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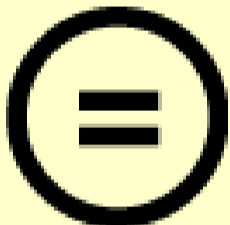
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**A METHODOLOGY FOR THE 'LIVE' CAPTURE AND
REUSE OF PROJECT KNOWLEDGE IN CONSTRUCTION**

by

HAI CHEN TAN

A Doctoral Thesis

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Abstract

The importance of capturing and sharing useful knowledge from construction projects has been recognised by the construction industry. However, issues such as the loss of important insights due to the time lapse in capturing the knowledge, the need for sharing the knowledge captured as soon as possible in order to maximise the benefits brought about by reusing the knowledge, and the need to share the knowledge before the opportunities for reusing the knowledge diminish have not been adequately addressed. To address this, it is crucial for knowledge to be captured as soon as possible once it is created or identified (i.e. 'live') in a collaborative environment, and presented in a format that will facilitate its reuse during and after the project. This research was aimed at developing a methodology that facilitates the 'live' capture and reuse of project knowledge in construction.

An extensive literature review was first conducted on the concept of knowledge management and the current practices for managing project knowledge. Subsequently, case studies involving six companies were carried out to investigate the shortcomings of current practice and the end-user requirements for the capture and reuse of project knowledge. These requirements informed the development of the methodology for 'live' capture and reuse of project knowledge. The Web IS Development Methodology (Avison and Fitzgerald, 2003) employing ASP.NET 2.0 was adopted to encapsulate the methodology into a Web-based prototype application. The evaluation of the prototype revealed that the methodology can enable project knowledge to be captured and shared 'live' across different organisations without significant additional workload and costs.

It is concluded that the 'live' capture and reuse of project knowledge in construction is important in preventing knowledge loss and helping to harness the project knowledge captured. A combination of both KM technologies and techniques is essential for the effective management of tacit and explicit knowledge. The prototype application developed can facilitate the 'live' capture and reuse of project knowledge as shown by the results of the evaluation. There is scope for enhancing this study by exploring the integration of the prototype application with other information systems, and the use of software agents to automatically locate useful knowledge from the Internet and project extranets. The methodology developed will help construction organisation to leverage their knowledge in a timely way to meet the challenge of today's fast evolving world.

Dedication

*This thesis is dedicated to
my mother, my late father,
and my wife*

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Chapter 1 Introduction

This chapter introduces the research project and briefly describes the background. It then justifies the need for the research, and identifies the aim and objectives, and the research methodology adopted. It finishes with an outline of the thesis's layout and contents.

1.1 Background

According to Drucker (1993), we have entered the age of knowledge economy where knowledge has sidelined both capital and labour to become the 'sole factor of production'. In a knowledge economy, knowledge is regarded as the single most important asset of organisations (Stewart 1997). An organisation's competitive advantage lies in the knowledge residing in the heads of its employees and the capability to harness the knowledge for meeting its business objectives, for continuous improvement and for avoiding the repetition of past mistakes (Demarest, 1997; Davenport *et al.*, 1997; Drucker, 1998; Bollinger and Smith, 2001). Related to this, some companies have started to audit the value of their knowledge and include this information in the annual report to stakeholders (Davenport et al, 1997).

Given the growing importance of knowledge towards the success and even the survival of an organisation, it is not surprising that the significance of a systematic or organised knowledge management (KM) approach is being increasingly recognised. KPMG's (2003) survey results revealed that the knowledge management practice in the organisations surveyed had improved from one mainly characterised by the lack of an established implementation strategy in 1998, to one approaching a higher maturity level with greater board/management support in 2002/2003. In the context of construction industry, a survey of construction organisations revealed that about 80% perceived KM as having the potential to provide benefits to their organisations (Carrillo *et al.*, 2003). However, in terms of implementation, knowledge management in the industry is still at its infancy with various shortcomings in the practice for managing knowledge relating to and arising from a project (Khalfan et al, 2002). The rationale for the research hence stems from the need to

study the main shortcomings for managing project knowledge in construction with an aim to address them as appropriate.

1.2 Justification of the Research

The shortcomings of knowledge management practices in construction are closely related to the industry's characteristic of a predominantly project-based industry. A typical construction project involves many people and organisations with different specialisations or expertise forming a virtual organisation for the duration of a project. These projects are usually unique, very complex and require the combined knowledge and expertise of all the project team members in order to deliver the project successfully. Hence, it is not surprising to find that most of the knowledge of the construction industry is generated in projects, by staff belonging to different disciplines, during the process to deliver a custom-built facility in accordance with the client's requirements and business objectives.

The knowledge generated from a project can be about the best practices learned on how to carry out tasks in a more efficient way, or some negative lessons learned which have led to losses and slowed down the progress of the project. The ability to manage the knowledge generated from the projects (including the capture of project knowledge and its subsequent transfer) not only can help to prevent the 'reinvention of the wheel' and the repetition of similar mistakes, but also serve as the basis for innovation and overall improvement. This is crucial in view that knowledge, particularly the lessons learned, is actually acquired from both the positive lessons learned and the mistakes made at a cost to the organisation. However, recent evidence revealed that the ability to learn from within and across projects are critical but difficult to achieve (Kamara et al, 2003). This is mainly due to the following reasons:

- In a project, each individual only knows bits of the whole story of the project (Kerth, 2000). Knowledge created in a project is scattered in the memory of various project team members but none retains a complete set of the knowledge created. Therefore, when the virtual organisation or the project team formed for a project is disbanded upon the completion of the project, the knowledge retained by each individual

members is likely to be minimal. Most of the knowledge learned from the project is not shared and is therefore lost;

- Some companies have tried to address the aforementioned knowledge loss problem by conducting Post Project Reviews to capture the knowledge learned after the completion of a project. However, the success of Post Project Reviews are often undermined by the lack of time for conducting it as other project team members may be transferred to and therefore involved in new projects. The effectiveness of Post Project Reviews in facilitating the capture and reuse of knowledge learned is also affected by the lack of a suitable format for representing the knowledge captured, and a mechanism for sharing the knowledge captured across projects for reuse. In addition, humans are not without weaknesses and this is particularly so when it comes to memorising facts (Ebbinghaus, 1885). The time lapse in capturing the knowledge learned through Post Project Reviews and the current practice of condensing the knowledge learned into bullet points have led to the loss of important details about the knowledge (Kamara et al, 2003);
- The reassignment of individuals or even the whole project team from one project to another as an attempt to transfer the knowledge acquired makes organisations vulnerable when there is a high staff turnover (Kamara et al, 2003). This is substantiated by the persisting high staff turnover rate, which was 20.2% in 2003, in the UK's construction industry (CIPD, 2004). In addition, this method does not proactively facilitate the sharing of knowledge learned from a project with others who are not involved in that project. Furthermore, it also suffers from the aforementioned human weakness in memorising facts; and
- Reluctance to share knowledge amongst the project team members due to commercial sensitivity, corporate restrictions as to the sharing of information and knowledge (Barson et al, 2000), and the fact that the organisations collaborating in one project may actually compete elsewhere (Kamara et al, 2003).

One potential solution for the above problems could be a methodology that is capable of:

- Facilitating and encouraging project team members to share important knowledge; and

- Storing the knowledge learned in a format that helps the sharing and understanding of its content; and
- More importantly, enabling the capture and reuse of knowledge in real-time or as soon as possible after the knowledge is created to address the knowledge loss problem due to time lapse in capturing that knowledge.

The importance of 'live' capture of knowledge is supported by the recent survey of construction and client organisations involved in PFI (Private Finance Initiative) projects where it was identified as crucial by over 70% of the organisations (Robinson et al, 2004). Kamara et al (2003) contend that a methodology that facilitates the 'live' capture and reuse of project knowledge allows the knowledge captured from initial stages of a project to be reused at subsequent stages of a project, and helps to ensure that a more complete set of project knowledge is captured. Using the term 'information' synonymously with 'knowledge', McGee (2004) also states that the capture and presentation of real-time 'information' is crucial in helping to:

- Prevent mishaps from happening owing to the capability to share lessons learned and critical information in real-time;
- Seize the opportunities to reuse the knowledge captured by making knowledge available for reuse once it is captured; and
- Maximise the value of reusing knowledge, particularly if the benefit brought about through reusing the knowledge is time-related.

A review of existing literature indicates that a number of research projects have been undertaken to help improve the management of knowledge in the construction industry. These research projects focused only on either specific types of knowledge (e.g. C-SanD (2001)), specific project phases (e.g. KLICON (McCarthy et al. 2000)), specific types of construction organizations (e.g. SMEs in Boyd et al (2004)), or strategic issues of managing knowledge in construction (e.g. CLEVER (Kamara et al, 2003)). The need for an approach which is capable of the 'live' capture of project knowledge, however, has not been adequately addressed. This research therefore addresses the importance of developing a methodology that facilitates the 'live' capture and reuse of project knowledge in construction.

1.3 Research Aim and Objectives

This research aims to develop a methodology for the 'live' capture of reusable project knowledge that will reflect both the organisational and human dimensions of knowledge capture and reuse, as well as exploit the benefits of technology. The 'live' capture of reusable project knowledge is defined, within the context of this research, as the capture of the knowledge as soon as possible once it is created or identified. This will be achieved through the following objectives:

1. To investigate the current practice of knowledge capture and identify the requirements for knowledge reuse by various end users of project knowledge. This will ensure that the right kind of knowledge is captured to avoid knowledge overload;
2. To explore various concepts and techniques that would facilitate the 'live' capture of reusable project knowledge in construction;
3. To develop a methodology for the live capture of reusable knowledge on construction projects; and
4. To test the methodology on a web-hosted project environment (for easy access to all project participants) and evaluate its effectiveness using live projects.

1.4 Research Methodology

This section outlines the research methodologies adopted for gathering the essential information for the purpose of the research, and for the development as well as the evaluation of the methodology developed. The details are as follows.

An extensive literature review was conducted as the ground-clearing and preparatory work for the research. First, it investigated mainly the concept of knowledge management, the distinctions between the different types of knowledge, the various knowledge management research projects in construction, and the current practices for knowledge capture. Second, it helped to establish the importance of 'live' capture and reuse of project knowledge in construction and provided the essential background knowledge prior to conducting the case studies. The location of the relevant literatures were carried out through Loughborough University Library Catalogue (i.e. Loughborough OPAC), Loughborough University

Metalib (i.e. an integrated search engine that facilitates searching across different databases and electronic journals at one time), CD-ROM based information products, and other internet search engines (e.g. Google™).

A case study approach was selected because it provided an in-depth insight into the current approaches for the capture and reuse of project knowledge within case study companies and end-users' requirements for knowledge capture and reuse. The case studies involved semi-structured interviews with eighteen senior staff from six companies whose positions ranged from Group Knowledge Manager to Company Partner to ensure that a comprehensive view was obtained. Each interview lasted one to two hours and was supplemented by presentations of the IT tools used for managing knowledge and sample documents showing the format used for capturing knowledge. The shortcomings of current practices and end-users' requirements identified were then analysed to formulate the methodology for the 'live' capture and reuse of project knowledge in construction. The findings of the case study revealed that a Web-based prototype application was required to help facilitate the 'live' capture and reuse of project knowledge.

A Web Information Systems Development Methodology (WISDM) proposed by Avison and Fitzgerald (2003) was used for the development of the prototype application. WISDM is a variant of Rapid Application Development (RAD) which is designed to address the specific requirements for the development of Web-based database and knowledge base. These include facilitating fast delivery, and emphasising the design and user-interface requirements as well as the security concerns for the development of Web-based information systems. These are often not fully addressed by other development methodologies. Based on the findings of the case study, the prototype application was developed on a personal computer using Microsoft™ ASP.NET Visual Basic 2.0 and Microsoft™ SQL Server 2005 Express Edition. The evaluation of the methodology developed was conducted subsequently.

The evaluation for the methodology involved ten participants from the four case study companies. It covered mainly one-to-one demonstrations of the operations of the prototype

to the participants and a session for them to experiment with the prototype application. A questionnaire was used to evaluate the prototype application against the end-users' requirements for developing the methodology for 'live' capture and reuse of project knowledge and to obtain suggestions for improving the methodology from the participants. The prototype application was further refined based on the feedback received from the evaluation.

1.5 Thesis Layout and Contents

The thesis is organised into eight chapters as detailed below:

Chapter 1 - Introduction: This chapter introduces the research topic and briefly describes the background. It then justifies the need for the research and identifies its aim, objectives, and the research methodology adopted. It finishes with an outline of the thesis's layout and contents.

Chapter 2 - Knowledge Management ~ A Review: This chapter reviews the definition of knowledge, the different perspectives and processes of knowledge management, shortcomings of current practice for knowledge capture and reuse in construction, knowledge management research projects in construction, and the importance of the 'live' capture and reuse of project knowledge in construction.

Chapter 3 - Knowledge Capture and Reuse: This chapter presents the reviews of the potential types of reusable project knowledge in construction, the learning situations where most of the new learning are created, the current practice for the capture of knowledge focusing on the capability to facilitate the 'live' capture of project knowledge, and the soft (organisational, cultural and human) issues that affect the knowledge capture and reuse.

Chapter 4 - Research Methodology: This chapter describes the various research methodologies available and that adopted throughout the research project. It first reviews a range of research methodologies and the methodologies for the development of information systems (IS). It then justifies the use of a case study approach for the research,

and the use of the Web Information System Development Methodology (WISDM) for the purpose of developing the associated information system. It also explains the activities undertaken to achieve the objectives of the research.

Chapter 5 - Knowledge Reuse Requirements: This chapter presents the case study findings and analysis of the nature and characteristics of reusable project knowledge, types of reusable project knowledge in construction, learning situations, the current approaches for knowledge capture, and end-users' requirements for knowledge capture and reuse.

Chapter 6 - Development and Operation of a 'Live' Capture Methodology: This chapter presents the structure of the 'live' capture and reuse of project knowledge framework, the system architecture of the prototype application, the development of the prototype application using ASP.NET 2.0 and Microsoft™ SQL Server Express 2005, and the operation of the prototype application.

Chapter 7 - Testing and Evaluation of Prototype: This chapter describes the definitions, procedures and results of the methodology adopted for the testing and evaluation of the prototype developed. The rationale for selecting the Acceptance Test and Entity-Life Histories Test as the tools for testing the prototype application is discussed. The results of the evaluation are presented and analysed in detail.

Chapter 8 - Conclusions and Recommendations: This chapter brings together the findings of the research and draws conclusions with specific reference to the research objectives. This chapter also highlights the limitation of the research and makes recommendations for further research.

The end of the thesis includes references and appendices used. The next chapter covers the review of the concept of knowledge management and the importance of 'live' capture and reuse of project knowledge in construction.

Chapter 2 Knowledge Management – A Review

This chapter reviews the definition of knowledge, the different perspectives and processes of knowledge management, shortcomings of current practice for knowledge capture and reuse in construction, knowledge management research projects in construction, and the importance of the 'live' capture and reuse of project knowledge in construction.

2.1 Defining Knowledge

In the context of knowledge management, knowledge is defined in various ways reflecting different research perspectives. Most of the definitions of knowledge fall into two categories: knowledge can be defined by comparing or relating it to data and information (e.g. Kanter, 1999; Marshall, 1997; Burton-Jones, 1999), or the knowledge can be defined as the knowledge per se (i.e. without directly linking knowledge to information and data, such as Davenport and Prusak, 2000; Nonaka and Takeuchi, 1995; OECD, 1996; Rennie, 1999).

