Framework and prototype system were made by the participants. Although the general comments about the Framework and prototype were positive, the following suggestions were made to further enhance the prototype.

- *Change request form*: within the change request form of the change management system, there is a text box to indicate which requirement the change is associated with. This link is crucial for dependency checking. Currently, users have to manually type in the 'Requirement Id'. This according to the evaluators could be difficult as there may be hundreds of requirements and to remember which one the change can be associated with may be challenging. Therefore, it was suggested to create a dropdown menu for that purpose. The menu can retrieve its values from the 'Requirements Table' of the database. Evaluators recognized this as an important improvement that can provide a user friendly interface when requesting changes.

- *The routing process*: dynamism of the process routing was another area the evaluators thought could be enhanced to improve the functionality of the prototype. Currently, the routing process is pre-determined according to the process model. This means the steps a process goes through and the participants involved is predefined. However, evaluators thought it necessary that some tasks within the process need to be flexible allowing a user to determine who to route a

task to instead of following a prior defined route. This they regarded relevant as sometimes a process may require specialist or urgent action from other participants not defined in the process.

- *Relevancy of the Framework and prototype*: none amongst the focus group participants indicated to have used or experienced a system of this nature (an integrated requirements repository and change management system) to manage client requirements information in construction projects. Dependency links employed in eRIM were regarded as very useful in specifying traceability between requirements and no known system that they used before had such functionality. Reference was made to project extranets such as 4project and BIW but neither was understood to take the dependency links approach employed in eRIM. The dependency checking facility within the change management system was also regarded as very useful in generating dependent requirements of a changing requirement which currently is manual and depends on intuition and experience.

The evaluation results indicated overwhelming interest from the participants to consider possibility of implementing the change management system component of the prototype as a drive to automate the request for change process.

8.8 Benefits of the Framework and Prototype System

Results from the evaluation indicated huge potential benefits of the prototype system and the underlying Framework. According to the evidence, the significant benefit which the system can deliver is efficiency and effectiveness and increase of quality of the requirements management process within construction projects. The benefits also include the following.

- Requirements information, which when adequately stored within the repository, will be readily available and accessible through the internet to any member of the project team despite of their geographical location.

- Implementation of the BPM-driven change management system will make the request for change process and its management traceable and visible and will provide more accountability within the process.
- The change management system will also simplify 'information push' in real time (requirements updates to the repository and notifications to relevant team members) because of the system's ('requirements updater' and 'notification') services.
- The change management system will also boost timely and comprehensive decision making on changes as people can collaborate real-time during the change request process.
- The prototype system can also facilitate standadisation of the requirements information management process across project teams through the lifecycle of buildings.

8.9 Summary

This chapter presented the eRIM prototype and its development process. The key contribution of the prototype was to implement a proof-of-concept of an integrated requirements information management system defined in the theoretical Framework (eRIM).

Consequently, a web database system was developed to serve as a central repository of client requirements. This system was developed using *MySQL* as the relational database management system, *PHP* as the scripting language for the user interface (web front-end) and *Apache HTTP* as the web server. A change management system was developed to implement the concept of a coordinated and controlled requirements change request management process. This system was developed based on the principles and philosophy of BPM and SOA and based on an open source platform. It demonstrated how client requirements information can be centrally stored and collaboratively accessed by different project teams from various geographical locations. The associated change management system demonstrated effectively coordination and control of the requirements change management

process. Its features including the dependency checking, updating requirements and change notifications reveal a better approach and efficiency in the process which are crucial in analysing impact, keeping requirements up-to-date and communication of changes to all those concern.

Evaluations were carried out in order to gauge industrial input and assessment of the Framework and prototype system. It is anticipated that when fully implemented, the eRIM Framework and prototype can contribute immensely towards a better client requirements information management in construction projects. Based on the work carried out and reported in this Thesis, a summary of the research is made in the next chapter along with limitations and recommendations for future work in this domain.

Chapter 9. **Conclusions and Recommendations**

9.1 Introduction

The research reported in this Thesis focused on client requirements information management in collaborative construction projects. 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.

9.2 Research Summary

The aim of this research was to specify a better approach to requirements information management to help construction organisations reduce cost and time in product development and service delivery; whilst increasing performance and productivity, and realising high quality of built facilities. Definition and implementation of a lifecycle requirements information management to support information flow, traceability and requirements change management in construction projects could help achieve the aim. Consequently, the following objectives were specified.

- Provide a detail review of the state-of-the-art of client requirements information management (RIM) in collaborative construction projects lifecycle (CCP).
- Identify inefficiency and ineffectiveness in existing methods, and define improvement for better client requirements information management across facility lifecycle phases.
- Develop an innovative integrated framework to enhance lifecycle requirements information management and to support production and service delivery business processes.
- Develop and evaluate a prototype of the framework base on information-centric, process management and service-oriented architecture.

Each of these objectives is discussed below summarising the detailed activities carried out and the results achieved from them.

Objective 1:

- ***Provide a detail review of the state-of-the-art of client requirements information management (RIM) in collaborative construction projects lifecycle (CCP).***

This objective was achieved with a review of literature of client requirements information management within construction industry. The review also included other industries where the discipline of requirements information management is well established such as software engineering, aerospace and defence. The review was able to highlight the current practice of client requirements information management and its importance in the design, development and maintenance of products (*including building and similar facilities in the construction industry*). This indicated the use of manual and paper-based approach to managing requirements information which are generally held in different locations, in different medium and accessed and utilised by different people. Research gaps were also identified from literature which required further study conducted by this research.

Most of the findings of requirements management included provision and facilitation of accessibility of requirements information to all those involved in product development and maintenance especially in a collaborative and distributed working environment. Findings also included providing traceability of requirements, managing changes; as well as impact analysis of those changes. Tools for requirements management were also identified in the literature; however, no known tool was specifically meant, established and used in the construction industry; neither did they define their adoption or functionality in this industry. The tools did not also define business process management approach to managing the requirements change process and they do not integrate with other enterprise systems.

Industrial case studies were conducted which helped reveal how client requirements are currently managed in construction projects. The research reported in this thesis adopted observations to conduct case studies to enable an in-depth analysis of the process of client requirements management as currently applied to construction projects. These case studies included observation of construction projects with focus on client requirements and how stakeholders interact towards managing the requirements. Another aspect of the review was on requirements changes and how to manage the changes between people, systems and the information processed. It also focused on how impact on cost/budget, time and quality could be assessed as the requirements change.

Objective 2:

- ***Identify inefficiency and ineffectiveness in existing methods, and define improvement for better client requirements information management across facility lifecycle phases.***

The review of the state-of-the-art revealed how client requirements are managed in the construction industry. It was then relevant to identify *'what goes well and what does not'* in order to define how this management can be improved.

Firstly, client requirements were not managed all through-life of buildings (i.e., the requirements were not managed at each phase of construction projects across the lifecycle). Instead, it is only applied during the early phases (preparation and design) and then the design is used subsequently to translate client requirements.

Secondly, it was identified that client requirements were not centrally documented and stored. As a result, various sets of requirements were held in different locations by different people. Most of those requirements were outdated as updating all the copies with everybody in the project development team was virtually impossible. Access to the requirements by all the project

stakeholders for their used in the construction process was difficult because of lack of an integrated and centralised repository.

Thirdly, the dynamic nature of client requirements meant that they often kept changing as projects progress and their management was a routine and iterative process involving a number of people, processes and systems. However, this process was manual and involved numerous paperwork which lacks efficiency and effectiveness. Sometimes delays were caused during this process which occasionally affected progress of projects. The change process would also require checking for dependencies between requirements in order to ascertain impact of changes. However, dependency checking was manual and involves physically checking for all paper work and in systems that hold requirements. This is time consuming, laborious, and ineffective as sometimes it is impossible to trace all dependent requirements. The process is also cumbersome because of the many people involved and this makes the coordination and control very difficult. Often, there is no visibility to the process and auditability is very rare as history of the information is not accurately captured and stored. Where information systems were used to document, store and manage the requirements information, another major problem that was also identified was the lack of integration and interoperability between those systems. Information cannot be seamlessly shared and exchanged between the systems.