For the former, knowledge is considered as an entity which is at a higher level and authority than data and information (Stewart, 1997). Data is said to be a set of discrete facts about events (Davenport and Prusak, 2000), while information is 'data endowed with relevance and purpose' (Drucker, 1998) which can be created by adding value to data through contextualising, categorising, calculating, correcting and condensing it (Davenport and Prusak, 2000). Knowledge is 'actionable information' (O'Dell et al, 1998; Tiwana, 2002) which 'gives one the power to act, to make decisions that are value producing' (Kanter, 1999). In the real world, however, a clear cut distinction between knowledge, information and data is not always possible as the differences between these terms are just a matter of degree (Davenport and Prusak, 2000). Furthermore, depending on the relevance of the knowledge and knowledge-base of individuals, knowledge for one person may be interpreted as information to others and vice-versa (Bhatt, 2001).

The second perspective defines knowledge as the knowledge per se, i.e. by depicting knowledge's characteristics, quality and constituents rather than contrasting it with

information and data. Hence, it avoids the intriguing distinction between knowledge and information in particular. An important example within this category is Davenport and Prusak's (2000) definition of knowledge as 'a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information'. Apart from this, knowledge is also defined as a series of know-what, know-how, and know-who (OECD, 1996; Rennie, 1999), a 'dynamic human process of justifying personal belief towards the truth' (Nonaka and Takeuchi, 1995) and the product of learning (Orange et al, 2000). The definition by Davenport and Prusak (2000) which has captured the various subtle features of knowledge is hence preferred for the purpose of this research.

2.2 Knowledge Management

Knowledge management (KM) generally deals with the systematic and organised attempt to use knowledge within an organisation to transform its ability to store and use knowledge to improve performance (KPMG, 1998). There are a plethora of definitions for knowledge management available, all attempting to encapsulate what knowledge management is and how it should be done (e.g. Quintas et al, 1997; O'Leary, 2001; Diakoulakis et al, 2004; Nicolas, 2004), but no consensus has hitherto been reached. The perspectives of knowledge management which are most relevant to this research are as follows:

- Functionalist vs. Interpretivist (Venters, 2002);
- Information Systems vs. Human Resource Management;
- Interdisciplinary perspective (Jashapara, 2004); and
- Soft and Hard approaches (Kamara et al, 2003).

Other perspectives include radical humanism and radical structuralism perspectives (Schultze, 1998), process-centred and product-centred perspectives (Mentzas et al, 2001), contingency perspective (Becerra-Fernandex and Sabherwal, 2001), process and interaction views (Rollett, 2003), artefact-oriented, process-oriented and autopoetic-oriented epistemology perspectives (Christensen and Bang, 2003). The aforementioned four most relevant perspectives are described in the following section.

2.2.1 Functionalist vs. Interpretivist

Applying the Burrell and Morgan's (1979) framework of social and organisational inquiry, Schultze (1998) identify four paradigms of KM research, namely radical humanism, radical structuralism, interpretivism and functionalism, as shown in Figure 2.1.

THE SOCIOLOGY OF RADICAL CHANGE		O B J E C T I V I T Y	
S U B J E C T I V I T Y	Radical humanism <ul style="list-style-type: none"> • Knowledge as the social practice of knowing • Value of knowledge and work is contested and serves as a source of conflict 		Radical structuralism <ul style="list-style-type: none"> • Knowledge as an object that can exist independently of human action and perception • Value of knowledge and work is contested and serves as a source of conflict
	Interpretivism <ul style="list-style-type: none"> • Knowledge as the social practice of knowing • Consensus about the value of knowledge and work 		Functionalism <ul style="list-style-type: none"> • Knowledge as an object that can exist independently of human action and perception • Consensus about the value of knowledge and work
	THE SOCIOLOGY OF REGULATION		

Figure 2.1: Four Paradigms in Knowledge Management Research (Schultze, 1998)

Within the paradigms, there is a continuum between the subjective and objective perspectives. From the objective perspective, knowledge is considered as an object waiting to be discovered and which can exist in a variety of forms (e.g. tacit and explicit) and in a variety of locations (e.g. in the individual, group or organisation) (Schultze, 1998). From the subjective perspective, it is asserted that knowledge is continuously shaping and being shaped by the social practices of communities, and cannot be located in any one place because it cannot exist independent of human experience and social practices of knowing (Schultze, 1998). In addition, these paradigms can also be contrasted by analysing how 'knowledge work' and the value of associated knowledge are viewed. From the sociology of regulation perspective, knowledge work is deemed necessary following the shift towards the knowledge economy and the value of knowledge is acknowledged (Schultze, 1998). However, from the sociology of radical change perspective, it is asserted that knowledge work is just 'another development in the political economy of capitalism' and knowledge is devalued through 'technologization' (Schultze, 1998).

Among the four paradigms, current research in KM is dominated by functionalism which is

frequently contrasted with interpretivism as there is a 'paucity of radical structuralist or humanist perspectives in knowledge management research' (Jashapara, 2004). The weight of both the radical structuralist and humanist perspectives is very likely being affected by their inability to accommodate the post-structural theories (Schultze, 1998). The aforementioned paradigms are therefore being combined into a 'critical perspective' to accommodate the post-structural theories (Schultze, 1998). Venters (2002) disregards the radical structuralist and humanist perspectives, and concentrates only on functionalist and interpretivist perspectives:

- *Functionalist perspective* - Apart from inheriting the characteristics of the objective perspective, the functionalist approach is highly scientific, employing accounting methods, codification and structures to exploit knowledge, and depends heavily on technology and 'database-led activities' to achieve these objectives (Venters, 2002).
- *Interpretivist perspective* - This approach inherits the characteristics of subjective perspective and focuses on supporting the social structures and processes within which knowledge is shared (Venters, 2002). This perspective does not view technology as the solution by itself, but rather as support to the social activity of sharing knowledge (Venters, 2002).

2.2.2 Information Systems vs. Human Resource Management

The current definitions of KM are predominantly from the information systems and human resource management perspectives (Jashapara, 2004), which correspond to the technocratic and behavioural schools of KM proposed by Earl (2001). From the information systems perspective, KM is concerned with the use of ICT to facilitate the capture, deployment, access and reuse of information and knowledge (O'Leary, 2001), whereas the human resource management perspective emphasises the establishment of means to motivate and facilitate knowledge workers to develop, enhance and use their knowledge in order to achieve organisational goals (Beijerse, 1999). However, leveraging knowledge through ICT alone is often hard to achieve (Walsham, 2001; Rollett, 2003; Siemieniuch and Sinclair, 1999) as there are human, cultural and organisational issues such as reluctance to share knowledge which are not readily resolved by ICT. Conversely, a purely human resource management approach is not going to benefit from the faster, cheaper and broader

source of data and means of communication to enable people to generate and share knowledge offered by ICT. Therefore, it is argued that an integrated approach of KM combining information systems (technology) and human resource management (people) synergised by the benefits of both perspectives is likely to be a more viable option (Davenport, 1998).

2.2.3 Interdisciplinary Perspective

Jashapara (2004) contends that KM has its roots in various disciplines, namely anthropology, economics, sociology, strategy, management science, human resource management, information science, philosophy, psychology and computer science. It is therefore argued that an integrated, interdisciplinary and strategic perspective of KM is necessary for a KM initiative to succeed (Jashapara, 2004). Based on this assertion, Jashapara (2004) groups the various KM disciplines into four dimensions (see Figure 2.2), i.e.:

- Strategy;
- Organisational learning;
- Systems and technology; and
- Culture.

Jashapara (2004) argues that the strategic purpose of KM is to increase intellectual property and enhance organisational performance. Organisational learning, which comprises individual, group and organisational level learning (Crossan et al., 1999), is the process of improving actions through better knowledge and understanding (Fiol and Lyles, 1985) within organisation. In order to fully explore and exploit knowledge, systems and technology are crucial to the facilitation and enhancement of the cycle of knowledge creation, capture, organisation, evaluation, storage and sharing (Jashapara, 2004). In addition to the systems, and technology and organisational processes, the interdisciplinary perspective also addresses the crucial cultural and change management dimensions for the implementation of KM as many well planned initiatives have been futile because of overlooking these dimensions (Jashapara, 2004).

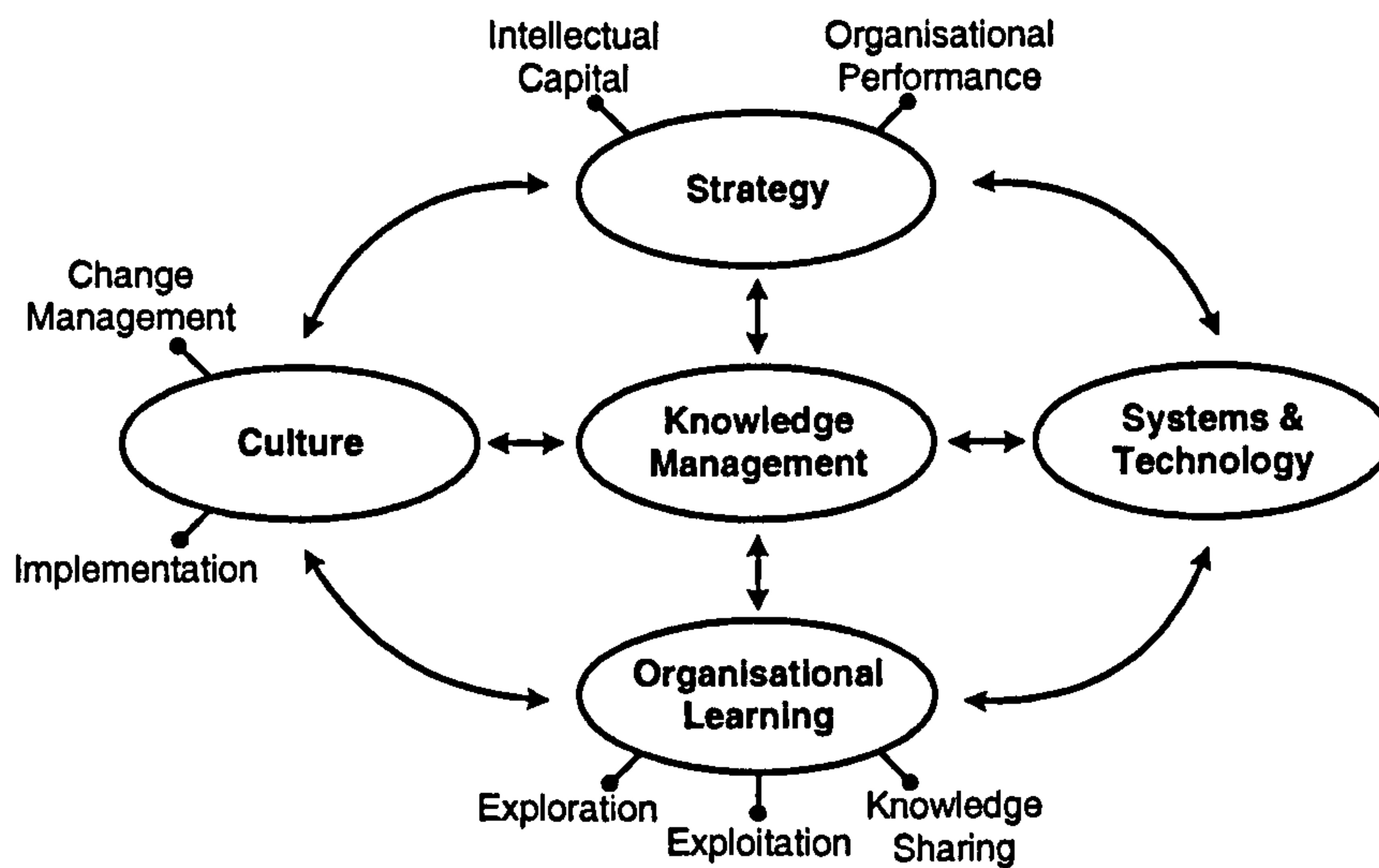


Figure 2.2: Dimensions of Knowledge Management (Jashapara, 2004)

2.2.4 Combined Soft and Hard Approaches

A combined ‘soft’ (i.e. organisational, cultural and people issues) and ‘hard’ (information and communication technologies – ICTs) approach is introduced by Kamara et al (2003) for the ‘live’ capture of knowledge in construction. The main feature of the ‘live’ capture methodology is the capability to facilitate the capture of knowledge once it has been created or identified. This combined soft and hard approach adopts a pragmatic view acknowledging that there are strengths and shortcomings in the KM practice solely focused on either technological (i.e. hard), or organisational and cultural (i.e. soft) issues. It is argued that the soft and hard approaches complement each other and a combined approach is therefore more appropriate (Kamara et al, 2003).

Soft concepts

The soft concept focuses on the development of organisational processes and procedures for the capture of knowledge within and across organisations. Two main concepts are used:

- Collaborative learning (Digenti, 1999); and
- Learning histories (Kleiner and Roth, 1997).

Collaborative learning is a business practice that is aimed at discovering explicit and tacit collaboration tools, processes, and knowledge, experimenting with them, and creating new knowledge from them (Digenti, 1999). It employs experimentation, methods, and

approaches that emerge from the preset situation and allows organisations to move across boundaries fluidly (Digenti, 1999). This ensures that the learning from a group, which can also be a construction project team, is transferred back to the organisation (Kamara et al, 2003).

A learning history is a process for capturing usable knowledge from an extended experience of a team and transferring that knowledge to another team that may be distant in terms of context (Dixon, 2000). Kamara et al (2003) argue that although construction projects and the teams that implement them are unique, the team structure, processes and skills involved in these projects are similar, and these provide the opportunity for the reuse of knowledge. Using the concept of learning history, the learning of one team (from critical events on a project) can therefore serve as a catalyst to a similar team to deal with issues in a different context (Kamara et al, 2003).

Hard concepts

The hard concepts include the available ICT applications that are currently being used in the construction industry, particularly project extranets, workflow management tools and other groupware applications for collaborative working (Kamara et al, 2003).

Project extranets are dedicated web-hosted collaboration and information spaces for the architectural, engineering and construction industry that support design and construction teams (Augenbroe et al, 2001; Kamara et al, 2003). Utilising web-based technology, projects extranets allow distributed team members to collaborate, as well as to share, view and comment on project-relevant information without the need to meet in one location (Kamara et al, 2003). Kamara et al (2003) argue that the growing use and the collaborative facilities provided by project extranets make them a suitable platform on which a methodology for 'live' capture of knowledge can be mounted. Due to the current limitations of project extranets (e.g. being purely document-centric with limited facilities for workflow), the proposed methodology will be complemented by other ICT such as workflow modelling and automation tools (Kamara et al, 2003).

If the soft and hard approaches are analysed individually, they are closely related to the information systems (or technocratic) and human resource management (or behavioural) perspectives respectively. However, the combined soft and hard approach resembles the integrated perspective proposed by Jashapara (2004) and presents a more balanced approach than that offered by the solution from either of the two extremes. This perspective appears to incline towards the functionalist perspective as it considers knowledge as something that can exist independently of humans and that can be captured using ICT. For the purpose of this research, (i.e. to develop a 'live' capture and reuse methodology for the reusable project knowledge in construction) the knowledge captured is very likely to be stored within an ICT system, this combined perspective is considered more suitable and is therefore preferred.

The issues pertaining to the soft and hard approaches are explored in detail in Chapter 3. The following section presents the benefits and barriers to knowledge management.