Consequently, based on the inefficiencies and ineffectiveness identified, an approach was defined in order to improve requirements information management as follows.

- Provide an integrated and centralised storage facility of all requirements information.
- Make sure the information is accessed collaboratively and distributed to all stakeholders remotely no matter their geographical location.
- Define traceability links between related and dependent requirements to facilitate dependency checking for cost and time impact assessment.

- To provide a mechanism for the management of the requirements change process.
- To make sure the information systems used for requirements management are integrated and can interoperate to enable information sharing and exchange.

Objective 3:

- ***Develop an innovative integrated framework to enhance lifecycle requirements information management and to support production and service delivery business processes.***

Based on the review of the state-of-the-art and the identification of inefficiencies and ineffectiveness of client requirements information management in construction industry, an innovative integrated Framework (eRIM) was developed which defined a lifecycle approach to managing requirements information to support construction of buildings and delivery of related services. It has been developed for better approach to managing client requirements information across the whole lifecycle of a facility. eRIM ensures that client requirements information is centrally collected and transmitted (including sharing, distribution and communication) across the lifecycle and available at all times to all stakeholders. eRIM has two major consequent components namely: a requirements repository and a change management system. A third component is a supporting scheme (lifecycle phases) which defines the identification of all requirements related information at each phase in a layer called ***'standard document layer'***. Another layer, 'requirements information layer' was also defined within the lifecycle phases on which requirements information will be extracted from the standard documents for storage in the repository. However, this extraction is currently manual; not automated.

The requirements repository will hold all client requirements information across the lifecycle. It will also facilitate remote access to the requirements collaboratively and distributed to all stakeholders. Links will be defined within

the repository between dependent requirements to provide traceability which is crucial for change management.

The change management system will be used to smoothen the requirement change process by enhancing the coordination and control of the process. This system will define the activities, task and resources (people as actors, systems rules) and their interrelation and interaction during the change management process. The system will also facilitate and enhance visibility and auditability of the process and help integrate the different systems used so that information can be shared and exchanged.

The Framework also identified the different stakeholders who need access to the requirement repository and the change management system as discussed in Chapter Seven of the thesis. It also defines the different channels used to request changes of client requirements. A requirements management role is also defined within the Framework.

Objective 4:

- ***Develop and evaluate a prototype of the framework base on information-centric, process management and service-oriented architecture.***

Based on the Framework, an information system prototype has been developed to test the applicability of the Framework. This system is based on two modules: a web database and change management systems. The web database system was developed using MySQL as the relational database management system, Apache HTTP as the web server and PHP as the web front scripting language. Database tables were created to hold requirements information for each project lifecycle phase. Links were created between the tables and requirements where two or more requirements were related or depend on each other. Because it is a web database system, people can log-in and access the requirements remotely depending on their individual roles which were implemented by defining security measures such as log-in and passwords. The change management system was developed using a BPMS

to model the requirements change request process base on BPMN and to automate that process. The automation was implemented using the process engine embedded with the BPMS. Integration between the two modules was achieved using SOA and web services thus information could be shared and exchanged between the web data-based and change management system. Visibility and auditability was provided for by this system.

Both the Framework and the prototype system were 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 suitability and applicability of the Framework and the prototype in the industry as well as areas for further improvement. Questionnaires were used to capture their comments which was analysed in (Section 8.7.3) of the thesis.

9.3 Conclusions

The research reported in this Thesis examined client requirements information management in construction with the aim to specify a better approach. Subsequent to the conduct of the research, the following conclusions are formulated.

- Construction firms have been practicing requirements management since the inception of the industry, though in a different approach. *Briefing* and *value management* have been widely applied in construction instead of requirements management in the quest to define and manage the interest of the client.
- Client requirements information management in construction projects is still manual and paper-intensive and this does not prove to be efficient and effective.
- There is no utilisation of an integrated and centralised storage of client requirements information. This does not facilitate collaborative access to the most current version of requirements by the various stakeholders. It does not also enhance integrated project delivery.

- The requirements information management process is not applied across the entire lifecycle phases. Once the initial design is developed, the brief document is put aside and is not carried forward into other phases of the construction project. As a result, emergent and changing requirements are incorporated within the design and rarely get updated in the original brief.
- The integrated eRIM Framework was developed and presented a novel approach to client requirements information management. eRIM was developed from a data/information-centric perspective with the concept of providing an ongoing view of client requirements. It facilitates shared and distributed access to requirements information over a centralised repository which remains up-to-date through-life. It places emphasis on collaborative working and interoperability, thus enabling information sharing and exchange between humans and systems (both homogeneous and heterogeneous). It enables the project manager to manage requirement changes effectively through a coordinated change management process, update the repository with changes and provide a history of previous changes to requirements; and facilitate notifications to other stakeholders.
- Integrated features of the Framework such as traceability between requirements at each lifecycle phase, and the associated dependency checking of the change management system to facilitate assessment of cost and time impact are crucial to improve the requirements information management process.
- The eRIM prototype system (*comprising a web database and change management system*) implemented the Framework and demonstrated how IT/IS can be used to operationalise, and to automate the requirements information management process for efficiency and effectiveness. It also demonstrated how to leverage the combined capabilities of web databases, business process management, service oriented architecture and web services to facilitate information flow;

enhancing project collaborative working, and integration and interoperability of systems in the construction industry.

- The requirements repository can support the creation of a knowledge repository because it can hold client requirements information of a project from inception to demolition. It can also hold requirements change information throughout a building lifecycle which can be referred to at any particular point in order to understand the rationale of a change(s) and how they were implemented.
- Decision support: BPMS are capable of performing business rule management. Therefore, even though this has not been implemented in eRIM as was not required by the case study projects, business rule management can be incorporated in the change management system component to help project managers in decision making based on organisation's procedural rules.
- The general feedback from the evaluation of both the Framework and prototype demonstrated keen interest from the participants in the application of the Framework and its associated prototype system to enable better client requirements information management in construction industry.

9.4 Contribution to Knowledge

The research reported in this Thesis has made significant number of contributions to knowledge in terms of outcomes on: (i) research gaps and problems, (ii) requirements management in construction, (iii) the developed Framework (eRIM) and (iv) the associated prototype.

Client requirements information management in the Architecture, Engineering, Construction and Facilities Management (AEC/FM) industry has generally been undertaken at the early phases of a project and does not extend throughout the lifecycle of the facility. The research was able to indentify research gaps and problems which stem efficiency and effectiveness of the current methods of managing client requirements.

This research develops and presents an Electronic Requirements Information Management Framework (eRIM), which defines an approach to manage client requirements information continuously across the whole lifecycle of a facility. This addresses the major problems associated with managing information about client requirements particularly dependency checking between requirements across the entire facility lifecycle. Previously, no known system has defined how this should be done within AEC/FM. This research was able to define and provide a remedy to this problem. Within eRIM Framework, dependency links are defined as weak, strong or none and can be used to link related requirements across the facility lifecycle. This research recognises the importance of '*rationale*' and '*priority*' as attributes of requirements and specifies their inclusion in the definition of construction client requirements. The research also specifies the identification of requirements information management activities and processes at each lifecycle phase and to develop them as services. These services can be transformed into web services, incorporated as process tasks within the process model and their operations invoked and consumed by the change management system.

Business Process Management (BPM) is applied to improve the coordination and control of the requirements change management process. BPM is coupled with Service Oriented Architecture (SOA) and Web Services (WS) technologies, to enhance business process and systems integration and interoperability; streamlining people and processes through the lifecycle phases, to enable more efficient and effective requirements information management. This research identifies a critical difficulty in the management of a request for change, the checking for dependent requirements and evaluation of impact (time, budget, quality and performance) of the requested changes. Currently, this process is conducted manually, is time consuming and error prone thus contributing to inefficiency and ineffectiveness. This research has developed a '*dependency checker*' as a Web Service which performs dependency inspection on the repository and returns all related requirements information for evaluation. The research stipulates the inclusion of the Identification information of the changing requirement on the change

request form which will assist in identifying dependencies. Implementation of integration between the many heterogeneous computer systems used within AEC/FM has proved to be challenging.

This research utilised SOA, BPM and Web Services technology to integrate the repository and change management systems. SOAP and Hypertext Transmission Protocol (HTTP) was used as the messaging/ transmission protocol based on XML schema and XSLT for transformation of the information for customise use. The research has also contributed to knowledge through the publications of papers as shown in Appendix L.

9.5 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 case studies were conducted within projects that were owned and/or funded by the same client and managed by the same project management consultancy firm. As a result the same project management method and technique was used all through which can limit the generalisation of the results. It is thought that the approach and mechanism of managing client requirements could be different from project-to-project and from client-to-client. It would have been useful to explore other project management approaches and styles to managing client requirements which could potentially draw out a different perspective. However, the relevant issues and concerns in managing client requirements are indeed general no matter the project management method employed and those have not been compromised in this research. However, despite these limitations, eRIM is applicable to various types of construction projects and clients as well as any particular project management methodology employed. It can also be adopted in other industries where requirements management is applicable such as manufacturing and aerospace.

- The prototype system focused on only two lifecycle phases (*preparation and design*) and not the later. This can also limit the generalisation of the results on its lifecycle applicability
- Dependency links between requirements as strong or weak were not implemented but described the links only as dependency in order to prove the concept of dependency checking which can facilitate impact analysis. This could limit the functionality of the prototype in terms of managing dependencies.
- The evaluation involved only a limited number of participants from the case study projects and not generally representative of the construction industry. It could have been much useful if the representation was broader including various disciplines and also participants from other projects outside those of the case studies.

9.6 Learning Outcomes and Appreciation of the Philosophical Considerations

Despite the limitations of the research, a lot has been learnt during the course of the study. The research provided a methodical understanding of the process of conducting research from formulation of ideas; reviewing literature and critically examining related work; to the identification of gaps and problems; the formulation of aim and objectives and the process of research design which includes the identification of the subjects (population and sample) to be studied.

Appreciation of epistemology and the different philosophical underpinnings of research approaches and methods; including data collection methods, analysis and evaluation of the outputs, and their implication and effects to the problems and general body of knowledge of the research subject is gained. As a result, both qualitative and quantitative methods have been applied to address the problems and bridge the gaps of this research.

Knowledge has also been gained that different scientific approaches can be applied to address a research problem(s), each with their own advantages and disadvantages; strengths and weaknesses. Thus, careful consideration, based on several factors should be made when selecting research methods to use. An understanding of the theoretical/epistemological underpinning of each research method enables their balanced application and combination to reduce bias in research. It is also appreciated that no matter how well a research is planned, the unexpected can always happen which may affect the scientific inquiry process. Thus, it is necessary to factor for risk and plan for contingency when planning the research process.

Amongst other important things learnt during the research is the importance of time management, effective communication and skills for networking with both internal and external stakeholders. Project management skills have also been developed during this period, which include resource mobilisation and management. Knowledge on dissemination of research results through the preparation of presentations and papers; attending and presenting at international conferences, workshops and seminars (both internal and external) has been achieved. Ethical considerations of conducting research such as confidentiality, bias, validity and accuracy of the data was learnt and applied in the research.

9.7 Recommendations for Further Work

This research has identified a number of key areas that requires further research in the area of requirements information management. These recommendations are divided into three main categories.

i. Recommendations on requirements management in the construction industry.
ii. Recommendations on eRIM Framework and its associated prototype.
iii. Recommendations on requirements management in general.

9.7.1 Recommendations on Client Requirements Management in the Construction Industry

The following recommendations were made on client requirements management in the construction industry.

- The industry should take a paradigm shift to documenting and storing requirements information in a manner that will facilitate its effective management. This should focus on moving from the traditional paper-based documentation to using dedicated information management system. Such system should support collaborative access to the requirements and its update.
- The industry should consider the viability of implementing requirements information management systems, which will be interoperable to enable sharing and communicating requirements information between all stakeholders. This is crucial because current systems used in the construction industry are mostly not interoperable making it difficult to share construction information such as requirements between heterogeneous systems.
- The industry must regard requirements information management as a lifecycle process and not to be focused in the early phases only. This will make sure the needs and wishes of the client are adequately carried forward in all phases and effectively managed. This will be useful in reducing assumptions, claims and disputes as the likelihood of producing quality facilities that will meet the needs of client and users will be very high.
- Within the construction industry, there is currently no standard role responsible for specifically managing client requirements. Given the difficulty of managing client requirements, it is recommended that introduction of '*Requirements Manager'* role be incorporated within the project team which is important in contributing towards successful projects. This role could shift between individuals as the lifecycle progresses from one phase-to-another. However, this may depend on

several factors such as client preferences and project procurement type amongst others.

9.7.2 Recommendations on eRIM Framework and its Associated Prototype

The following recommendations were made on eRIM Framework and its associated prototype.

- It is important that further research is conducted to find out the suitability of eRIM in the later phases of the lifecycle (i.e. from use/operation and demolition/decommission). Due to time constraints, enough data could not be collected for these two phases and as a result, sufficient test could not be conducted during the development and evaluation of eRIM. However, the concept of managing requirements which is common to all phases has already been established by eRIM; nonetheless, further tests need to be conducted so that proofs on functionality and robustness are established.
- According to the research findings, request for change can be initiated using various channels. Currently, the prototype implemented a manual data entry using web forms. Investigations could be made to incorporate telephone conversation into the change management system so that data can be captured automatically from those conversations and transferred into the change management system. In this way, there will be no need to independently record the conversations and enter them into the system later. Instead any change requested via telephone would trigger a change request through the change management system. Similarly, any request via Email could also trigger the same via a link between Email systems and the change management system.
- Further work is required to incorporate the calculation of cost and time implications of the impact analysis a feature within eRIM. This is because currently, automated dependency checking during the process of request for change has been implemented by this research. The essence, of checking for the dependencies between changing

requirements is to facilitate impact analysis in terms of cost and time implications.

- Construction project extranets have been and still continue to be used in facilitating project information and document management. Such information and document is the brief which is used to develop the design. It is therefore crucial to explore the possibility of incorporating eRIM within project extranets such as 4projects.
- BIM has emerged as a solution to capture and make available the whole lifecycle information of a facility. Current research in BIM does not define how client requirements is captured and managed. eRIM has define a philosophical approach to better management of the whole lifecycle client requirements information in a manner that can integrate people, processes and systems. This is in line to the BIM philosophy and process thus its amalgamation as a model component will immensely compliment current trends. Therefore, further research needs to be employed to investigate how eRIM can be integrated within a BIM environment as a client requirements information management module. Already the design of eRIM based on service and process orientation sets a solid foundation to enable this.
- The Framework has stipulated that requirements information be structured and formatted to support information sharing and exchange. Therefore, recommendation is made to further study the format of the structure and to determine what standards to conform to, e.g. IFCs, agcXML, requirements model specification, etc.
- Another important area that would also require further work is implementation issues of the system. Generally IT implementation is known to be an issue with regards to funding and maintenance. Therefore it is fitting to examine industrial implementation issues of eRIM in terms of who will fund and own the system and provide maintenance during and after projects and all through-life. Social, cultural and other organisational issues need to be considered in implementing eRIM.

- An increasing importance of IT use in the construction industry is how technology can help boost performance. This can only be achieved if all participating sectors can make use of the necessary systems in their activities. The emergent of cloud computing business model promises to facilitate access to readily available services through the internet. Thus it is recommended that further work should be carried out on the prototype for the possibility of providing eRIM services on the cloud as software-as-a-service (SaaS).

9.7.3 Recommendations on Requirements Management in General

The following recommendations were made on requirements management in general.

- This research paves the way for exciting innovations in client requirements information management. eRIM specifies three innovative types of dependency links that can exist between primary requirements and secondary requirements, namely: *no dependency, strong dependency and weak dependency*. To the knowledge of this research, currently, this categorization does not exist. Therefore, it is significant that the nature of these different types of links is investigated further; and eventually to adopt and implement them as standards of requirements management in general.
- Dependency checking has been implemented using database links between requirements and other components within the requirements repository. Therefore, the dependency checker relies entirely on the links that have been defined between requirements and sub-requirements during the requirements entry process. Due to human error, it is highly likely that possible links between requirements may not be established thus making it impossible for the dependency checker to trace dependencies. Therefore, it would be worthwhile to improve eRIM so that it will be more intelligent to determine dependencies between requirements even where links are not defined. This can be implemented by developing the ‘dependency checker’

module using artificial neural networks, fuzzy logic or other appropriate tools.