2.3 Benefits and Barriers to Knowledge Management

The growing importance of KM is often related to the emergence of the knowledge-based economy and the importance of knowledge in providing competitive advantage (Drucker, 1993; Beijerse, 1999; Bollinger and Smith, 2001). KPMG (1998) indicates that KM can lead to:

- Better decision making;
- Faster response time to key issues;
- Increased profit;
- Improved productivity;
- Creation of new/additional business opportunities;
- Reduced costs;
- Better sharing of best practice;
- Increased market share and share price; and
- Better staff attraction and retention.

Other benefits identified include:

- Reduction of rework, and continuous improvement and better sharing of tacit knowledge (Carrillo et al, 2004);
- Improved efficiency in project implementation (CBPP, 2004); and
- More effective discovery and access of knowledge (Egbu and Botterill, 2001).

Although the benefits of KM are apparent, its implementation may not be so straightforward and trouble-free. Very often, it is undermined by main barriers that prevent the full leverage of the benefits. According to Carrillo et al (2004), the barriers to KM implementation are:

- Lack of standard work processes;
- Not enough time;
- Organisational culture;
- Not enough money;
- Employee resistance; and
- Poor IT infrastructure.

Corresponding to the findings by Carrillo et al (2004), KPMG (1998) also identifies the lack of time, standard work processes or skills in KM, funding, appropriate technology, and a supporting culture as the main barriers to KM implementation. Other than this, KPMG's (1998) findings reveal that about a quarter of the respondents mention the lack of commitment from the senior management as a barrier to the implementation of KM. The lack of senior management commitment is critical as the implementation of KM is time consuming and may entails huge investment of organisational resources. Furthermore, the attempt to address the aforementioned barriers (such as the modification of existing organisational culture to one that is supportive to KM activities and the provision of sufficient funding for new IT infrastructure) for the implementation of KM is less likely to be successful without continuous commitment from the senior management.

2.4 Knowledge Management Processes

Different researchers have used different terms for the same knowledge management processes or stages (See Appendix B). What differentiates each of the models is the difference in perspectives, focus and level of detail. Bhatt (2001) delineates the sequence of the knowledge management processes as: knowledge creation, knowledge validation, knowledge presentation, knowledge distribution and knowledge application. However, there is evidence that knowledge management processes may not exist in that linear sequence (Demarest, 1997). Demarest (1997) notes that there can be iterations between the knowledge management processes such as that between the embodiment (i.e. presentation) and dissemination (i.e. distribution) of knowledge. His study also reveals that some of these stages may exist simultaneously, such as in the case of the construction (the process of discovering and structuring knowledge) and use of knowledge, where people may have put the knowledge into practice while it is being 'constructed'. The knowledge management process models also differ in the levels of detail: some of which do not take into consideration the issue of knowledge obsolescence in knowledge management (e.g. Demarest, 1997; Soliman and Spooner, 2000; Kululanga and McCaffer, 2001) and some do not address the need to validate the knowledge.

Four main KM processes (see Table 2.1), which have incorporated the notions of knowledge obsolescence and validation, are proposed based on the KM process models that are developed within the context of construction (i.e. Robinson et al, 2001; Kululanga and McCaffer, 2001):

- Knowledge capture;
- Knowledge sharing;
- Knowledge reuse; and
- Maintain knowledge.

Table 2.1: Relationship between the capture, reuse and maintenance of knowledge

CAPRIKON		Robinson et al (2001)	Kululanga & McCaffer (2001)	Bhatt (2001)	Rollett (2003)
Capture	<ul style="list-style-type: none"> • Identifying • Locating 	<ul style="list-style-type: none"> • Discovering • Locating • Capturing 	<ul style="list-style-type: none"> • Acquiring • Creating 	<ul style="list-style-type: none"> • Creation 	<ul style="list-style-type: none"> • Planning • Creating • Assessing • Integrating • Organising • Transferring
	<ul style="list-style-type: none"> • Representing • Storing 	<ul style="list-style-type: none"> • Organising • Storing 	<ul style="list-style-type: none"> • Storing 	<ul style="list-style-type: none"> • Presentation 	
	<ul style="list-style-type: none"> • Validating 			<ul style="list-style-type: none"> • Validation 	
Sharing	<ul style="list-style-type: none"> • Sharing 	<ul style="list-style-type: none"> • Sharing • Transferring 	<ul style="list-style-type: none"> • Sharing 	<ul style="list-style-type: none"> • Distribution 	
Reuse	<ul style="list-style-type: none"> • Adapting • Applying 	<ul style="list-style-type: none"> • Modifying • Applying 	<ul style="list-style-type: none"> • Utilising 	<ul style="list-style-type: none"> • Application 	
Maintain	<ul style="list-style-type: none"> • Archiving • Retirement 	<ul style="list-style-type: none"> • Archiving • Retirement 			<ul style="list-style-type: none"> • Maintaining

2.4.1 Knowledge Capture

Knowledge capture comprises three sub-processes:

- *Identifying and Locating Knowledge* - This deals with the identification of the types/categories of knowledge to be managed, and the location of learning situations (Kamara et al, 2003) where most of the new knowledge is created and people with the knowledge required. Knowledge can be captured internally within an organisation (e.g. conducting an internal review) or externally (e.g. by recruiting staff from other companies) (Kululanga and McCaffer, 2001), and through ‘creating new knowledge’ or collating ‘already existing knowledge’ (Rollett, 2003).
- *Representing and Storing Knowledge* - This encompasses indexing, organising and structuring knowledge (Robinson et al. 2002; Goodman and Chinowsky 2000; Rollett 2003) into theme-specific knowledge areas (Maier 2002), and authoring knowledge (Markus, 2001) in the standard or format specified with the details required, adding context to the knowledge depicting where the knowledge was generated and used, where the knowledge may be useful and the conditions for reuse (Hansen and Davenport, 1999).

- *Validating Knowledge* - Knowledge validation often refers to the verification and evaluation processes of the knowledge base (KB) but there is evidence that it is also a crucial process in KM (Mach and Owoc, 2001; Bhatt, 2001). In the context of KM, it is argued that validation is likely to focus on (albeit not restricted to) explicit or codified knowledge instead of the tacit knowledge which is notoriously difficult to articulate and capture. Validation of knowledge may comprise the following:
 - ✓ Verification – Like information, the accuracy, correctness and completeness of knowledge captured need to be verified before it is shared or transferred for reuse; and
 - ✓ Evaluation – The pertaining question is whether the knowledge entered is important and reusable. Only important and reusable knowledge should be captured in order to prevent and reduce the knowledge overload problem (Kamara et al, 2003).

Validation of knowledge is intended to ensure the credence of knowledge captured, and that the knowledge captured is stored with all the relevant contextual details and in the format required.

2.4.2 Knowledge Sharing

This is about the provision of the right knowledge to the right person at the right time (Robinson et al, 2002; Mertins et al, 2001) or within the shortest time possible. This process can be passive, such as publishing a newsletter or populating a knowledge repository for users to browse, or active, such as ‘pushing’ knowledge via an electronic alert to those who need to know (Markus, 2001), which may also be known as knowledge-pull and knowledge-push (Rollett, 2003:83) respectively. Dixon (2000) has recognised five types of knowledge transfer, i.e. serial, near, far, strategic and expert transfer, based on who the intended receiver is, the nature of the tasks and the types of knowledge to be transferred. The details are summarised as follows (Dixon, 2000):

- *Serial transfer* is a process that moves the unique knowledge that each individual has constructed into a group or public space so that the knowledge can be integrated and made sense of by the whole team;
- *Near transfer* is the replication of knowledge learned by a team to other teams that are

doing very similar work;

- *Far transfer* is very similar to near transfer, except that far transfer is non-routine and the knowledge concerned or to be transferred is mainly tacit;
- *Strategic transfer* is the transfer of the crucial collective knowledge (both tacit and explicit) of an organisation in order to accomplish a strategic task that occurs infrequently but is of critical importance; and
- *Expert transfer* is applicable when teams facing an unusual technical problem beyond the scope of their own knowledge seek the expertise of others in the organisation to help them address it.

Knowledge transfer can also happen between people (e.g. meetings and conferences), person to computer (e.g. knowledge bases and expert systems) and computer to computer (e.g. data mining and intelligent agents) (Skyrme, 1998). Although the tools and methods used are dominated by ICT applications (Mertins et al, 2001), effective knowledge sharing are also underpinned by a supportive organisational culture and trust between the people involved (Newell et al, 2002).

2.4.3 Knowledge Reuse – Adapting and Applying

This covers the reuse of knowledge through the re-application of knowledge, such as the re-application of best practice as mentioned by Szulanski (2000), and the reuse of knowledge for innovation with necessary adaptation or integration (Majchrak et al, 2004; Egbu et al, 2001). The reuse of knowledge through adaptation involves re-conceptualising the problem and searching for reusable ideas (i.e. knowledge), scanning and evaluating reusable ideas, analysing the ideas in-depth and selecting the best idea, and developing fully the reused idea, which may ultimately lead to innovation (Majchrak et al, 2004).

2.4.4 Maintain Knowledge – Archiving and Retirement

Knowledge may become obsolete over time (Pakes and Schankerman, 1979; Rich and Duchessi, 2001). The development of a discipline often constitutes new information, rules and theories, which may render part of the old information, rules, theories and hence the relevant knowledge obsolete (Bhatt, 2001; Nonaka and Takeuchi, 1995). In addition, when

new sets of tools and technologies, and processes and procedures are employed by an organisation, these also often result in the need to update and refine the skills of its employees so that they can swiftly switch to the new competitive realities (Bhatt, 2001). This process covers reviewing, correcting, updating and refining knowledge to keep it up-to-date, preserving, and removing obsolete knowledge from the archive (Rollett, 2003).

For the purpose of the research, only the capture, sharing and reuse processes are emphasised although the maintenance of knowledge is highlighted.

2.5 Knowledge Management in Construction

There is evidence that the importance of knowledge management has been recognised by the construction industry. A survey of UK project-based organisations shows that about 50% of the respondents (majority were from the construction industry) noted that KM would result in new technologies and new processes that will benefit the organisations (Egbu, 2002). This finding is supported by another survey of construction organisations which reveals that about 40% already had a KM strategy and another 41% planned to have a strategy within a year (Carrillo et al, 2003). Furthermore, about 80% also perceived KM as having the potential to provide benefits to their organisations, and some had already appointed a senior person or group of people to implement their KM strategy (Carrillo et al, 2003). Despite the awareness of the importance of KM to the industry revealed in the above studies, there are still limitations identified in current practice for the capture and reuse of project knowledge in the industry (Kamara et al, 2003). These are discussed below.

2.5.1 Shortcomings of Current Practice

It is identified that the overall processes of KM in the construction industry (architecture, engineering and construction) are characterised by the following:

- Most of the construction knowledge resides in the minds of individuals working within their specific domain (Khalfan et al, 2002);
- The knowledge gained is often poorly organised and there are seldom processes in place for disseminating useful knowledge to other projects (Khalfan et al, 2002);

- The intent behind decisions is often not recorded or documented. There is difficulty to track the people involved in a decision making process and who understand the context of making the decision for the purpose of knowledge sharing (Khalfan et al, 2002);
- There is a strong reliance on the knowledge accumulated by individuals, but no formal way of capturing and reusing much of this knowledge (Kamara et al, 2002b);
- The use of long-standing (framework) agreements with suppliers to maintain continuity (and the reuse and transfer of knowledge) in the delivery of projects for a specific client (Kamara et al, 2002b);
- The capture of lessons learnt and best practice, such as in the operational procedures and design guidelines, which serve as a repository of process and technical knowledge. Post project reviews (PPR) are usually the means for capturing lessons learned from projects (Kamara et al, 2002b);
- The involvement (transfer) of people in different activities as the primary means by which knowledge is transferred and/or acquired (Kamara et al, 2002b);
- The use of formal and informal feedback between providers and users of knowledge as a means to transfer learning/best practice, as well as to validate knowledge (for example, site visits by office-based staff to obtain feedback on work progress) (Kamara et al, 2002b);
- A strong reliance on informal networks and collaboration, and ‘know-who’ to locate the repository of knowledge (Kamara et al, 2002b);
- Within firms with hierarchical organizational structures, there was a reliance on departmental/divisional heads to disseminate knowledge shared at their level, to people within their sections (Kamara et al, 2002b); and
- The use of appropriate IT tools (such as GroupWare, Intranets) to support information sharing and communication (Kamara et al, 2002b).

Kamara et al (2002b) note that the heavy reliance on knowledge accumulated by individuals, post project reviews and specific contractual/organisational arrangements (e.g. framework agreements) are considered the key approaches for direct transfer of project knowledge. However, shortcomings impeding the effective capture and reuse of project knowledge are observed in the aforementioned approaches (Kamara et al, 2003).

2.5.1.1 Post Project Reviews

This is the most common approach used in the industry for the capture of learning (Orange et al. 1999). The shortcomings of post project reviews identified by Kamara et al (2003) are:

- Insufficient time is often allocated for the review to be conducted effectively (if conducted at all), as relevant personnel would have moved to other projects;
- It does not allow the current project to be improved by incorporating the lessons being learnt as the project progresses;
- Loss of important information or insights due to time lapse in capturing the learning;
- In consolidating the learning of people involved, it is not an effective mechanism for the transfer of knowledge to non-project participants; and
- The learning captured is limited in scope as the perspective is that of members within only one of the participating organisations to the project (i.e. it is not collaborative).

The shortcomings of PPR are explored in detail in Chapter 3.

2.5.1.2 Reliance on People for the Transfer of Knowledge

Kamara et al (2003) note that the reliance on people, based on the assumption that the knowledge acquired from one project can be transferred to another project by that individual when s/he is reassigned to another project, makes organisations vulnerable when there is a high staff turnover. This is critical in view of the persisting high staff turnover rate, which was 20.2% in 2003, in the UK's construction industry (CIPD, 2004). Furthermore, the transfer and sharing of knowledge through this method is very likely to be limited to the people who are working together with the knowledge provider in the project. Other projects, other members of staff within the organisation but not involved in the project, and those located at other offices may therefore not benefit from this method. The availability of the knowledge provider and the relationship between the knowledge provider and the knowledge receiver are also likely to influence the willingness of the knowledge provider in sharing his/her knowledge.

In addition, humans are not without weaknesses and this is particularly so when it comes to memorising facts (Ebbinghaus, 1913). The problem of the loss of important information or

insights due to the time lapse in capturing the learning through post project evaluation is in fact due to the weakness of human memory. As the transfer of knowledge through reassignment of people is also heavily dependent on human memory, it is not surprising that it still suffers from the same knowledge loss problem as in the case of post project reviews.

2.5.1.3 Contractual and Organisational Arrangements

The dominant culture of competitiveness and the fact that construction organisations collaborating in one project may actually compete in another project have made the construction organisations reluctant to share critical knowledge or to divulge secrets to others, as that might weaken their competitive advantage (Kamara et al., 2003). Therefore, even though the use of long-standing framework agreements (e.g. within partnering contract) with suppliers to maintain continuity in the delivery of projects for a specific client is designed to ensure that the learning is reused in future projects, there is still no guarantee that the learning of individual firms is shared with other participants in the agreement (Kamara et al, 2003).

Commercial sensitivity and security of knowledge is another critical issue and barrier to inter-organisational knowledge capture and reuse which involves a number of organisations with different business objectives (Barson et al, 2000). Corporate security restrictions imposed on posting of information/knowledge have further added to the problem (Ardichvili et al, 2003) as people have been indirectly discouraged from sharing their knowledge especially where the boundary of such restrictions is not made clear.

2.5.2 Knowledge Management Research Projects in Construction

In view of the numerous shortcomings of KM current practice in construction and hence the ample room for improvement, it is not surprising that a number of research projects have been undertaken in this area. In the UK, some of these include:

2.5.2.1 Cross-sectoral Learning in the Virtual entERprise(CLEVER)

This project aimed to derive generic structures for KM practices and to develop a

framework for the transfer of knowledge in a multi-project environment in construction (Kamara et al, 2002a). The framework developed assists construction firms in articulating their KM problems and in selecting an appropriate strategy for the transfer of knowledge that is appropriate to their organisational and cultural contexts (Kamara et al, 2003).

2.5.2.2 Knowledge Management for Improved Business Performance (KnowBiz)

The aim of the project was to establish the relationship between KM practices and business performance in construction firms (Carrillo and Anumba, 2000). A KM framework which enables organisations to link their KM initiatives to improved business performance (IMPaKT) was developed (Carrillo et al, 2003), and has been encapsulated in a software tool.

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

This project was focused on the development of a mechanism, which includes a software tool, to facilitate the capture, retrieval and creation of knowledge pertaining to sustainability in construction (C-SanD, 2001).

2.5.2.4 Building a Higher Value Construction Environment (B-Hive)

This project aimed to develop processes and systems to enhance organisational learning between construction project partners (B-Hive, 2001). B-Hive has developed a Cross-Organisational Learning Approach (COLA), which comprises innovative processes for review, evaluation, feedback and organisational learning supported by an information system (B-Hive, 2001).

2.5.2.5 Knowledge and Learning in CONstruction (KLICON)

This project investigated the role of IT in capturing and managing knowledge for organisational learning on construction projects (KLICON, 2001). The research also explored how detailed IDEF0 models of construction activities and information models in EXPRESS can enhance understanding of generic construction knowledge and specific project knowledge (McCarthy et al, 2000). The focus was on the passing on of knowledge

about the project from early design to detailed design stages and to the contractor (McCarthy et al, 2000).

2.5.2.6 Methodology, tools and architectures for electronic COnsistent knowledGe maNagement across prOjects and between enterpriSes in the construction domain (e-COGNOS)

This EU-funded project aims at specifying and developing an open model-based infrastructure and a set of tools that promote consistent knowledge management within collaborative construction environments (Whetherill et al, 2002).

2.5.2.7 An Approach to Knowledge Management for SMEs

This project aimed to improve KM in SMEs in construction industry. The pilot study of the research involved recording the managers' personal knowledge and thinking about problem solving events on a weekly basis using a dictaphone. The managers were then debriefed about the set of their recorded events every month in order to explicate the embedded knowledge and transform it into knowledge accessible to wider audience (Boyd et al, 2004).

2.5.2.8 A Knowledge Transfer Approach to Continuous Improvement on PFI Projects

This project was aimed at identifying the scope for improvement and knowledge transfer on Private Finance Initiative (PFI) projects (Robinson et al, 2004).

2.5.2.9 Benchmarking Knowledge Management Practice in Construction

The project's primary objectives were to provide a deeper understanding of successful knowledge management programmes and the approaches used to successfully overcome the challenges, and to identify effective ways to improve both the short and long-term competitiveness of participating companies, all through benchmarking the activities of the group's members (Dent and Montague, 2004). A report which sets out the methodology used and the findings of the study under three areas, i.e. strategy, processes and tools, and measurement and application, was published.

2.5.2.10 Business Case for Knowledge Management: Guidance & Toolkit for Construction

This project aimed to provide good practice guidance and a supporting management toolkit for practitioners to develop business plans and metrics for Knowledge Management within their company (CIRIA, 2004). The outputs of project were tailored to the needs of the target audience and the specific business context and promote opportunities for performance improvement by adoption of KM practice in the UK construction industry, by raising awareness of the benefits of KM and enhancing confidence of construction organisations to apply such practices (CIRIA, 2004).

2.5.2.11 Sharing Knowledge between Aerospace and Construction

This project aimed to investigate the extent to which managerial practices can be shared between the aerospace and construction sectors (Green et al, 2004). In addition, it also sought to develop an approach to knowledge sharing that could be implemented as part of a knowledge management initiative within individual companies (Green et al, 2004).

The literature reveals that the aforementioned research projects are focused at either:

- Strategic and business perspectives (CLEVER, KnowBiz, ‘Business case for knowledge management: guidance & toolkit for construction’ and ‘Benchmarking Knowledge Management Practice in Construction’);
- Specific types of knowledge, i.e. knowledge pertaining to sustainability (C-SanD, 2001), PFI projects (Robinson et al, 2004) and management practice (Green et al, 2004) and sustainable competitiveness (www.knowledgemanagementuk.net);
- Specific project phases, i.e. KLICON which focused on the transfer of knowledge from early design to detailed design stages and to the contractor (McCarthy et al, 2000); or
- Specific type of construction organisation, e.g. SMEs in Boyd et al (2004).

The need for an approach which is capable of capturing project knowledge, irrespective of the type of project, the type of construction organisation and project phases, and particularly capturing the knowledge ‘live’ (Kamara et al, 2003), has not been adequately addressed. Research at Stanford (Reiner and Fruchter, 2000) is considered as being closest to the goal of ‘live’ capture and reuse of project knowledge, the research does not cover the

entire project but focuses only on the design evolution stage. The importance of a ‘live’ methodology proposed by Kamara et al (2003) to address the limitations of current practice is discussed in detail in next section.

2.6 The Importance of ‘Live’ Capture and Reuse of Project Knowledge Approach

Kamara et al (2003) contend that in order to overcome the limitations in current industry practice on the capture and reuse of knowledge, it is necessary that learning from projects is captured while it is being executed (i.e. ‘live’), and presented in a format that will facilitate its reuse both during and after the project, and in other contexts such as professional education and training of new construction staff. The imperative of ‘live’ capture of knowledge is supported by the recent survey result of construction and client organisations involved in PFI (Private Finance Initiative) projects where the ‘live’ capture of knowledge is noted as crucial by 76% and 70% of construction and client organisations respectively (Robinson et al, 2004). Hari et al (2005) noted that the speed of technological advancement requires construction organisations to ‘quickly’ capture, assimilate and use their knowledge in order to remain competitive. Furthermore, the need for ‘live’ capture of knowledge is also being indirectly addressed by Whetherill et al (2002). They assert that the construction organisation’s only sustainable advantage lies in its capability to learn faster than its competitors and the rate of change imposed by external environment, and that there is a need to ‘integrate learning within day-to-day work processes’.

The strategy of the ‘live’ capture proposed by Kamara et al (2003) adopts the aforementioned combined soft and hard approaches, which attempts to address the cross-organisational knowledge transfer issues (through collaborative learning and learning histories in particular) and to facilitate ‘live’ capture and reuse of knowledge through web-based technology respectively. The ‘live’ capture and reuse of project knowledge will (Kamara et al, 2003):

- *Facilitate the reuse of collective learning on a project by individual firms and teams involved in its delivery.* In addition, other project teams can use the learning captured from previous/similar projects to deal with problems; reflection on previous learning can also trigger innovative thinking (to think about issues that might be relevant to their

project).

- *Provide knowledge that can be utilised at the operation and maintenance stages of the assets' lifecycle.*
- *Help to solve the aforementioned cross-organisational knowledge transfer issue.* The 'live' methodology involves the members of the supply chain in a collaborative effort to capture learning in tandem with project implementation, irrespective of the contract type used to procure the project from the basis for both ongoing and post-project evaluation.
- *Benefit the client organisations with enriched knowledge about the development and construction of their assets.* This will contribute to the effective management of facilities and the commissioning of other projects. In the longer term, clients will benefit from the increased certainty with which construction firms can predict project outcomes.
- *Benefit the construction industry as a whole.* The construction supply chains will benefit through the shared experiences that are captured as part of the learning on key events (e.g. problems, breakthroughs, change orders, etc.) in both short- and long-term. Short-term in the sense that project teams would be enabled to manage better the subsequent phases of a project through the capture and transfer of learning from a previous phase. Long-term because it will increase their capacity to better plan future projects and their ability to collaborate better with other organisations. Project staff and students of project/construction management and the institutions providing such courses/training will also benefit through the use of captured project knowledge as case study material.

Other potential benefits identified include:

- *Prevention of knowledge loss due to time lapse in capturing the knowledge.* Ebbinghaus's (1885) study reveals that the percentage of human memory retained on a set of data depletes over time. Corresponding to this, the probability of forgetting an event of everyday life (which may include the learning event where new learning is created) is increasing as time elapses (Linton, 1975). Therefore, by facilitating the capture of the knowledge as soon as it is created or identified, 'live' capture of

knowledge helps to reduce the loss of knowledge or important insights due to time lapse and to ensure the completeness of knowledge captured.

- *Maximisation of the value of reusing the knowledge captured through 'live' reuse.* 'Live' capture and 'live' reuse of knowledge are interconnected. The true benefit of capturing knowledge comes only when the knowledge is being used (McGee, 2004), particularly if the knowledge is being reused 'live' after it has been captured. Siemieniuch and Sinclair (1999) assert that knowledge can become obsolete and the value attached to the knowledge deteriorates as time passes and the competitive environment for its reuse changes. Some knowledge (used synonymously to data) are required in real-time so that effective responses can be deployed at the right time, thereby avoiding mishaps and more importantly seizing opportunities before it is too late (McGee, 2004). McGee (2004) argues that as time passes after an event the possible responses to the event narrow, depicted by the area of triangle in Figure 2.3. This shows that the potential value of 'live' reuse of knowledge in an event may as well narrow and diminish towards the end of the event where the knowledge can be reused, depicted by the area of the triangle in Figure 2.4. This is particularly obvious when the benefit accrued through reusing the knowledge is time-related, e.g. when the knowledge can lead to a saving of £x/day.

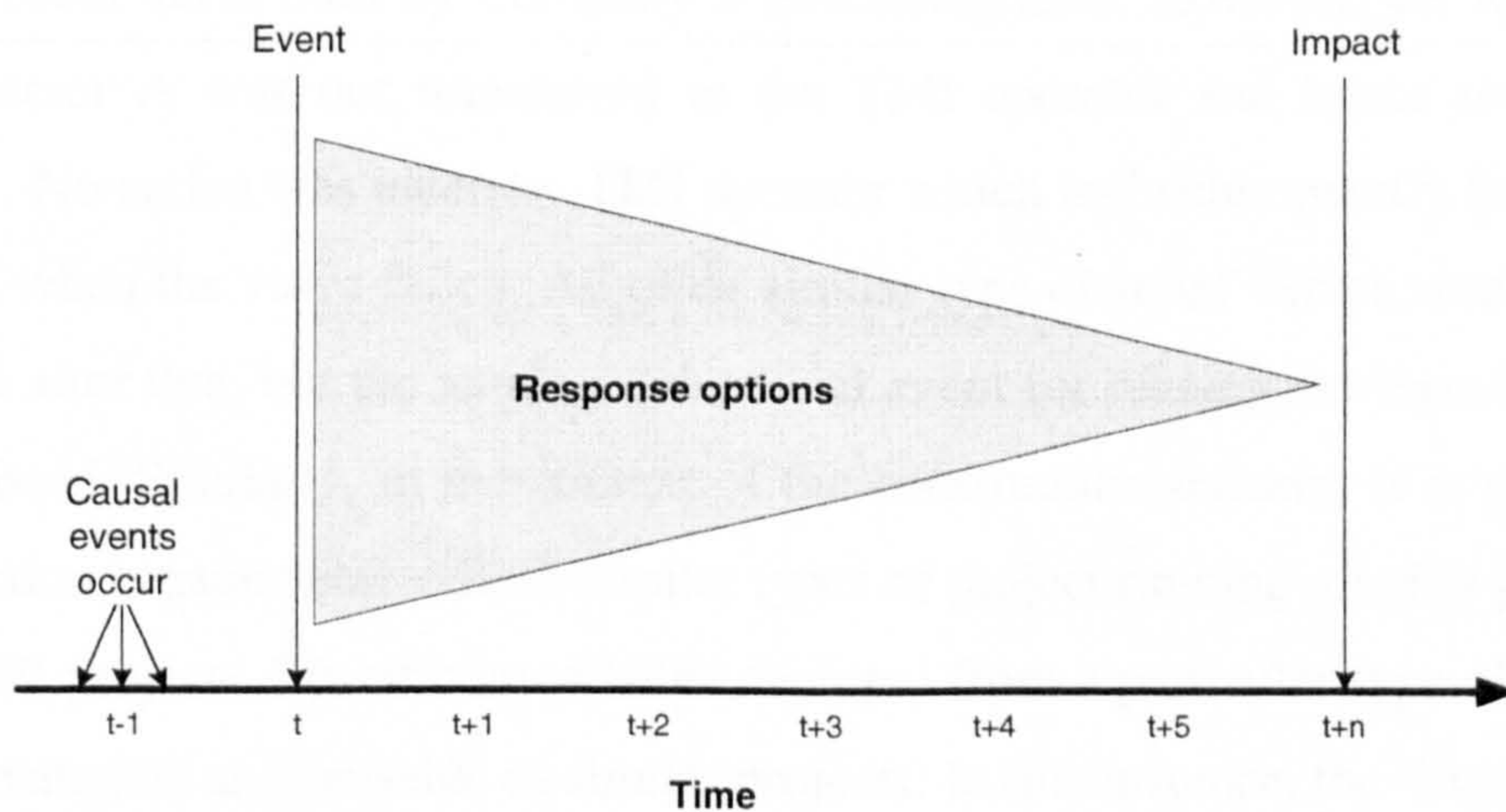


Figure 2.3: As time passes after an event, the possible responses to the event narrow, depicted by the area of the triangle (McGee, 2004)