9.8 Concluding Remarks

The traditional approach to managing client requirements information concentrates hugely on production of the initial brief. Once a design is produced, the brief is put to one side and all subsequent client wishes and changes are centred on the design. The original requirements information within the brief is rarely consulted or updated as the management of requirements does not take a lifecycle approach. Requirements are not centrally stored to facilitate shared access and as a result, duplicates exist which opens up the possibility of errors. Relationships and dependencies between requirements are not explicit. Client requirements change management is a laborious, manual process. It is also virtually impossible to track the status of a request effectively once it is in the change process using the manual system. The request would become invisible to the initiator. Business Process Management (BPM) has emerged as a technology that can be utilized by organisations to help coordinate and control processes. Web services address the difficulties associated with checking for dependencies, updating change information and communicating the information to all stakeholders. This was done by services that were developed which performed these specific functions. The services were then transformed into web services and consumed as ‘tasks’ within the change management system. The combination of SOA with web services and BPM can contribute towards integration and information sharing between disparate computer systems such as the web database and change management systems. From a systems integration and interoperability point-of-view, these technologies will help in reducing cost, time and the complications in implementing eRIM and similar approaches as well as incorporating legacy systems and other back end systems with far less changes. SMEs, often limited in IT budget, cannot afford traditional IT expenditure; can benefit immensely through the use of service oriented systems such as eRIM because implementation and

maintenance cost could be reduced drastically and they would not be burdened with their legacy systems. This approach can be useful in boosting performance and productivity and increasing profitability of construction companies.

It is anticipated that when fully implemented, eRIM will contribute immensely towards better client requirements information management in construction projects lifecycle. This evidence has been manifested in the results from the industrial evaluations. Key points of consideration toward the implementation of the system are organisational, social and cultural issues relating to information systems in construction. These considerations include funding and ownership of the system (i.e., who will fund the development and maintenance of the system) and social issues (such as ergonomics or human factors) relevant to design, development and use/operations of the system.

The construction industry should take a shift towards BPMN and BPEL for process modelling and orchestration. This will facilitate the Industry to model well defined, dynamic and interactive processes which can be utilised by developers to develop IT/IS systems that will be agile and flexible and be able to respond to business and enterprise changes much rapidly than current approaches.

Majority of IT systems within construction are heterogeneous and isolated, operating on islands of information preventing the full exchange of information between project participants. This makes collaboration between project teams difficult and the heterogeneity makes interoperability virtually impossible. Integrating such systems is significantly relevant for improved business performance and competitive advantage. In our case, integrating the change management system with the requirements repository will help satisfy user demands for interoperability. The combination of Business Process Management (BPM), Service Oriented Architecture (SOA) and Web Services (WS) can be the architecture to utilise in order to mitigate this trend which can be boosted by the use of the *'cloud'*. The Framework was developed with this philosophy in mind and the prototype system implemented around those

technologies as a quest to improve the requirements information management process in construction projects.

In the final closing remarks, the following were the ***core*** areas of contributions and achievement of the research.

- A detail review of the state-of-the-art of client requirements information management (RIM) in collaborative construction projects lifecycle (CCP) was conducted.
- Inefficiencies and ineffectiveness issues in the existing requirements information management methods were identified, and improvement approaches were defined.
- Development of an innovative integrated Framework (eRIM) to enhance lifecycle requirements information management, and to support production and service delivery business processes.
- Design, development and evaluation of an information system prototype to implement eRIM Framework as a proof-of-concept.

These contributions and achievements are corroboration that the objectives set out in Section 1.5 of this Thesis have been achieved. A methodical and 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. Consequently, three case studies of ongoing construction projects were investigated and different data collection methods applied. The results of these case studies coupled with the literature contributed to identifying inefficiencies and ineffectiveness, which also helped shape the development of the Framework and prototype. Significant benefits of the Framework and prototype to the construction industry were identified.

It is expected that when adopted and implemented in the construction business process, eRIM which specifies *a better approach to requirements information management in construction projects lifecycle, will help construction organisations reduce cost and time in product development and service delivery; whilst increasing performance and productivity, and realising high quality of built facilities.*

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Appendices

Appendix A: Interview Questionnaire on Requirements Management

Semi-structured interview

Researcher: Abdou Karim Jallow Participant: xxx xxx -

Thank you very much for honouring the request for this interview. Please be informed that the information you provide will be treated with due care and shall be used solely for the purpose of the research.

1. What sort of projects (commercial, schools, hospitals etc) do your company specialise? What is your standing within the construction industry?
2. History shows that word processing and spreadsheet packages have dominantly been used with some few exceptions, databases to store requirements. What medium is used to archive or store client's requirements after contract sign-off?
    a. Do all stakeholders have access to the documented and stored requirements?
3. Reflecting on some of the changes to the requirements such as the Morris Vermaport Lift to an evacuation lift and district heating to gas boilers and the time it takes for their procurement, what effect would it have if your procurement system is integrated with your requirements management system.
4. Sometimes, the client is unable to provide some of the requirements in detail. Such would be developed as the project progresses. E.g. architectural design suggestions to flooring, wall and furniture colours as well as lighting. Once agreed, would they be regarded as client requirements for the project? Who would be responsible for their management? *Contractor, Client or Architectural designer*

5. Requirements are constantly open to change throughout the lifecycle of a project. Different stakeholders may initiate change from different platforms such as meetings.
    a. How are changes initiated and what medium of representation is used for this?
    b. When changes are implemented, how is the information reflected to the initial requirements?
    c. How are the changes communicated to all stakeholders?
6. Client Requirements are important for use during the later phases of a facility's lifecycle after construction. The responsibility of a Project Manager ends when the building is completed and handed over to the client / users. However, the requirements would be vital for operations and eventually refurbishment and/or demolition. What sorts of documents are handed over and how are the requirements represented in this?

Appendix B: Questionnaire on Changes and the Change Process

This brief study aims to investigate client requirements changes in construction projects. Specifically, it concentrates on the change process and changes within your projects.

Please be assured that the information you provide in this questionnaire will be treated with due care and shall be used solely for the purpose of the research. No individual or organisation will be identified from it.

Questionnaire on changes and the change process

1. How many change orders did the client and/or designer requested in the project you were involved? Between what periods?

2. How long does it take for a change order to go through the authorisation process?

3. How often are delays caused on decisions on the change orders? If any, what effects do the delays cause?

4. What medium do you use to communicate the change orders (Email, hard copy, digital documents (pdf, etc), telephone, online, projects extranet, others)?

5. How do you assess impact of the changes in relation to other requirements?

6. Do you document the rationale of changes? If so in what form?

Thank you very much for your time.

Abdou K Jallow, Department of Civil and Building Engineering, Loughborough University

Appendix C: RFC Form

Client Name/Company Name

Project Name – Request For Change ##

Change Control

SECTION 1	
Project Name: xxxxxxx	**Job no** xxxx **Change request no** xxx
Sponsor: xxxxx	**Charge code: xxxxx**
Project Manager: xxxxx	**Agresso code: N/A**
Originator of request: Client Name	**Date of request:** Datexxxxx
SECTION 2	
PART 1. Change proposal *Xxxxxxxx* State changes here	
Supporting Documents Xxxxxxxxxxxx Any supporting documenting should be stated here and attached	
Reason for change xxxxxxxxxxxxxxxxxxxxRationale for the changes	
PART 2. Effect on cost £xxxxxx	PART 3. Effect on delivery timescale xxxxx
PART 4. Consequence of rejecting change request xxxx	

SECTION 3. Change request approved (N.B. Further Authorisation is Required)

Name	Signature	Date

SECTION 4. Change request approved

Name	Signature	Date	PMI Reference no

Change request rejected

Name	Signature	Date

Appendix D: Project Manager's Instruction (PMI)

PROJECT MANAGER'S INSTRUCTION (PMI)

Project Name

Section 1

Project

To

PMI Number

Package

RFC Number

Section 2

Description of Instruction:

Description stated here:

Attachments:……..