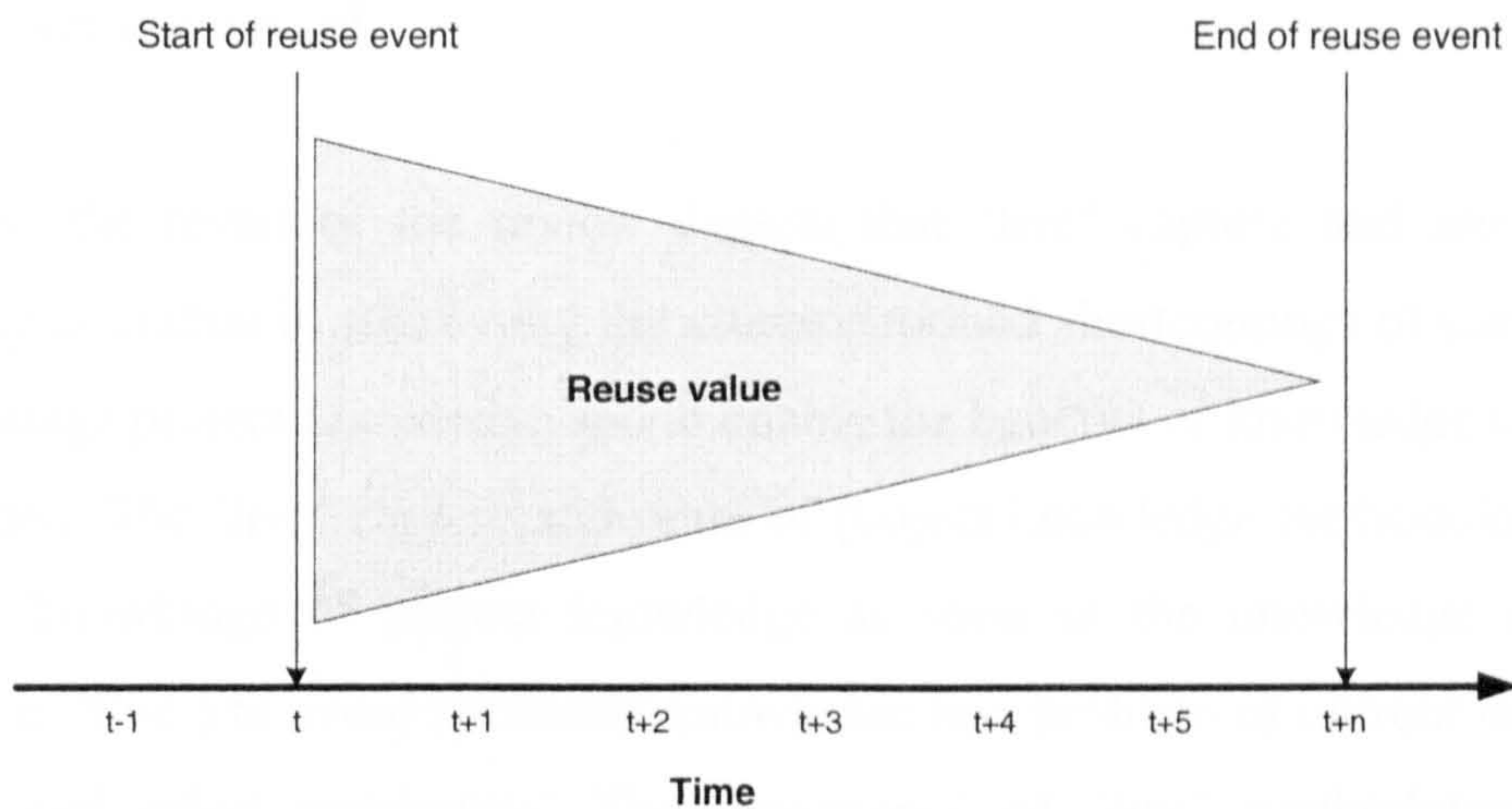


Figure 2.4: As time passes, the potential value accrued through reusing knowledge reduces, depicted by the area of the triangle

- *Help to seize every knowledge reuse opportunity.* Another unique situation is that the knowledge captured may have limited number of events for reuse and hence has to be disseminated for reuse as soon as possible (i.e. 'live') before such events diminish, as in the Three Mile Island (TMI) incident mentioned by McGee (2004). In the instance, a lesson had been learned that the relief valve used in a nuclear reactor built by Company X had failed to function properly in one occasion and further action was needed. The immediate event for reusing the lesson learned was at the TMI nuclear reactor where another relief valve built by Company X was being used. However, the lesson learned from reactor A was not transferred to the TMI operator and hence was not being 'reused'. No action was taken by TMI operator which had subsequently led to the TMI incident when the valve failed. All other similar type of relief valves would have been replaced after that, but the single most crucial event for reusing the lesson learned had been missed. Similarly, in the context of the construction industry it is possible for a construction organisation to have similar types of project running roughly parallel, such as the PFI projects. Specific knowledge captured from a particular type of project may only be valuable and reusable in similar projects. In this instance, the 'live' capture and reuse methodology can help to ensure that the specific knowledge created or identified from one courthouse project is made available for sharing and reuse in another courthouse project (or just another courthouse in the same project) so that the triggers

for reuse are not missed.

In summary, the result of the review depicts that 'live' capture and reuse of project methodology is crucial in addressing the aforementioned shortcomings of current practice, to better manage project knowledge and to enable the benefits of knowledge captured to be fully exploited. The 'live' capture and reuse of project knowledge methodology facilitates the capture knowledge of project knowledge as soon as the knowledge is created or identified (i.e. 'live') to avoid persistent knowledge loss problem of current practice due to time lapse and other constraints. The importance of 'live' methodology is further strengthened by the reduction of knowledge loss facilitated which helps to ensure that a more complete set of project knowledge is captured from construction project, and which allows the knowledge to be reused 'live' to reap the most from the knowledge.

Having established the importance of the 'live' capture and reuse of project knowledge in construction, next chapter presents the reviews on the potential types reusable project knowledge in construction, the learning situations where most of the new learning are created, the current practice for the capture of knowledge focusing on the capability to facilitate 'live' capture of project knowledge, and the soft (organisational, cultural and human) issues that affect the knowledge capture and reuse.

Chapter 3 Knowledge Capture and Reuse

This chapter presents the reviews of the potential types of reusable project knowledge in construction, the learning situations where most of the new learning are created, the current practice for the capture of knowledge focusing on the capability to facilitate 'live' capture of project knowledge, and the soft (organisational, cultural and human) issues that affect the knowledge capture and reuse.

3.1 Types of Reusable Project Knowledge

Reusable project knowledge is defined as project knowledge which may be reused in subsequent stages of the same project, or other projects with necessary adaptation to avoid the reinvention of the same knowledge, avoid recurrence of the same mistakes and for continuous improvement. Clearly, identifying the various types of reusable knowledge available before attempting to capture all knowledge is more likely to give a successful result. Existing literature reveals that there are various types of knowledge identified in the context of knowledge management which are different both in terms of scope and nature (Maier, 2002). The types of knowledge listed in Table 3.1 are by no means exhaustive but illustrates the varieties available. For the ease of discussion, the various types of knowledge are grouped into construction-domain specific and generic perspectives as shown in Table 3.1.

Table 3.1: Classifications of knowledge

Authors	Classification of knowledge	
(a) Generic perspective		
Nonaka and Takeuchi (1995); Polanyi (1958)	• Tacit knowledge	• Explicit knowledge
Bhatt (2001)	• Foreground knowledge	• Background knowledge

Blacker et al (1993) ¹	<ul style="list-style-type: none"> • Embrained knowledge • Embodied knowledge • Encultured knowledge 	<ul style="list-style-type: none"> • Embedded knowledge • Encoded knowledge
Rollett (2003:36)	<ul style="list-style-type: none"> • Core knowledge • Innovative knowledge 	<ul style="list-style-type: none"> • Advanced knowledge
Ruggles (1997)	<ul style="list-style-type: none"> • Process • Factual 	<ul style="list-style-type: none"> • Cultural • Catalogue
KPMG (1998)	<ul style="list-style-type: none"> • Methods and processes • Company's own markets • Company's own products and services 	<ul style="list-style-type: none"> • Regulatory environments • Customers • Competitors • Employee skills
(b) Construction-domain specific perspective		
McLoughlin et al (2000)	<ul style="list-style-type: none"> • Know How • Know Where/When 	<ul style="list-style-type: none"> • Know Why • Know What
Whetherill et al (2002)	<ul style="list-style-type: none"> • Project • Organisational 	<ul style="list-style-type: none"> • Domain
Robinson et al (2001)	<ul style="list-style-type: none"> • Process • People 	<ul style="list-style-type: none"> • Product
Kamara et al (2002b)	<ul style="list-style-type: none"> • Organisational processes & procedures • Client's business • How to predict outcomes, manage teams, focus on clients and motivate others 	<ul style="list-style-type: none"> • Technical / Domain knowledge • Know-who

For the generic perspective, the foremost tacit-explicit distinction drawn by Nonaka and Takeuchi (1995) and Polanyi (1958) is found to be at a level too high for the purpose of identifying reusable project knowledge as most (if not all) of the knowledge are covered

¹ Embrained knowledge relates to the conceptual skills and cognitive abilities of individuals; Embodied knowledge is action-oriented and is rooted in specific contexts; Encultured knowledge refers to the process of achieving shared understanding; Embedded knowledge is knowledge which resides in systematic routines; and Encoded knowledge is information conveyed by signs and symbols.

under the wide umbrella of tacit and explicit knowledge. The same applies to the distinctions put forward by Bhatt (2001) and Blacker et al (1993). The types of knowledge identified by Ruggles (1997) and KPMG (1998) cover all the potential areas for knowledge capture in organisations. However, the scope might be too broad for the purpose of capturing reusable project knowledge as intended in this research. For instance, ‘cultural knowledge’ is knowledge to be managed at an organisational level rather than project level. A scope which is too wide could result in unnecessary knowledge overload and affect the knowledge capture and reuse processes. This will then contradict the ‘live’ capture and reuse concept of this research.

For the construction-domain specific perspective, McLoughlin et al’s (2000) four types of knowing have added insights into the scope of knowledge to be managed in long term engineering projects but they are less helpful in identifying exact types of reusable project knowledge. Whetherill et al (2002) note that knowledge in this perspective (i.e. organisational, domain and project knowledge) are strongly inter-linked in that any amendment introduced to one category is very likely to have a critical impact on the others. Robinson et al’s (2001) findings reveal that the knowledge within the construction domain can be grouped into the three process, product and people context-based factors. The three context-based factors relate to the issues of what is produced (products), how it is produced (processes) and by whom (people) (Robinson et al, 2001). The various types of knowledge identified by Kamara et al (2002) serve as a guide to the various types of knowledge that exist, but it must be noted that it is not solely based on the perspective of a construction organisation. The exact types of reusable project knowledge to be captured in construction will therefore be identified from detailed case studies conducted in this research (see Section 5.2.1).

3.2 Learning Situations

In discussing the ‘live’ methodology for the capture and reuse of project knowledge, Kamara et al (2003) introduce the notion of “learning events” which are synonymous to learning situations. Learning situations are a range of circumstances emerging during the course of the project where new learning can be captured. They can be critical events and

also normal day-to-day operations (Kamara et al, 2003). Literature suggests that there are at least two categories of learning situations, i.e. formal and ad hoc learning situations.

3.2.1 Formal Learning Situations

Formal learning situations are routine events, such as the weekly site meetings, project reviews conducted at the end of each of the project stages (e.g. feasibility study, full conceptual design and construction stages) or at predetermined intervals, and post project reviews. Among the examples given, post project reviews have been identified as the most common approach for the capture of learning from construction projects (Orange et al, 1999). Formal learning situations can also be identified through the RIBA Plan of Work and Process Protocol depicted in Table 3.2. This illustrates the potential types of formal learning situations.

Table 3.2: Potential formal learning situations based on RIBA Plan of Work and Process Protocol

RIBA Plan of Work	Process Protocol
• Stage A: Appraisal	• Phase 0: Demonstrating the need
• Stage B: Strategic brief	• Phase 1: Conception of need
• Stage C: Outline proposals	• Phase 2: Outline feasibility
• Stage D: Detailed proposals	• Phase 3: Substantive feasibility study & outline financial authority
• Stage E: Final proposals	• Phase 4: Outline conceptual design
• Stage F: Production information	• Phase 5: Full conceptual design
• Stage G: Tender documentation	• Phase 6: Coordinated design, procurement & full financial authority
• Stage H: Tender action	• Phase 7: Production information
• Stage J: Mobilisation	• Phase 8: Construction
• Stage K: Construction to Practical Completion	• Phase 9: Operation & maintenance
• Stage L: After Practical completion	

3.2.2 Ad hoc Learning Situations

Ad hoc learning situations are the non-routine special learning situations such as problems

and unforeseen circumstances encountered which have a bearing on the performance of the project. Ad hoc learning situations such as problem may lead to the capture of 'lessons learned', whereas the solutions formulated to resolve the problems may contribute towards the creation of 'best practice'. It is therefore believed that a great proportion of new learning from construction projects is created in the learning situations. Hence, identifying the various learning situations is crucial for the capture of reusable project knowledge in construction.

Further details of learning situations in construction will be explored in the case studies undertaken in Sections 5.2.3 and 5.2.4.

3.3 Current Practice on Capture and Reuse of Project Knowledge

Knowledge Management (KM) practice depends significantly on the use of various KM tools to perform the KM sub-processes (e.g. knowledge capture, sharing and reuse). KM tools can be either IT-based or non-IT based. There is confusion over the definitions of KM tools as most authors infer KM tools to mean IT tools (Al-Ghassani, 2002). However, as Ruggles (1997) points out, not all KM tools are IT-based. Everyday tools such as papers, pens, and photos can be utilised to support KM. To avoid confusion, Al-Ghassani (2002) proposed that the terms 'KM Techniques' and 'KM Technologies' to be used to replace 'Non-IT tools' and 'IT tools' respectively. This distinction is used for the purpose of the research.

This research does not attempt to cover each of the KM Techniques and KM Technologies in detail because a wide range of them are available for different KM sub-processes (Ruggles, 1997; Wensley, 2000; Jackson, 1998; Laudon and Laudon, 2000; Gallupe, 2001; Tsui, 2002; Al-Ghassani, 2002; Rezgui, 2001). The following section discusses only the most relevant and important KM Techniques and Technologies for the capture and reuse of project knowledge.

3.3.1 Post Project Reviews

Post Project Reviews (PPR) are debriefing sessions used to highlight lessons learned

during the course of a project. These are important to capture knowledge about causes of failures, how they were addressed, and the best practices identified in a project (Ruikar et al., 2003). The term is also used interchangeably with its variants, such as Debriefing (Schindler and Eppler, 2003), Post Project Appraisal (Gulliver, 1987), After Action Review (Cross and Baird, 2000), Project Post-Mortem (Williams et al., 2001), Post Implementation Evaluation (Kartam, 1990), Project Audit, Project Close-out and Post Completion Review. Post Project Review (PPR) is the most common approach used in construction industry to capture the learning from projects (Orange et al, 1999).

3.3.1.1 Facilitation of Knowledge Capture and Reuse

The importance of PPR in knowledge capture and reuse is related to the temporary nature of project team. After the project ends, the team is dissolved and it is hard to access the learning from the project (Disterer, 2002). Therefore, if planned in advance, the PPR is the last chance for an organisation to capture learning from the project so that it can be transferred to other projects.

PPRs are also tied to collective and group learning where it is seen as a means to synergise the learning of individuals. Kerth (2000) points out that 'there are many pieces to the whole story of the project, and each individual on the project knows his piece of story', and until everyone on the team joins together and they collectively tell the story, the learning is likely to be minimal. The collective telling of the story facilitated by PPR illuminates pieces of the project that no one can see by themselves (Kerth, 2000). Therefore, by gathering the whole team together PPRs aid knowledge capture and reuse across the team with the potential for distributing the learning across organisations.

Disterer (2002) argues that the documented 'lessons learned' from PPR can play significant role in externalising, storing and sharing tacit knowledge. This is because the 'lessons learned' document covers the full and detailed description of the problems and how they were solved taking into consideration technical issues, organisational issues and social situations (Disterer, 2002). Therefore, tacit knowledge can be acquired through an understanding of the process and the underlying mental models and insights.

3.3.1.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

As PPR is conducted at the end of a project, it certainly does not facilitate the 'live' capture and reuse of project knowledge in construction. Other than this, it is also undermined by the following issues:

- *Time constraint.* This is a critical issue for PPR. There is time pressure towards the project's end as the team strives to meet the completion deadline and new tasks already await the dissolving team (Schindler and Eppler, 2003). With personnel often transferred to other projects and others soliciting new work, project team members can only be identified with huge effort (Disterer, 2002) and people may not want to dedicate time to review past issues (Kartam, 1996). Therefore, PPR are sometimes treated as a burden to be rushed through so that attention can move on to more pressing matters (Kartam, 1996);
- *Reluctance to share mistakes.* Apart from the loss of important information or insights due to time lapse in capturing the learning (Kamara et al., 2003), there is also insufficient willingness for learning from mistakes of the person involved (Schindler and Eppler, 2003) where mistakes are deliberately forgotten and not to be disclosed (Kartam, 1996);
- *Objectivity.* The objectivity of findings and opinions of PPR are questionable in some cases. Shapiro (1999) argues that as PPR are undertaken retrospectively, they are susceptible to 'the characteristics partial and selective memory recall' by managers who, after the event, are rarely neutral or objective; and
- *Lack of a format for representing knowledge.* Kartam (1996) argues that the most serious shortcoming of PPR is a failure to uniformly document lessons learned in a manner useful to others in the future. He further points out that the lack of such format renders the retrieval of lessons learned for use in future work difficult. Corresponding to this, Schindler and Eppler (2003) identify that the compiled result of PPR might be described too generically or are not visualised where necessary which prevents reuse due to the lack of context, and archived in a way that others have difficulties in retrieving them. Moreover, the result of PPR may not be accepted although they are well-documented and easy to retrieve due to the so-called 'not-invented here

syndrome' (Schindler and Eppler, 2003).

3.3.2 Communities of Practice (CoPs)

The term Community of Practice (CoPs) is found to be used interchangeably with communities of knowing, knowledge communities, knowledge networks, learning communities, communities of interest, and thematic groups. Wenger et al (2002) define CoPs as “groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis”. There are a number of different types of CoPs based on dichotomised categorisation (informal/formal; organic/structure; natural/engineered), or as a range of types (informal, supported and structured) as identified by Saint-Onge and Wallace (2003). Members of CoPs possess different skill sets, development histories and experiences but they have commonly shared goals that they are working together to achieve (Ruggles, 1997).

3.3.2.1 Facilitation of Knowledge Capture and Reuse

The significance of CoPs towards KM is generalised by Saint-Onge and Wallace (2003) as providing a platform for their members to pool their expertise, experience, and ideas, and to find solutions. Other importance of CoPs includes:

- CoPs can provide better access to knowledge bases within their collaborative space and that located externally through affiliated professional organisation's internet site or personal sources (Saint-Onge and Wallace, 2003). Indirectly, CoPs can help to group the knowledge of individuals within the community into collective knowledge resources for the benefits of their members;
- CoPs are important in the sharing of tacit knowledge which is typically based on experience (Newell et al., 2002). This is because these communities share 'a common experience of practice' and their members have developed a set of shared meanings deriving from their common experience (Newell et al., 2002). Therefore, the basic assumptions and contextual features which are closely related to tacit knowledge and provide insight into the knowledge shared do not have to be explained and are readily understood;

- In CoPs, new knowledge may be created through an incremental improvement of an idea that results from the synthesis of community members' contributions in a brainstorming session. This can also be achieved through collaborative problem-solving facilitated over a period of time which is supported by external expertise and access to additional resources (Saint-Onge and Wallace, 2003);
- Best practice guides also can be produced from the result of CoPs members' interactions and discussions. The guide, which is the members' externalised tacit knowledge, can be channelled back to everyone in the organisation and expand the organisation's knowledge base; and
- Timeliness of knowledge. CoPs, particularly those aided by IT, may allow the user to obtain the knowledge required quicker than other sources (Ardichvili et al., 2003).

3.3.2.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Information and Communication Technology (ICT) can be used to link geographically dispersed CoPs together to facilitate communication between these CoPs (Ardichvili et al., 2003). From here, it is possible that online CoPs can be one of the KM tools capable of supporting 'live' sharing and reuse of knowledge in construction. However, in terms of 'live' capture, its role is found less significant unless a mechanism is developed for the capture of knowledge from members of CoPs once knowledge is created or identified.

Furthermore, the efficacy of knowledge sharing and transfer in CoPs is deeply influenced by the organisational culture and trust. Newell et al (2002) point out that knowledge-sharing in CoPs is actually facilitated by the norms of reciprocity - 'you help me and I will help you' – and the level of trust generated amongst the community. If the supportive culture does not exist, cultural change is necessary to create a supporting behaviour around knowledge sharing in CoPs.

3.3.3 Training

Training programmes are organised for employees changing job description or being promoted, and to enhance their skills and knowledge. In the context of KM, training is found inseparable to 'learning' and 'skill', and is important for the implementation of KM

systems (Harman and Brelade, 2000). Training can be broadly categorised as conventional training and the training aided by ICT. Conventional trainings are instructor-led and mainly involve face-to-face interactions. For the latter, it is known as online training, net-based training (Gotschall, 2000) or computer-based training (Zahm, 2000). This form of training is usually delivered via CD-ROM and the internet or intranet download (Gotschall, 2000; Zahm, 2000). Maier (2002) indicates that ILOI's (1997) and Bullinger et al's (1997) studies reveal that 83% of the organisations reported personnel training and education as the most important KM instrument for experiences, and as the most frequently used instrument for knowledge acquisition respectively.

3.3.3.1 Facilitation of Knowledge Capture and Reuse

The roles of training in KM are as follows:

- Training can aid individual and organisational learning. In organisations, only people are said to be able to learn and organisations ultimately learn from individuals (Hwang, 2003). Through training, however, organisation's collective knowledge can be transferred back to individuals. Training may also help to transfer tacit knowledge through the face-to-face interactions of people involved during the events; and
- Training can aid personal knowledge management. It can help the development of personal KM capacity, i.e. the ability to evaluate, learn, structure, share and use knowledge, using the organisation's KM systems (Vorbeck and Finke, 2001). The importance of this type of training can be viewed from Hwang's (2003) contention that 'although there may be a wonderful knowledge management system built, knowledge cannot be directed at sustaining profitability if people do not have the skill or ability to use knowledge creatively'. Furthermore, training can also be designed to help creating a supportive KM culture by nurturing the open-mindedness as well as the self-motivation among staff towards capturing and sharing of knowledge.

3.3.3.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Explicit knowledge can be disseminated in the form of handouts and tacit knowledge can be shared through the face-to-face interactions during the training sessions. However, little evidence is revealed by literature on the capability of training to support the 'live' capture

and reuse of project knowledge. This is possibly because it is very difficult for training on certain topics to be conducted immediately for the capture and sharing of the relevant knowledge. The role of training is more significant in terms of the sharing than the capture of project knowledge.

3.3.4 Recruitment

Recruitment is a process of finding new people to join a company, and bringing new knowledge into an organisation.

3.3.4.1 Facilitation of Knowledge Capture and Reuse

Recruitment is regarded as one of the easiest ways to acquire or capture new knowledge especially when an organisation is engaged in a new project sector (Tan, 2002:84). Current literature also suggests that recruitment should be geared towards getting new people to fill existing and future anticipated knowledge and skills gaps (Harman and Brelade, 2000).

Recruitment adds new knowledge and expands the organisational knowledge base, and allows other members within the organisation to learn from the recruited member (Ruikar et al, 2003). This approach might prove successful in many situations as creditability is often higher for external experts and organisation experts might be more willing to accept and reuse ideas from outside the organisation than from within (Robertson, 1999). Furthermore, the introduction of new recruits into organisations may ask for knowledge explication that stimulates the exploration necessary for innovative activities and for the creation of new knowledge (Levina, 1999). Some organisations also attempt to codify the recruited person's knowledge that is of critical importance to their business (Ruikar et al, 2003).

3.3.4.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Maier (2002) identifies the following difficulties on recruiting experts as a means to acquire new knowledge:

- Experts are scarce and it is therefore difficult to recruit and retain them (Maier, 2002). This problem is magnified by competitors' constant attempts to entice knowledge

workers from their rivals (Robertson, 1999);

- It is difficult to integrate experts into the organisation's knowledge networks, culture and processes so that core competencies can be built-up; and
- It is difficult to assess the capability of experts. The assessment process can also be very costly (Harman and Brelade, 2000).

As mentioned by Ruikar et al (2003), recruitment is a measure to acquire new knowledge to expand an organisation's knowledge base, rather than a 'live' knowledge capture and reuse technique. Furthermore, the issues of recruitment identified by Maier (2002) and the fact that recruitment is a lengthy time consuming process also indicates that it cannot be considered a 'live' knowledge capture technique.

3.3.5 Face-to-face Interaction

This is the oldest (Ribes et al, 1981), most fundamental yet powerful form of knowledge capture and sharing practice in organisations (Ruikar et al, 2003). It is reliant on people meeting 'face-to-face'. Therefore, despite the fact that there are a plethora of KM Techniques and KM Technologies available, the human channel such as face-to-face interaction is still being regarded as the most effective way of knowledge sharing (Davenport et al, 1997).

3.3.5.1 Facilitation of Knowledge Capture and Reuse

Face-to-face interaction is important in the transfer of tacit knowledge for which richness is difficult to document (Engström; 2003; Hansen et al, 1999; Ladd and Heminger, 2002). Hansen et al (1999) point out a case where Xerox once attempted to embed the know-how of its service and repair technicians into an expert system. However, Xerox's attempt failed as technicians learned from others by sharing stories about how they had fixed the machines, and the expert system could not replicate the tacit knowledge exchanged in the face-to-face interactions.

In a project environment, face-to-face interactions within and between project teams have also been identified as a central feature of resolving issues and generating new ideas

(Marshall and Sapsed, 2000). Lang (2001) asserts that face-to-face interaction also helps to create social ties and tacit shared understandings which give rise to collective sense-making. This in turn leads to emergent consensus as to what is valid knowledge and the creation of new knowledge.

3.3.5.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

There is evidence showing that face-to-face interaction is pertinent to 'live' knowledge capture and reuse. Koskinen et al (2003) identify that face-to-face interactions enhance the use of tacit knowledge in engineering projects due to its 'capacity for immediate feedback'. This allows understanding to be checked and interpretations corrected instantly. This method also allows simultaneous interpretation of multiple cues, including body language, facial expressions and the tone of voice, which convey knowledge beyond spoken knowledge (Koskinen et al, 2003), and facilitates 'live' capture of knowledge.

However, the efficacy of 'live' knowledge capture and reuse through face-to-face interactions is influenced by the following factors:

- Geographical distance. Face-to-face interaction is not always possible as in the case of multinational organisations. In addition, the fact that a project team consists of personnel from different organisations further compounds the problem;
- An intimate relationship between the source and recipient to remove the barriers of knowledge transfer (Hall et al, 2000);
- The source and scope of knowledge available is restricted to people around the community who can be met with ease when required; and
- Access to knowledge. Others may not have access to the knowledge shared unless they are also physically involved, or manage to identify someone who is involved in the process.

Therefore, although face-to-face interaction is effective in the sharing of tacit knowledge, the various issues associated with this method suggest that it alone cannot meet the requirement of 'live' capture and reuse of project knowledge.

3.3.6 Mentoring

Mentoring is a practice where new personnel or junior staff are assisted in their work by attaching them to an experienced colleague for a certain amount of time (Al-Ghassani, 2002). Literature suggests that mentoring can be grouped as formal/informal (Chao et al, 1992), and internal/external (Ragins, 1987) based on the formation of the relationship between the mentor and protégé, and the relationship between the mentor with the protégé's organisation. Informal mentorships are not formally recognised and formed by the organisation, whereas formal mentorships are managed and sanctioned by the organisation (Chao et al, 1992). Internal mentors are employed in the same organisation as the protégé. An external mentor is a member of staff from another organisation. Mentorship is primarily focused on 'career and development' (Tabbron, 1997) and aimed at developing necessary transitional competencies when people are given tasks that are new, unfamiliar, and fraught with stress and uncertainty (Von Krogh et al, 2000).

3.3.6.1 Facilitation of Knowledge Capture and Reuse

Kleinman et al's (2001) research reveals that mentoring helps to expedite and improve learning of the protégés about the context within which the professional works (e.g. on how one's performance affects others and other departments), and broadens their portfolio of skills and abilities by modelling behaviours displayed by the mentor. Under the guidance of the mentor, the protégé can go through a learning process in which s/he creates the tacit and explicit knowledge to accomplish the task, and develop the skills at identifying and sharing tacit knowledge (Von Krogh et al, 2000).

Mentoring is also crucial in the sharing of tacit knowledge. Engström (2003) argues that effective sharing of tacit knowledge depends on an enabling context, which is likened to a space or an open and trusting relationship between individuals, for the sharing of tacit knowledge. He further argues that mentoring can help in establishing the required enabling context. Apart from this, the face-to-face conversation and interaction associated with mentoring also facilitate the sharing of tacit knowledge (Engström, 2003).

In addition, the protégé is not the sole beneficiary of mentoring. The mentor also benefits

from gaining insights into the issues faced by their protégés (Tabbron et al, 1997), and the opportunity to make productive use of his/her knowledge and to learn in new ways (Burke et al, 1994).

3.3.6.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Despite the favourable findings on the significance of mentoring in KM, further study reveals that the effectiveness of mentoring is undermined by the following issues:

- Organisational practices and management decisions (e.g. a decision to promote and transfer a mentor to another department) may decrease the opportunity for interaction between the mentor and protégé (Kram, 1988). This will affect knowledge sharing and transfer through mentoring;
- Cross-gender mentoring, where the mentor and protégé are of opposite gender. This is due to the difficulties for women to find female mentors (Burke et al, 1994:23) and to handle their relationship with male mentor (Clawson and Kram, 1984), and the likelihood of experiencing greater social distance as well as discomfort with male mentors (Kram, 1988);
- Time constraint (Carrillo, 2004; Billett, 2003). Today's delayed, lean and complex matrix organisations do not naturally allow the time or offer the right climate and structure to encourage experienced managers or colleagues to voluntarily provide mentoring to protégés (Tabbron et al, 1997);
- Restriction in transfer of Knowledge. Mentoring is mainly a one-to-one relationship (Tabbron et al, 1997) thus the transfer of knowledge is more likely to be restricted to that between mentor and protégé;
- Fear of displacement. Experienced members of staff may be concerned about displacement by the protégé whom they have mentored (Billett, 2003); and
- Mentor quality. The competence of mentors is attributable to previous experience, depth of and confidence in the knowledge of the work in which they are mentoring, and their ability to develop mentoring skills in a supportive environment (Billett, 2003). Megginson (2000) contends that sufficient training of mentors is crucial to ensure that they have the necessary skills to perform the task.

In terms of the 'live' capture and reuse of knowledge, it is worth mentioning that the knowledge captured 'live' by the mentor may not be shared 'live' with the protégé due to aforementioned issues such as time constraint, distance between mentor and protégé, and the perception that the knowledge is not important. In addition, it is unlikely for a protégé to have control over the type of knowledge to be shared by a mentor. Moreover, a protégé's access to the mentors' knowledge is greatly dependant on the availability of the mentor. The issues that undermine the effectiveness of mentoring identified also suggest that mentoring may not be the best tool to facilitate the 'live' capture and reuse of project knowledge.

3.3.7 Succession Planning and Management

Traditionally, succession planning and management is concerned with the identification of the gaps which are likely to occur in an organisation due to anticipated future changes or known factors such as retirement and reassignment (Harman and Brelade, 2000), the selection of talented employees to fill the gaps to ensure continuity in management practices (Huang, 2001; Hirsh et al, 1990) and development of people (Hirsh et al, 1990).