Completed RCF Received:* Yes No

Completed RFC Attached:* Yes No

*Delete as applicable

Section 3

We confirm that the instruction contained above does not give rise to an increase in the Contract Price

We can confirm an increase/decrease* in the Contract Price of:: £

We can confirm that the instruction does not give rise to an extension of the Contract Period

The effect on the overall programme will be:

*Delete as applicable

Section 4

The instruction is hereby withdrawn*

Please submit revised proposals with respect to time and cost by*

Please act on this instruction forthwith*

The above instructions is issued under the terms of our agreement with you*

Signature Date

[Consultancy firm]

Distribution:	File:

Appendix E: Evaluation Questionnaire

Evaluation Questionnaire

This study aims to evaluate the applicability and functionality of eRIM framework and prototype system for client requirements information management in construction industry.

Please be assured that the information you provide in this questionnaire will be treated with due care and shall be used solely for the purpose of the research. No individual or organisation will be identified from it.

Evaluator's role and responsibility: ……

Company:……

Date:……

This evaluation uses Likert scale with values ranging 1 to 5 (1 = Strongly Disagree; 2 = Disagree; 3 = Undecided; 4 = Agree; 5 = Strongly Agree).
Please indicate how much you agree or disagree to the following statements with regards to eRIM framework and prototype system demonstrated in this session.

1. Instruction: Please mark (x) the area corresponding to the value that best describes your perception towards the client requirements management process in construction sector.

	Statement	**1**	**2**	**3**	**4**	**5**
i	Lack of lifecycle client requirements management could affect successful completion of building projects.					
ii	The current manual and paper-based process in managing client requirements information lacks efficiency and effectiveness.					
iii	Lack of a centralised storage and access of client requirements could affect their effective management.					
iv	Traceability between requirements is very important in the management of client requirements information management.					
v	Lack of proper coordination and control of the request for change process could affect the proper management of client requirements information management.					
vi	Impact analysis is relevant for effective client requirements information management.					

2. Instruction: Please mark (x) the area corresponding to the value that best describes your perception towards the impact of the enterprise requirements information management (eRIM) framework and the prototype system for effective client requirements management in construction sector.

	Factors	**1**	**2**	**3**	**4**	**5**
i	eRIM clearly represents the client requirements management problem in construction.					
ii	eRIM clearly defines a solution to client requirements information management problem.					
iii	The centralised web data-based system will facilitate collaborative and distributed access to client requirements information management.					
iv	The dependency links defined in the prototype will enhance traceability between requirements.					
v	The change management system will improve the manual and paper-based request for changes process.					
vi	The change management system will provide better integration of people and systems.					
vii	The change management system provides an improved dependency checking functionality for impact analysis.					
viii	The change management system provides a better facility to updating requirements information.					
ix	The change management system provides an improved and efficient communication of requirements changes through the Email notification functionality.					
x	In general the prototype system will contribute towards effective and efficient project management in construction.					
xi	If I had the prototype system in my day-to-day work, I would use it extensively.					

Provide additional comments about your perception of the Framework and prototype system which could be helpful for further enhancement.

……

……

……..

By Abdou Karim Jallow, PhD Researcher, Loughborough University

Appendix F: Sample Transcribed Interview Data

Questionnaire Interview on Requirements Management

Researcher: Abdou Karim Jallow **Respondent A(R_A): xxx**

13th November 2007

Thank you very much for honouring the request for this interview. Please be informed that the information you provide will be treated with due care and shall be used solely for the purpose of the research.

1. *What sort of projects (commercial, schools, hospitals etc) do your company specialise? What is your standing within the construction industry?*

   R_A: We don all sorts of project/buildings. We are not large enough to be in the top 10 construction companies in the country but are classified as a medium size enterprise with a turnover of about two hundred and fifteen million Pounds (£215, 000, 000).

2. *History shows that word processing and spreadsheet packages have dominantly been used with some few exceptions, databases to store requirements. What medium is used to archive or store client's requirements after contract sign-off?*

   a. *Do all stakeholders have access to the documented and stored requirements?*

   R_A: We keep all the information on site such as the letters, e-mails and drawings which are stored / archived on disc. We e-mail the drawings to the 'printers' who prints these and send us the hard copies as well as e-mails which we again archive on disc obviously for space. Actually most of the drawings we receive electronically are printed on hard copies on site. We keep the hard copies of the client requirements on site and also on the office file because we have to have one to relate to during the contract; we have to revert to it, it's easier.

When the Quantity Surveyor places orders to suppliers, we send the relevant part of the specification and the contract decision with the specified drawings and their requirements. The external project managers are not bothered about our subcontracting. We write to them to let the m know who we look to subcontract to. Unless the client has their nominated supplier, then we will go for those.

3. *Reflecting on some of the changes to the requirements such as the Morris Vermaport Lift to an evacuation lift and district heating to gas boilers and the time it takes for their procurement, what effect would it have if your procurement system is integrated with your requirements management system.*

   R_A: What we have is a procurement programme when we set our contract programme which states what the actual sequences; to come up what dates we provide a design programme to the Architect and the Structural Engineers to ensure that we have the drawings and information in time before we have to procure or subcontract. When we have all the drawings and information, from that design programme, we have a procurement programme and the Surveyor and I (Project Manager) know exactly what date we have to issue orders to ensure we fulfil our contract dates/programme dates.

   If we are given instructions throughout the contract by our client and there is a change or a variation, we notify the client which describes whether there will be an impact on the programme or procurement is going to impact on the actual contract period on site. The client then makes a decision. For instance if the installation or change to the lift would have ea major impact and results in finishing late to the contract, we will let the client know straight away why and is left with the client to make the decision if OK. If the decision is no, then we will not have the evacuation lift and we will stick to the original requirement. If the variation is quite early in the contract, it may only have cost effect but not programme or procurement implications. In this particular scenario, the original requirement was a ‘Morris Vermaport Lift’ and the client wanted to upgrade it to an ‘evacuation lift’ which was not a great deal of change; rather it

was a cost implication but no great deal of change as in procurement or programme.

4. *Sometimes, the client is unable to provide some of the requirements in detail. Such would be developed as the project progresses. E.g. architectural design suggestions to flooring, wall and furniture colours as well as lighting. Once agreed, would they be regarded as client requirements for the project? Who would be responsible for their management? Contractor, Client or Architectural designer*

   R_A: At the time of signing of signing the contract, colours or some minor little requirements are not discussed. The architects design team would have worked with the client for a long time even before a contractor is brought on board. They would have agreed a design or most of the design; colours would have been talked about. When a contractor is on board such as us; and the Architect produces drawings, we would meet the client the client and put forward certain colours what is thought to be required and is left with the client to approve it.

   The client is then given certain amount of time under the contract (14 days) to approve those. Once they are agreed, then they become contractually bonded. They eventually become risk to the client and any change could have cost implications or impact on programme over-run. Such requirements are not stored with the original requirements because at the start of the contract they would not have been specified in the specifications and drawings. They are only developed and approved when the contract starts.

5. *Requirements are constantly open to change throughout the lifecycle of a project. Different stakeholders may initiate change from different platforms such as meetings. Once a change is initiated and applied,*
   a. *How are changes initiated and what medium of representation is used for this?*
   b. *How is this reflected to the initial requirements?*
   c. *How are the changes communicated to all stakeholders?*

R_A: A client can initiate a change by sending a request for change by an e-mail to myself (Project Manager) asking for a quotation as a result of the change. We respond by telling the client whether we can implement the change or not and we provide a quote for it. The External Project managers will then be informed who will issue instructions to us on behalf of the client.

We as the contractor can also request a change by going directly to the client and the consultant detailing the change. The design team is copied the correspondence of the change requests and that will result in a drawing being revised by the Architect or Structural Engineer. That revised change drawing will then be sent for approval by the client and to all stakeholders.

6. *Client Requirements are important for use during the later phases of a facility's lifecycle after construction. The responsibility of a Project Manager ends when the building is completed and handed over to the client / users. However, the requirements would be vital for operations and eventually refurbishment and/or demolition. What sorts of documents are handed over and how are the requirements represented in this?*

   R_A: We handover O&M manuals, the drawings, specifications, types of materials (doors, locks, windows, glasses, etc), manufacturers, cleaning instructions and all the other information to help the client to maintain the building.

   Abdou: Do the documents handed-over include the requirements and the rationale to those requirements?

   R_A:No, not in the O&M manuals because that's part of the specification already been through during design and construction. We have already me the specification of the requirements, so the O&M manuals detail the type of materials, cleaning measures based on what is already been specified.

   Abdou: Are those specifications with all stakeholders?

R_A : Those specifications would have been with the client, Architect, Structural Engineer and that was issued as part of the contract document we have been through.

Questionnaire Interview on Requirements Management

Researcher: Abdou Karim Jallow **Respondent B (R_B): xxx**

Date: 13th November 2007

Thank you very much for honouring the request for this interview. Please be informed that the information you provide will be treated with due care and shall be used solely for the purpose of the research.

1. *What sort of projects (commercial, schools, hospitals etc) do your company specialise? What is your standing within the construction industry?*

   R_B: My company is perhaps involved in everything. We are a multidisciplinary construction consultancy company. Our sort of core skills are quantity surveying, project management, building surveying but also employ other specialists such as construction legal experts, construction & design management coordinators. We are split into sectors:

   a. Public sector: which does hospitals, schools, etc
   b. Private sectors: which does commercials, offices, retails, hotels, etc
   c. Infrastructures
   d. Affordable housing

   Those are our four main sectors.

   We are one of the 4 or 5 largest in the country and probably in Europe as well. We employ over 2000 people. Our turnover is around two hundred million Pounds (£200, 000, 000) and my role in the company is as 'Senior. Project Manager'

2. *History shows that word processing and spreadsheet packages have dominantly been used with some few exceptions, databases to store requirements. What medium is used to archive or store client's requirements after contract sign-off?*

   a. *Do all stakeholders have access to the documented and stored requirements?*

R_B: If you look at the traditional Quantity Surveyor role, we get information from the client. That information is given to us through different mediums (meetings) in which case, we as project managers will take that information and put into words. The design team will take that information and transfer it into drawings, specifications and brief. In most instances, we will take that brief from a client.

In terms of cost, information will be tabulated into an excel format or a version of excel format which is a specific software package we use in the company called xxxxx.

When we gather all the information, in this case the Architect produces a report at each design stage. The Lead Architect coordinates a report at stages A, B, C, D and E. That report encapsulates the client requirements in a single document and that is also maintained as an electronic copy. There is no database as such.

Abdou: How do stakeholders get access to these requirements?

R_B : Stakeholders are issued hard and electronic copies of the requirements. The Lead Architect (LA) can also produce them on the web and we can access them through an internet link but traditionally it's through a hardcopy and electronic. We cannot change anything on the web, only LA can.

3. *Reflecting on some of the changes to the requirements such as the Morris Vermaport Lift to an evacuation lift and district heating to gas boilers and the time it takes for their procurement, what effect would it have if your procurement system is integrated with your requirements management system.*

R_B: The change to the lift was that the client wanted a fire enabled evacuation lift and this was approved. The initial sign-off was a Morris Vermaport lift and was to be upgraded to an evacuation lift. Unfortunately the Morris Vermaport lift was ordered for. Somewhere down the communication line, the upgrade was not included in the order.

Yes, if you know what your requirements are upfront before getting sign-off, it will make life lot much easier when you are on-site. If you start with little brief, without understanding what is happening, then you make life really hell. In fact getting a clear brief is one of the most important.

4. *Sometimes, the client is unable to provide some of the requirements in detail. Such would be developed as the project progresses. E.g. architectural design suggestions to flooring, wall and furniture colours as well as lighting. Once agreed, would they be regarded as client requirements for the project? Who would be responsible for their management? Contractor, Client or Architectural designer*

   R_B: At tender stage when the contractor is putting price together, it doesn't really matter what sort of colours. Such requirements would not affect cost; they will allow enough amount of money. When it goes down the line and the contractor wants to know what colours need to be ordering, the Architect will produce finish drawings and suggest what colours that the client can have. The client will then select the ones he wants and those become the requirements. Any change to those would then go through the normal change process.

5. Requirements are constantly open to change throughout the lifecycle of a project. Different stakeholders may initiate change from different platforms such as meetings. Once a change is initiated and applied,
   a. How are change initiated and what medium of representation is used for this?
   b. How is this reflected to the initial requirements?
   c. How are the changes communicated to all stakeholders?

   R_B: Both client and contractor can request for a change to the initial requirements and as said before, this should go through the normal changes process using hardcopy. We sign hardcopies and convert them to PDF files and send to other parties.

Yes, let say if the colour of the chairs change, then the Architect will re-issue a drawing which will indicate that the colours have changed. They wouldn't necessarily go and change the specification.

In a more complicated project such as T5, the change request would be more complicated and may request a lot of signatories. That would be a good place to find out.

6. Client Requirements are important for use during the later phases of a facility's lifecycle after construction. The responsibility of a Project Manager ends when the building is completed and handed over to the client / users. However, the requirements would be vital for operations and eventually refurbishment and/or demolition. What sorts of documents are handed over and how are the requirements represented in this?

   R_B: We handover the 'As-built' document which is part of the O&M manuals which will have all the revised drawings; capturing and changes made to them during the contract period. It details everything such as what types of doors were used, so that if the client later is going back to it in 10 years, to replace/repair, he will know what sort of materials were used.

   Abdou: Would it include the rationale of the requirements?

   R_B : No, O&M manuals do not include that sort of information. The design history isn't included also included in the O&M. it would only include what was used in the building and how to maintain it; and where to get the materials when need for replacement.

   Abdou reflected on some points from the project meetings regarding complaints from people in a building the new one being built. They complained of headaches/migraine as a result of glare coming from the shiny glasses of the building. If the client decides to change the glass to much darker glasses and after 10/20 years somebody wanting to change the glass to a shiny glass wouldn't know the rationale behind that initial change.

Appendix G: Focus Group Transcript

Focus Group Transcript

Participants: Participant A - Senior Project Manager, Participant B - Project Manager and Participant C - Quantity Surveyor, Participant D – Professor of Construction Management,

Facilitator – Abdou Karim Jallow - PhD Researcher

Meeting date and Time: 3rd March 2009 – 10.35am

1. Introduction

Following introductions, The Facilitator gave an outline of the research being undertaken by Abdou Karim Jallow which was focused on Requirements Management in the context of construction projects. A brief outline was given on how requirements are documented for storage and retrieval, communication and distribution between all project stakeholders, how changes to the requirements are managed and impact analyse. The issues surrounding traceability, visibility and auditability were also outlined.

2. Research relevancy and importance

The Facilitator introduced historically, how construction projects run over budget and time which in most cases is as a result of lack of proper requirements management. That with proper requirement management, significant improvement would be realised by the construction industry in developing projects within budget and time and achieve quality of the built facilities as well as client satisfaction.

Participants confirmed the importance of requirements management and outlined their current methods to ensure that client requirements were identified at the Briefing stage of the project and any changes to these requirements monitored throughout the project. Details of Requirements were included within the Project Execution Plan. Changes in Requirements were monitored through Change Control Procedures, Changes being identified, and recorded together with the cost implications. Other approaches, such as Value Management were used to evaluate potential changes. Project execution plan is what they used within their projects.

3. Requirements repository and change management

The Facilitator introduced the concept of requirements repository as a central location for all client requirement information. This can be developed as a database system that can be accessed by all stakeholders through a web interface. The advantage of this is that all stakeholders will have direct access to the requirements and up-to-date for that matter. This will reduce the bottlenecks involved in storage and communication of the requirements, version control etc.

Change management was recognised to be complex to manage because of the number of processes a change goes through as well as the number of people involved. With a change management system, changes become much easier to manage and control because of the automation of the processes and improves on traceability and visibility as well as auditability.

To record these changes, participants' company used a common platform of software packages such as WORD, Email, Excel especially for costing, etc. The company offered to provide blank forms to show the types of data recorded as well as change request form and the process they go through. A risk register is also maintained by the company where changes are forwarded and monitored. They also informed the meeting that how changes are managed depends on the type of project employed and sometimes clients has preferences to what tools or system to be used; sometimes they are not ready to pay for such systems.