3.3.7.1 Facilitation of Knowledge Capture and Reuse

In the context of knowledge management, succession planning and management is extended to 'meeting anticipated knowledge and skills gaps' when there is someone leaving the organisation (Harman and Brelade, 2000), the retention of corporate knowledge (Ministry of the Premier and Cabinet, 1999), and to facilitate the transfer of mainly tacit knowledge between the successor and incumbent (Carrillo, 2004). Harman and Brelade's (2000) and Ministry of Premier and Cabinet's (1999) findings reveal that succession planning and management actually involves the systematic use of other tools and techniques available to achieve its goals. These include the following:

- Training and development (Harman and Brelade, 2000);
- Structured work experience (Harman and Brelade, 2000);
- Formal and informal mentoring programmes (Ministry of the Premier and Cabinet, 1999);
- Formal knowledge transfer forums (Ministry of the Premier & Cabinet, 1999);

- Oral histories/briefings (Ministry of the Premier and Cabinet, 1999; Kransdorff, 1996);
- Electronic systems designed specifically for knowledge transfer (Ministry of the Premier and Cabinet, 1999); and
- Imbedded systems to retain innovation (Ministry of the Premier and Cabinet, 1999).

Kransdorff's (1996) finding indicates that the knowledge transferred through this approach are pertaining to corporate culture, management and communication style, and the details of recent events which enable one to take over the new tasks with ease and perform the tasks to the standard required quickly.

3.3.7.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Some problems which may undermine the capability of succession planning and management in facilitating 'live' knowledge capture and reuse of project knowledge in construction are identified. These include:

- Over-concentration on general management skills rather than functional and specialist skills (Hirsh et al, 1990);
- Literature suggests that succession management is related more to the senior rather than lower positions in organisations (Byham, 2002; Hirsh et al, 1990);
- Its reliance on the early identification of potential candidates tends to exclude those who take a later decision to pursue a management career, those who move between employers and those who interrupt their career (especially women) (Hirsh et al, 1990);
- It is dependent on the availability of key people for the purpose and their willingness to release or share their talent (Leibman et al, 1996); and
- It is a lengthy and time consuming process. Byham (2002) notes that succession management can consume a significant number of executive hours each year.

Although elements of knowledge sharing and transfer are identified from the review, the main focus of succession planning and management is still the transfer of general management skills and to prepare a person to take up a particular position. Therefore, it is not surprising that a range of problems are identified when succession planning and management are assessed against the capability to support 'live' capture and reuse of

knowledge.

3.3.8 Reassignment of People

This method is based on the assumption that the knowledge acquired from one project can be transferred by reassigning the people involved to another project (Kamara et al, 2003).

3.3.8.1 Facilitation of Knowledge Capture and Reuse

Reassignment of experienced staff or experts to other projects can create the opportunity for the transfer of more tacit knowledge through the face-to-face or people-to-people interactions among the members of staff. Less experienced members of staff in particular may be assisted and supervised in carrying out their work by the experienced staff reassigned to the project where knowledge can be captured through observation and mirroring the experienced staff.

3.3.8.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Reassignment of staff inherits some of the shortcomings of the face-to-face interactions.

These include:

- Vulnerability to staff turnover;
- The transfer of knowledge is likely restricted to a smaller group of people who have the opportunity to interact with the knowledge provider; and
- The willingness of the knowledge providers to share knowledge.

These suggest that it also may not be a suitable tool to facilitate the 'live' capture and reuse of project knowledge.

3.3.9 Knowledge Bases

Knowledge bases are repositories that store knowledge about a topic in a concise and organised manner (Ruikar et al, 2003), such as lessons learned and best practices. Knowledge bases are distinguished from the knowledge bases of expert systems which incorporate rules as part of the inference engine that searches the knowledge bases to make decisions (Ruikar et al, 2003).

3.3.9.1 Facilitation of Knowledge Capture and Reuse

Knowledge in the knowledge base can be captured through very formal sessions specifically conducted for the purpose and from voluntarily contributions from members of staff. An example is found for the former approach: A two-hour session of twenty five people worldwide was conducted in an organisation to capture lessons learned, with facilitators and some people specifically assigned to codify knowledge (Leavitt, 2003). The knowledge was documented in various forms ranging from a Gartner-like report to a magazine article. These were subsequently validated by participants and made available to all employees through the company's knowledge base (Leavitt, 2003). The details captured may include where the idea originated, a brief description of the practice, the savings it achieved, and the name and phone number of a contact from whom more information can be obtained (Dixon, 2000:56).

For the voluntarily approach, it is implemented by encouraging members of staff working on a project to capture and contribute lessons learned from a project into a knowledge base in a predetermined format from time to time (Eppler and Sukowski, 2000). The entries are flagged according to their possible impact to the team's success, i.e. high, medium or low. To facilitate the use of the knowledge base, simple electronic forms (e.g. best practice templates) and aids (search engines) are normally offered (Heisig and Vorbeck, 2001). This method helps to build up the team's collective memory (or knowledge) which can be consulted (or reused) before critical events (Eppler and Sukowski, 2000) and also in other projects.

Major organisations that have already employed such methods are NASA, the US Army, Siemens Information and Communication Networks, British Aerospace plc, Ford, Texas Instruments, etc. (Eppler and Sukowski, 2000; Heisig and Vorbeck, 2001; Dixon, 2001).

3.3.9.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Nowadays, knowledge bases are often Web-based, or accessible through internet and intranet. These types of knowledge bases are capable of facilitating 'live' capture and reuse of project knowledge as they allow people to enter and access knowledge whenever the

connection to the knowledge base is available. Current literature does however reveal that although the more explicit knowledge can be captured and shared through knowledge bases, the more tacit dimension of the knowledge still depends mainly on human to human interactions for its sharing and transfer (Heisig and Vorbeck, 2001).

3.3.10 Intranets

An intranet is a company-wide information distribution system that uses internet tools and technology (Tyndale, 2002). Intranets use World Wide Web servers and browsers in association with other information retrieval software to deliver information and knowledge to a closed group of users over an organisation's network (ITCBP, 2003).

3.3.10.1 Facilitation of Knowledge Capture and Reuse

Company procedures, templates, standard statements, frequently asked questions, glossaries, and knowledge can be stored in intranet to preserve organisational memory and for future reuse (Tyndale, 2002; ITCBP, 2003). Intranets allow members of an organisation to access the information or knowledge available from remote office, business partner's office and home (ITCBP, 2003).

Intranets can be used to publish (e.g. home pages, newsletters and documents), to search (for a variety of information), to transact (with functionality on intranet pages and other organisational computer-based information systems), to interact (e.g. via discussion groups and other collaborative applications) and to record (e.g. best practices) (Newell et al, 2000). A well-managed intranet can improve cross-organisational communication and enable greater collaboration between different functions (ITCBP, 2003), and hence better sharing of knowledge.

3.3.10.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

The intranet's main roles are to provide the necessary ICT backbone (e.g. the network) to facilitate communication across different operating systems and equipments (Newell et al, 2000), and Web-based applications. It mainly depends on other software applications (e.g. knowledge base and groupware) which run on it to facilitate the capture, sharing and reuse

of knowledge. Intranets are therefore an enabling technology to facilitate 'live' capture and reuse of project knowledge, complemented by other KM software applications running on it, rather than a solution by itself.

3.3.11 Groupware

Groupware is Information and Communication Technologies (ICTs) that supports collaboration, communication, coordination of activities and knowledge sharing of geographically dispersed groups of people (Robertson et al, 2001; Dennis et al, 1996). It includes the ability to send a receive email, conferencing, shared scheduling of appointments, workflow management, and multimedia document management (Rezgui, 2001).

3.3.11.1 Facilitation of Knowledge Capture and Reuse

Groupware may support a single workgroup on a single LAN, or it may support a number of workgroups and LANs together (Duffy, 1996). Groupware allows the actors collaborating on specific tasks to exchange ideas, helps to keep track of the project memory and record all its learned lessons in a way that promotes reuse (Rezgui, 2001). It improves information flow to enhance organisation learning and creativity (Bhatt et al, 2005).

Groupware can be useful for the exchange, coordination and articulation of low-level information and explicit knowledge, particularly if the project members are geographically dispersed (Robertson et al, 2001). In addition, recent development has allowed data mining within groupware's databases to identify potentially valuable knowledge patterns (Bhatt et al, 2005). Furthermore, to an extent it may also help to capture, store, retrieve and distribute part of tacit knowledge in the form of rituals, histories and organisational stories (Bhatt et al, 2005).

3.3.11.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Robertson et al. (2001) argue that groupware is less efficient for the communication and exchange of more complex tacit knowledge. While a groupware's database provides

relevant knowledge in a timely fashion, often clarification may be still required on particular complex information through face-to-face or telephone conversation (Robertson et al, 2001). Furthermore, in many cases the basic functionalities and mechanisms of groupware systems are not sufficient to support users in finding the required knowledge (Smolnik and Erdmann, 2003).

3.3.12 Project Extranets

A project extranet is a network linking the various parties to a construction project for the exchange and storage of project information in digital form (Hamilton, 2005). Its access is only extended to a privileged user group from those parties or organisations (Watson, 1999).

3.3.12.1 Facilitation of Knowledge Capture and Reuse

According to Howard (2004) project extranets can help organisations to:

- Share up-to-date documents, files or images with suppliers, partners, or customers in disparate locations;
- Work collaboratively by making documents or digital assets available for editing, reviewing, updating, versioning and storing;
- Manage projects in a centralised workspace and track the history of work; and
- Provide current versions of frequently updated documents, such as product specifications, inventories summaries and design documents.

Project extranets also allow the project data (including the documents uploaded) to be stored permanently for future access (Hamilton, 2005). Ruikar et al's (2005) research findings reveal that this function can be very valuable to end-user companies as they can be used to resolve future issues of similar nature, e.g. lessons learned from previous project(s) or stages of the same project can be applied to latter projects/stages. However, Ruikar et al (2005) also state that none of the companies they studied have taken measures to benefit from this.

3.3.12.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Rezgui (2001) states that most project extranets only provide support for document

storage, retrieval, versioning and approval, and do not handle the semantics of the information being processed in the documents. Therefore, they are less efficient in facilitating the reuse of the knowledge and lessons stored within these documents (Rezgui, 2001). This may be the cause of the lack of attempts from end-user companies to benefit from reusing the knowledge captured in the documents, as revealed by Ruikar et al (2005). Furthermore, there are some issues undermining the use of project extranets. These include the security of the information stored, necessary culture change for adopting the technology, cost for implementation, and legal issues as to the ownership of data (Ruikar et al, 2005).

3.3.13 Case-Based Reasoning (CBR)

Case-based reasoning (CBR) is a problem-solving approach that relies on past similar cases to find solutions to problems (Kolodner, 1993). According to Kolodner (1993), a case is a 'contextualised piece of knowledge representing an experience that teaches a lesson fundamental to achieving the goals of the reasoner'. In most CBR systems, the internal structure can be divided into two major parts: the case retriever and the case reasoner (Shiu and Pal, 2004). The case retriever's task is to find the appropriate cases in the case base, while the case reasoner uses the retrieved cases to find a solution to the given problem description (Shiu and Pal, 2004). According to Aamodt and Plaza (1994), CBR essentially consists of four processes (i.e. the four REs):

- *Retrieve* the most similar case or cases;
- *Reuse* the information and knowledge in that case to solve the problem;
- *Revise* the proposed solution; and
- *Retain* the parts of this experience likely to be useful for future problem solving.

Though not included in the four REs, Aamodt and Plaza (1994) acknowledge that the representation of case is crucial to make the case search and matching processes of the case retriever and case reasoner both effective and reasonably time efficient. The representation of cases covers what to store in a case, the finding of an appropriate structure for describing case contents, and the decision on how the case memory should be organised and indexed for effective retrieval and reuse (Aamodt and Plaza, 1994).

3.3.13.1 Facilitation of Knowledge Capture and Reuse

CBR has been used with positive results for customer service and help desk applications (Belecheanu et al, 2003). In terms of knowledge capture and reuse, the roles of CBR are:

- It reduces the knowledge acquisition task by eliminating the need to extract a model or a set of rules, as required in model/rule-based systems (Shiu and Pal, 2004). CBR's knowledge acquisition tasks involve mainly the collection, representation and storage of existing cases (Shiu and Pal, 2004);
- It provides flexibility in knowledge modelling (Shiu and Pal, 2004). CBR systems deal with case specific knowledge and do not require that the domain must be modelled in rules (Belecheanu et al, 2003);
- It may help to discover and retrieve quality design solutions that are stored in a specifically designed knowledge base (Cirovic and Cekic, 2002); and
- It helps to avoid repeating all the steps that need to be taken to arrive at a solution (Shiu and Pal, 2004). The ability of CBR to help modifying a previous solution to solve a new problem, instead of creating a solution from scratch, leads to significant time saving (Shiu and Pal, 2004).

3.3.13.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Belecheanu et al (2003) note that CBR systems can be costly to develop and implement, demand substantial technical training and support, and their efficiency depends on the willingness of people to use and improve the system on daily basis. Furthermore, the applicability of the solutions retrieved cannot be guaranteed when the problem is too complex and covers a wide scope (Belecheanu et al, 2003).

3.3.14 Text Mining

Text mining, also known as text data mining or knowledge discovery from textual databases, refers to the process of extracting interesting and non-trivial patterns or knowledge from text documents (Tan, 1999). The difference between text mining and data mining is that in the former the patterns are extracted from natural language text rather than from datasets (Hearst, 2003). Text mining links together the extracted information to form new facts or new hypotheses to be explored by further research (Hearst, 2003).

3.3.14.1 Facilitation of Knowledge Capture and Reuse

Tan (1999) notes that text mining tools can help in:

- Organising documents based on their similarities and presenting the groups or clusters of the documents in certain graphical representation. Tan (1999) also points out that some tools can map the links between concepts in the document collection; and
- Analysing texts. This covers extraction, retrieval, categorisation and summarisation of texts and information (Tan, 1999). Some of the tools can 'learn' the relationships between words and phrases automatically from sample documents and guide the users to construct searches (Tan, 1999).

Hearst (1999) adds that text mining may aid the discovery of unknown information or the finding of answers to questions for which the answer is not currently known. Text mining may involve finding the unexpected patterns and trends among text articles or information (Hearst, 1999).

3.3.14.2 Issues and Capability to Support 'Live' Capture and Reuse of Project Knowledge

Literature reveals that text mining is mainly concerned with identifying and searching of the unexpected trends, and unknown information and knowledge. Its main purpose is the support of the knowledge discovery process in large document collections (Karanikas and Theodoulidis, 2002), where knowledge captured in other formats (e.g. drawings and video clips) are ignored. Furthermore, literature also suggests that text mining technology is still undermined by the inability of computers to understand text as humans do and in sorting out ambiguous words (Leong et al, 2004).

3.4 Soft Issues in Knowledge Management

IT has been the centre of many KM initiatives (Walsham, 2001) probably because of the growth in knowledge-based expert systems in the eighties and early nineties (Kamara et al., 2003). However, it is now acknowledged that IT tools alone do not stimulate individual affection for the generation of knowledge (Neve, 2003), and leveraging knowledge exclusively through ICT is often hard to achieve (Walsham, 2001; De Long, 1997). This section presents the findings from the review on the impacts of 'soft' or non-IT issues on

KM. The findings are grouped into human, organisational and cultural issues.