4. Project management systems

The Facilitator introduced for discussion that currently, no known system exists that manages construction project requirements from an information centric point of view as well as change control. This research aims to develop a framework and to validate that with a software prototype.

Participants also recognised the fact that any particular system that may be suggested should take in consideration of project management protocols such as the process protocol and RIBA. The company believed that web based tools such as 4Projects provided good facilities for managing requirements and represented the future platform for software based systems. Depending of the Client requirements it was sometimes necessary to use other project management systems, e.g. PRINCE2. There exists an in-house built project

management system called ‘xxx system’ within the company but is not used much and that 4porject is one to be explored more.

5. Conclusion and future collaboration

It was noted that Requirements Management was not easy to undertake and relied on the full participation of all members of the project team to evaluate the changes that occur. Requirements Management varied with the type of procurement method used by the client. (e.g. Procure 21)

The Facilitator and the Professor thanked the participants for their information and asked whether it would be possible for the company to contribute to the research on an ongoing basis through case studies, interviews with participants etc. The participants indicated that they had no objection to this in principle but that all such participation would need to be agreed at senior management level and would need to be costed internally. Participation would therefore need to be seen as cost effective. They requested that the researcher provide a ‘Research Action Plan’ detailing the form of participation required and when this would need to take place.

Appendix H: The three responses of the questionnaire on change and the change process

This brief study aims to investigate client requirements changes in construction projects. Specifically, it concentrates on change is processed.

Please be assured that the information you provide in this questionnaire will be treated with due care and shall be used solely for the purpose of the research. No individual or organisation will be identified from it.

A questionnaire on change and the change process

Name: **Respondent A – Project Manager – Case A Project**

1. How many change orders were requested in the project you were involved?

   32

2. How long does it take for a change order to go through the authorisation process?

   Varies widely between 12 and 60 days

3. How often are delays caused on decisions on the change orders? If any, what effects do the delays cause?

   Delays are usually caused by the time it takes to agree final costs with the main contractor and their sub-contractors. Variations are usually agreed in principle before the formal instruction is issued so don't normally affect progress on site

4. What medium do you use to communicate the change orders (Email, hard copy, digital documents (pdf, etc), telephone, online, projects extranet, others)?

   Drafts are usually circulated by e-mail but as they have to be signed by all the parties the final documents are hard copy

5. How do you assess impact of the changes in relation to other requirements?

   These are usually discussed by the design team with the contractor before a draft instruction is issued. At the time the building was built there was no formal discussion ahead of the instruction being issued but now any significant variations would be discussed by the Project Management Board before being implemented.

6. Do you document the rationale of changes? If so in what form?

   Not on this project though again this would now be done through a Project Management Board

Thank you very much for your time.
Abdou K Jallow, Department of Civil and Building Engineering, Loughborough University

This brief study aims to investigate client requirements changes in construction projects. Specifically, it concentrates on how changes are processed.

Please be assured that the information you provide in this questionnaire will be treated with due care and shall be used solely for the purpose of the research. No individual or organisation will be identified from it.

A questionnaire on change and the change process

Name: **Respondent B – Project Manager – Case B Project**

1. How many change orders did the client and/or designer requested in the project you were involved? Between what periods? 128 between Sept 08 – Dec 09

2. How long does it take for a change order to go through the authorisation process? On average two weeks this depends on the urgency. Final authorisation takes the time it takes to respond to an Email. It is the preparation of the costs prior approvals that takes the time and is dependent on the nature and magnitude of the change.

3. How often are delays caused on decisions on the change orders? If any, what effects do the delays cause? None on this project

4. What medium do you use to communicate the change orders (Email, hard copy, digital documents (pdf, etc), telephone, online, projects extranet, others)? Email backed up with hard copy

5. How do you assess impact of the changes in relation to other requirements? This is discussed at the Site and Design meetings prior to the preparation of the necessary paperwork, should it be agreed that it is a necessary change. Changes impacting on costs and programme are designed out so as not to, thus ensuring any sign off is a formality and does not delay the process.

6. Do you document the rationale of changes? If so in what form? This is carried out under the Change Control document.

Thank you very much for your time.

Abdou K Jallow, Department of Civil and Building Engineering, Loughborough University

This brief study aims to investigate client requirements changes in construction projects. Specifically, it concentrates on how changes are processed.

Please be assured that the information you provide in this questionnaire will be treated with due care and shall be used solely for the purpose of the research. No individual or organisation will be identified from it.

A questionnaire on change and the change process

Name: **Respondent C – Project Manager – Case C Project**

1. How many change orders were requested in the project you were involved?

Epdc 100 + and we have not completed yet!

2. How long does it take for a change order to go through the authorisation process?

1 week to 3 months depending on type form inception incl design

3. How often are delays caused on decisions on the change orders? If any, what effects do the delays cause?

Managed so that delays do not occur

4. What medium do you use to communicate the change orders (Email, hard copy, digital documents (pdf, etc), telephone, online, projects extranet, others)?

Email as PDF

5. How do you assess impact of the changes in relation to other requirements?

Request for changes are considered in term of the cost, programme and brief impact. Furthermore key parties including the client are consulted with regard to the impact of the change on the brief and the impact on other requirements.

6. Do you document the rationale of changes? If so in what form?

Changes are processed and documented. For RFC that are more significant these are discussed the project management Board.

Thank you very much for your time.

Abdou K Jallow, Department of Civil and Building Engineering, Loughborough University

Appendix I: Sample Field Notes Taken From Case A

(1) Research. Tues. 27. 11. 2007

Meeting observation

Project mgr.
Quantity Surveyor
Project mgr × Quantity Surveyor – External
Client Project Mgr.

---

* No Proper Communication btw external Consultant and Contractor regarding process for evacuation lift. As asked by external Consultant – To be emailed or telephone.

Programme & Progress (Conductwork Zone 1 & 2)

* Client doesn't understand what the Zones are. Project mgr promises to give copies after pointing to the ones attached.

* [illegible] requires for Schedule for changes. i.e. why changes, how much Cost etc.

* Design & Specification Changes agreed with client? How?

Design team meeting Next Tuesday

Change to the ceiling height. Project Mgr indicates "I think what he means". This is from another person but Project Mgrs doesn't know the rationale to the change. Client also thinks differently.

* E-mails use to notify of some change and requirements.

Section 12.

Changes to specification causing delay in procurement of materials & Sub-Contractor Orders. (Flooring specification changes, Immersion tank requirements, gas boilers heating changes, lift spec.

* Non-Conformant Report? How is it produced? excel? Does client and have access to this apart from meetings?

How are the requirements stored. Are they / How are they access by all parties. Does change reflect immediately to all instances.

Requirement change process. This defines how the change information is initiated by the client to the project mgr back and then to the external project mgr.

Appendix J: Sample Field Notes Taken From Case B

Tape recording (2B)

[redacted] Project Meeting 05-05-2009. 10 am

① Progress Report No. 8. – Total 62 weeks → 31 weeks gone.
* brick wall laying Completed * floor decoration Completed.
* M&E Selection in progressinon.

② Design Team Report. – [redacted] – ?
* All Information recieved and forwarded to all parties. ? What info.
* Meeting room 3 is not to have a ------ So will have to omit.
* To find out if [redacted] requires amplifier or ..... ??
(recording 13:28)

* Reception Desk and hotdesk: Recieved brief and currently progressing on design.

* Wifi – location – [redacted] submit email over the weekend, ~~meeting~~; sld be in yr inbox.

* Info Issued: Spec, sketches, design, ------

* Omit – ------ [redacted] to issue instruction for that?
What is Omitted? and what process does this instruction goes?
(recording) 20.58)

* Issued and rec'd change on edges of ---?? (23:20)

* To go and look at paint to help materials ordered.

③ Contract Programme (28:25..)
* Review Gantt chart. – In general – Comfortable – on programme.

④ Change Instruction Tracker. (30:18): How is this done, (Manual or.

* 38:18 – Satellite fixing point. May on top of the roof incase [redacted] wants to fix a Satellite later. (This is important to be defined and put in the requirement repository to be accessed during operations for Sual purposes.

② 05-05-2009

*It is observed that Extranets exits but are not widely used?? — - - -

⑤ Info required Schedule
Land Scaping - - -
* We received it but have to review the email [redacted]" (46:02)

⑥ Design Development Tracker
ⓐ Some changes within the design (doors & glass) changes. requests Clients approval to that. This needs to be clearly defined and put in requirements repository for future under standing. Client requests paper work on those changes. (58,59:1hr)
Questn: Are these design development incorporated within the initial brief?)
Observation: Some of the design development or variations results to either Some Savings or extra Cost*. Project mgr (consultants) wants to raise request for change to such developments. Clearly there would then be info for audit purposes but what abt those that may not impact on cost? Would info be available to them.?!

* lighting protection needed but was not included in the design. Needs Client to be aware. (01:05).

[BREAK: 01:15] —
Tape recording ㉔

*General window design will be upgraded to included the motorisation. (2mins)

NEXT DESIGN TEAM MEETING
THUR. 14TH MAY 09.

* Blinds to be fitted on top floor. Not Sure if was requested in the Specification. Though was for the ground floor. BREEAM assessors to confirm.
* Carpets.
Some decisions are made on a gentlemanly agreement but Contractor requires a Contractual agreement. [14,15 mins]
WIFI: [redacted] wants wifi in the building but not specific which part or the whole.

[redacted] Meeting 05-05-2009

· Previous Minutes

* Needed to know if Audio is required in the Conference rooms. This not specified in the brief.
* Induction loop separate from Audio provision. Costing to be done for the Induction loop.

Observation: Costing needs to be done base on clear stated requirements. Costing could potentially ~~be~~ incorrect if requirements not stated/or stated clearly, or not comprehended.

Wifi: 40 mins - 44 mins
Location of wifi - [redacted] needs to find out from his Board.

* Blinds: Specified on the bottom floor: Weather needed throughout the building.
* Comments: blinds more bcos of glare rather than direct sunlight! (56, 57, 58 mins).

* Lighting to Coffee Area.
→ Info received from [redacted] ... [~~56,5~~ 01:04/5 mins]

Observation: Some of the emerging requirements are informed through email to individuals ~~not~~ unknown to the rest of the team. * Clearly it should be an industry best practice to use a defined and dedicated system to use for requirements and changes to enable collaborative working.

LUNCH!

BREEAM Assessment:
Blinds over or ontop of windows need to have client agreement that it is needed ~~be~~ in order to gain Assessment Credit.

Appendix K: Sample Field Notes Taken From Case C

(1) Voice recordings 21+22

Project Meeting Observations [redacted] 06/04/2009 11AM

2.2. Survey Procurement update: Check with Ian as he sent a format to [redacted] Which was not part of the brief.

2.3. ~~Simon~~ Programme Review and key Milestones.
[redacted] Sent an email to [redacted] with ~~an email~~ a URL link of the Stage C report. He ~~was~~ asked if he has the soft copy with him at the meeting but 'no'. [redacted] ([redacted]) requested to be forwarded the same link to distribute to his Project mgmt Board. The issue of sending the same link to all members of the ~~Board~~ was an issue. The Architects decided to send hard copies through express delivery and also 5 CDs as electronic as [redacted] needs these for his meeting with the Director of facilities by close on Wednesday.

2.6. Request for Change → 25-mins 28 mins recording.
There is none as of today - - - -

2.7. [redacted] update.
Cost plan requested by [redacted]. [redacted] promised to send close of Wednesday

[redacted] Sent an report to [redacted] and [redacted] (Mechanical Engineers)
Which details out where the University is and where it wants to be. Detailing things such as Sustainability, heating, data networks etc. Unfortunately, [redacted] rep at the meeting did not see that document. Discussion on this could not progress as would have if [redacted], had seen the doc (report). [redacted] ~~needed to know~~ know the connections for gas, water, central heating, but not voice and data which IT Services should let know. For timescale these connections needs to be known. [redacted] later claimed to have seen the report.

Conf. Planning report sent to [redacted] who needs to send to [redacted]. This is a clear testimony that any requirements management framework should incorporate a facility of sending and receiving reports relevant to requirements.

(2)

Project meeting observations. 06/04/09

* It appears most of the decisions are made during the project meetings. However there are times when certain docs are not available to refer to for decision making. Attendants keep saying "I cannot remember what is on the doc/report;" "I have not brought the doc. It is then necessary for successful project mgmt meeting to have a projector showing project docs from a central database where the meeting can refer to.

2.9. Car Park.
There is a suggestion that the car park sld be multi-use (Parking & sporting such as netballing) though this is not fully discussed fully at [redacted] level. There is an issue of building something that costs a lot of money that would not be used for other purposes or maintenance becoming a problem. This requirement needs to be discussed.

2.10. Borehole
[redacted] mentioned: "Providing a borehole isn't part of the brief."

2.12.6 BREEAM Pre Assessment Review 1:32 mins recording.
[redacted] to review - Types of materials, building leakages etc - - - - - check recording.

2.12.7 Main Contract Procurement update
[redacted] relocated some of the services functionality of the building. e.g moving some of the toilet location. (the question is are these updated on the brief?? - -) check recording 1:35 mins

* Stage C of the report details the types of materials the Architect is suggesting to use on the building. 1:40 recording.
[redacted] asked if the issue of sustainability is being incorporated in these.
* Based on the maximum occupancy level (1000) the Architect also added 6 extra toilets. The M&E ([redacted] has to look at how this impacts on their services. They have not known this before until at this meeting; Meaning also M&E Stage C drawings would be diff. from Architects.

Project meeting observation 06/04/09. (3)

* Video facility to be incorporated in the building. This was not part of the brief. [redacted] to put in a request for change and take it through the Board for authorisation looking at cost implication, and Architect to look at design implications.

Any O.B.: [redacted] needs ~~requested~~ all requested info. to be sent by midweek and through the communication channel i.e. through [redacted]

14.00 – 15.00 meeting with [redacted]

User request for a 'Server' room. This will have an impact on room sizes.

* [redacted] to organise a user group meeting as well as meeting with IT services abt their infrastructure. These meetings will come out with some user requirements.

* It was identified that the revision (current version) of the 'Risk and items to be clarified' for the evacuation strategy was not the one on the Stage C report. [redacted] Confirmed that the current version is '01' instead of the '00' on the report. [redacted] Confirmed that '00' was the one sent to them.

* [redacted] to send 'Stage 2' report to [redacted].
⇒ What is this 'Stage 2' from the user?

Appendix L: List of Publications

Conference Papers

Jallow, A.K; Demian, P; Baldwin, A and Anumba, C. (2010). An Integrated Requirements Management System for Construction Projects, In: Tizani, W. (Ed) In Proceedings of the 13th International Conference on Computing in Civil and Building Engineering (ICCCBEXIII) and the 17th EG-ICE International Workshop on Intelligent Computing in Engineering, June 30 – 2 July 2010. The University of Nottingham, UK, Nottingham University Press, Paper 149, PP. 297. ISBN: 978-1-907284-60-1.

Jallow, A. K; Demian, P; Baldwin, A. N. and Anumba, C.J. (2010). Development of an Innovative Framework for Clients' Requirements Information Management in Construction Projects, In: Anumba et al. (Ed) Proceedings of the 6th International Conference on Innovation in Architecture, Engineering and Construction (AEC), June 9-11, 2010, Penn State University, USA. pp 298-301.

Jallow, A. K; Demian, P; Baldwin, A. N. and Anumba, C. J. (2009). BPM-driven construction client requirements change management. In: Dikbas, A(Ed), Ergen, E(Ed) Proceedings of CIB W078 26th International Conference, Managing IT in Construction, 1-3 October 2009, Istanbul Technical University, Istanbul, Turkey. pp 249 - 256.

Jallow, A. K., Demian, P., Baldwin, A. N., Anumba, C. J. "(2008). Lifecycle approach to requirements information management in construction projects: State-of-the-art and future trends". In: Dainty, Andrew (Ed.) Proceedings of 24th Annual Conference of Association of Researchers in Construction Management ARCOM, September 1-3, 2008, University of Glamorgan, Cardiff, Wales. Vol.2, pp 769-778.