3.4.1 People Issues

People play a vital role in knowledge capture and reuse practices as only people are regarded to be able to learn in organisational learning theory, and ultimately organisations learn from people (Hwang, 2003). The various people issues identified are described as follows:

3.4.1.1 *Willingness to Share Knowledge*

Ardichvili et al (2003) identify that people's willingness to share knowledge is influenced by the perception as to the ownership of knowledge; that is either viewing it as a public good or a personal belonging. When knowledge is regarded as public good, knowledge exchange is motivated by moral obligation and community interest and not by a narrow self-interest (Ardichvili et al, 2003). On the other hand, if knowledge is being regarded as a personal belonging then knowledge hoarding or reluctance to share knowledge is envisaged.

3.4.1.2 *Self-confidence*

The lack of self confidence and the confidence towards the knowledge to be shared of employee have also undermined knowledge capture and sharing practices. Ardichvili et al's (2003) findings reveal that employees may hesitate to contribute their knowledge out of fear of criticism, or misleading others being unsure that their contribution are important, or completely accurate, or relevant. Furthermore, they may simply think that they have not earned the right to post and share their knowledge within the organisation.

3.4.1.3 *Trust*

The lack of trust is being identified by Mason and Pauleen (2003) as one of the barriers to implement knowledge management. This finding corresponds to Ardichvili et al's (2003) contention that people are less reluctant to share knowledge if they think that others will not misuse their knowledge (e.g. taking undue advantage of confidential information and using the posted information to personally attack those who posted it). In addition, trust is

also in turn built upon people's confidence that the knowledge shared is reliable and objective.

3.4.1.4 Shared Meaning

The transfer of knowledge demands the existence of shared meaning, which is a shared mental model or system of meaning that enables others to understand and accept the knowledge, and apply another's insight to their own context (Bresnen et al, 2003). Time required for developing the shared meaning for inter-project knowledge transfer is a main issue of concern as project teams are normally temporary and culturally differentiated (Bresnen et al., 2003).

3.4.1.5 Personal KM Capability

Personal KM capability refers to the capability of employees to capture and share knowledge, and use the IT-based KM system for the purpose. This capability can greatly influence the efficiency of knowledge capture and reuse practices, particularly when IT-based KM systems are used. However, it is argued that personal KM capability is something which people can improve over time, assisted by appropriate training.

3.4.1.6 Staff Mobility and Turnover

Change in the membership of a project team during the course of a project and high staff turnover often result in organisational knowledge fragmentation and loss of organisational learning (Kasvi et al., 2003). Reducing frequent change in project team membership, and the retention of members of staff is therefore crucial in preventing such knowledge gaps from developing (Harman and Brelade, 2000).

3.4.2 Organisational Issues

Both inter- and intra-organisational knowledge sharing are affected by issues such as commercial sensitivity of the knowledge, existence of rewards to encourage knowledge sharing and other management issues. The details of the main issues are as follows:

3.4.2.1 Commercial Sensitivity and Security Issue of Knowledge

Commercial sensitivity and security issue of knowledge is critical for inter-organisational knowledge sharing (Barson et al, 2000). The corporate security restrictions imposed on posting of information/knowledge (Ardichvili et al, 2003) may indirectly discourage people from sharing their knowledge where the boundary of such restrictions is not made clear.

3.4.2.2 Creation of a Reward and Incentive Structure

Current literature suggests that the impacts of incentives on knowledge capture and reuse are two-sided. From one perspective, incentives and rewards have been identified as the key success factor in knowledge sharing process (Robinson et al, 2001; Eppler and Sukowski, 2000; Hall et al, 2000; Hansen et al, 1999), in sustaining a knowledge sharing culture (O'Dell and Grayson, 1998; Neve, 2003) and in encouraging people to engage in knowledge-based roles, activities and processes (Zack, 1999). From another perspective, ill-designed and the lack of an incentive structure can also act as disincentives and lead to knowledge hoarding (Hall et al, 2000). The dominating outcome oriented approach where one's reward is judged from the amount of work done on the codification and dissemination of knowledge (Hall et al, 2000) is very individual-based and does not encourage collaborative behaviour (Walsham, 2001). Therefore, the more balanced 'scorecard' incentive system suggested by Goh (2002) whereby both collaboration with other teams and sharing of knowledge are taken into account to avoid internal competition is likely to be a better option.

3.4.2.3 Allocation of Resources

Hall et al (2000) argue that conflicts exist as the strategic benefits from knowledge transfer are accrued by the organisation as a whole, but the tactical cost for the resources (budget and staff time) associated with knowledge capture is borne by the individual projects. Consequently, knowledge capture and sharing may be sacrificed particularly when the risk of project cost overrun is greater than the risks associated with the loss of organisational knowledge (Hall et al., 2000). It is therefore suggested that the cost incurred is treated as overhead expenses for the organisation to solve this problem (Hall et al., 2000).

3.4.2.4 *Company Policy towards Lessons Learned*

Knowledge sharing should both cover the best practices learned and the mistakes made (i.e. lessons learned). However, people are reluctant to admit mistakes (De Long, 1997) and the organisation's disciplinary procedures further discourage the sharing of this kind of knowledge (Hall et al, 2000). Heisig et al (2001) suggest that organisations should recognise that errors are an essential factor in the process of learning and should hence maintain a 'culture of errors' where making errors are tolerated to an extent to encourage the sharing of lessons learned.

3.4.3 Cultural Issues

De Long (1997) contends that culture has a major impact on the implementation of any KM strategy, and it comprises the following three elements:

- *Values* that indicate what an organisation's members believe is worth doing or having. They indicate preferences for specific outcomes or behaviours, or what the organisation aspires to achieve.
- *Norms* which are the shared beliefs about how people in the organisation should behave, or what they should do to accomplish their work. It represents the expected patterns of behaviour. For example, they describe how employees actually create, share and use knowledge in their work.
- *Practices* which are the formal or informal routines used in the organisation to accomplish work.

Organisational cultures can either be supportive or negative towards KM as follows:

3.4.3.1 *Supportive and Negative Knowledge Culture*

A supportive KM culture where employees are motivated to share their knowledge and use external knowledge for their own activities is essential (Walsham, 2001). Culture has even influenced the performance of IT-based KM systems. As De Long (1997) asserts, IT-based KM systems will be implemented and used effectively only to the degree that a culture is aligned to support the objectives for KM. However, such a KM supportive culture may not readily exist within an organisation, and the creation of one very often requires the

alteration of existing organisational culture (De Long, 1997).

Negative cultures which include resistance to search, receive and share knowledge are found to have undermined organisations' KM practice (Ladd and Heminger, 2002). In the context of the construction organisation, negative culture such as employee resistance may inhibit knowledge sharing as people feel insecure about their job situation and do not trust their employers (Robinson et al, 2001).

3.4.3.2 Cross-cultural Knowledge Sharing

Cross-culture knowledge sharing may cover the sharing of knowledge across organisations, societies and countries. Knowledge sharing across organisations is complicated and often unsuccessful due to the differences in educational background, skills base and approach to coordination of work (Walsham, 2001). This is critical in the context of construction industry as construction projects normally involve various organisations with different expertise, objectives, and working cultures. Bresman et al (1999) contend that the problems associated with knowledge sharing will increase with geographical and cultural distance. Therefore, the knowledge sharing across organisations will be even more challenging if it involves the organisations from different societies or countries. This is substantiated by Hutchings and Michailova's (2004) research findings which reveal that very often the successful knowledge sharing across organisations from different countries entails a detailed study of the relevant countries' cultures in advance and involves extensive relationship or network building in order to facilitate it.

In summary, a range of reusable project knowledge and learning situations are identified from the literature. The assessment of the various KM technologies and techniques based on current literature suggests that a knowledge base is a potential KM tool capable of facilitating a methodology for 'live' capture and reuse of project knowledge in construction. The various soft issues that may influence the implementation of a KM system within an organisation are also identified. All these are explored in further details in the case study chapter.

Chapter 4 Research Methodology

This chapter describes the research methodology adopted throughout the research project. It reviews a range of research methodologies and the methodologies for the development of information systems (IS). It then justifies the use of a case study approach for the research, and the use of the Web Information System Development Methodology (WISDM) for the purpose of developing the associated information system. It also explains the activities undertaken to achieve the objectives of the research.

4.1 Types of Research Methodology

Research is a systematic investigation to find answers to a problem (Blaxter et al, 2001), whereas a research methodology is the principles and procedures of logical thought processes which are applied to an investigation (Fellows and Liu, 2003) for the answers of the problem. One of the primary classifications of research methodologies is the quantitative and qualitative distinctions (Fellows and Liu, 2003), which are built upon different philosophical backgrounds. As no single study or method is universally appropriate for all research questions (Hakim, 2000), the quantitative and qualitative methodologies are therefore sometimes integrated or triangulated for the purpose of research. Details of the methodologies are described in the subsequent sections.

4.1.1 Quantitative Research Methods

The quantitative research method is also known as the scientific and positivist research methods. It is about gathering factual data and studying relationships between facts in order to find out how such facts and relationships accord with the theories of previous research (Fellows and Liu, 2003), and determines whether a hypothesis holds true (Creswell, 1994). In addition, quantitative methods can also be employed to establish general laws or principles (Burns, 2000). It often involves the collection of a very large amount of data sets if compared to the qualitative approach (O'Leary, 2004). Three main approaches are used in data collection for quantitative research (Fellows and Liu, 2003), namely:

- Asking questions of respondents by questionnaires and interviews;

- Carrying out experiments; and
- ‘Desk research’ using data collected by others.

The data collected are in numeric form (Punch, 1998; Blaxter et al, 2001) and mainly analysed using statistics (O’Leary, 2004; Creswell, 1994).

4.1.2 Qualitative Research Methods

The qualitative research method is regarded as a naturalist, subjectivist or interpretivist research method and tends to focus on exploring in much detail a smaller number of instances which are seen as being interesting or illuminating (Blaxter et al, 2001). Its data sets are relatively small scale (O’Leary, 2004) and chiefly non-numeric, such as in the form of text and image (Punch, 1998). This is because it aims to investigate and gain insights into the beliefs, understandings, views, opinions, etc. of people involved in depth rather than breadth (Fellows and Liu, 2003). The tools for qualitative research are action research, case study, ethnographic research and grounded theory (Myers, 1997). The analysis of qualitative data involves filtering, sorting and other manipulations to prepare them for analytic techniques (Fellows and Liu, 2003). The analytic process includes scrutinising the content of transcribed texts based on interviews in order to establish the meanings, intentions, interpretations etc. of the people concerned (Fellows and Liu, 2003).

4.1.3 Triangulation

Triangulation, also known as multiple measurement or ‘multimethod’ research (Brewer and Hunter, 1989), involves the use of two or more methods of data collection in the study of a research problem. These methods might be drawn from ‘within methods’ approaches (such as different types of quantitative data collection strategies) or ‘between methods’ (which draws on quantitative and qualitative data collection methods) (Creswell, 1994). Burns (2000) notes that the exclusive reliance on one method may bias or distort the researcher’s picture of the particular slice of reality being investigated. Triangulation of different research methods may be employed to reduce or eliminate the disadvantages of an individual method, and gain the advantages of the methods used (Fellows and Liu, 2003). In addition, the multiple measurement also offers the chance to assess each method’s validity in light of other methods (Brewer and Hunter, 1989). The fundamental

strategy of triangulation is to ‘attack a research problem with an arsenal of methods that have no overlapping weaknesses in addition to their complementary strengths’ (Brewer and Hunter, 1989).

The suitability of the quantitative, qualitative and triangulated research methodologies for purpose of this research is assessed in subsequent sections.

4.2 Selection of Research Methodology

In examining the design of a research project, it is useful to consider the intended output from the research (Fellows and Liu, 2003), and the data requirements (i.e. level of detail) and the necessary analyses required in order to produce the intended output. The intended output of the project is a methodology for the ‘live’ capture and reuse of project knowledge with the aid of IT. This might involve the development of an Information Systems (IS). All of these entail detailed information on:

- The various types of reusable project knowledge in construction;
- The current practice for the capture and reuse of the aforementioned reusable project knowledge;
- The shortcomings of the current practice for knowledge capture and reuse; and
- The detailed requirements for knowledge capture and reuse by various end users of project knowledge.

The key features of the various research approaches identified, distinguished as either quantitative or qualitative, are depicted in Table 4.1.

Table 4.1: Approaches to Research - A Comparison

IS Research Approach	Key features
<i>(a) Quantitative</i>	
Laboratory Experiments	Identification of the relationship between the variables via a designed laboratory situation using quantitative analysis in the hope of making generalisable statements applicable to real-life situations (Galliers, 1985)
Field Experiments	Extension of the laboratory approach to real organisations (Galliers, 1985)

Surveys	Including cross-sectional and longitudinal studies using questionnaires or structured interviews for data collection with the intent of generalising from a sample of population (Babbie, 1990)
Desk Research	Data used are obtained from secondary sources (Naoum, 1998).
Futures Research	Employing techniques such as regression analysis, time-series analysis and Delphi method to extrapolate, or deduce future possible events or impacts (Galliers, 1985).
<i>(b) Qualitative</i> Action Research	Based on the principle that the researcher is within the field of that research and becomes a partner in the action and process of change (Wood-Harper, 1985)
Phenomenological Studies	Human experiences are examined through extensive and prolonged engagement to develop patterns and relationships of meaning (Galliers, 1985).
Grounded theory	Designing a theory using multiple stages of data collection, and the refinement and interrelationship of categories of information (Strauss and Corbin, 1998).
Case studies	Entailing the detailed and intensive analysis of a single case, though it may also be extended to include the study of two or more cases (Bryman, 2004)
Longitudinal Studies	Case studies undertaken over a period of time to identify changing relationships and their causes (Galliers, 1985).

4.2.1 Assessment of Suitability of Quantitative Approaches

Quantitative methods are less relevant to this research as:

- It does not aim to find out how such facts and relationships accord with the theories of previous research; and
- It has no detailed secondary source of information available for carrying out desk research.

Furthermore, knowledge management in construction is still in embryonic state (Carrillo, 2004) with low overall understanding of knowledge management processes amongst the whole industry. Therefore, it is unlikely that quantitative approaches such as questionnaires or surveys will be able to gather the information in the level of detail required. As noted by Galliers (1985), little insight is usually obtained from surveys regarding the causes or the processes behind the phenomena being studied. For this research, laboratory and field experiments are also excluded as the detailed information required for the research are

mainly based on personal experience and company's practice, which can be obtained through other methods without setting up a laboratory for experiments. Furthermore, the laboratory and field experiments are known for their weaknesses such as the limited extent to which identified relationships exist in the real-world due to over-simplification of the experimental situation and the difficulty of finding organisations to be experimented on (Galliers, 1985). Futures research was considered inappropriate because the research did not involve the study of how to deal with rapid changes taking place in KM and IT due to changing economic and political environments.

4.2.2 Assessment of Suitability of Qualitative Approaches

The study of people's experiences in the areas investigated through extensive prolonged period engagement (phenomenological study) was unlikely to be feasible due to the tight schedule of people working in the industry. Action research was ruled out as its application is restricted to a single project and organisation (Galliers, 1992). This restriction was considered too narrow for the scope of information required and would lead to biases. Grounded theory was not selected as this research does not aim to develop new theory.

For the purpose of this research, a case study approach was adopted because it afforded an opportunity to explore and to obtain deeper insights into the areas investigated. The triangulation method was not applied since quantitative methods had been ruled out and the case study approach had been chosen for the purpose of the study. Longitudinal case studies were also ignored as the objective of the research was not to identify the changes in relationships and their causes.

Although a case study approach was considered to be most appropriate, it has been criticised mainly for (Yin, 2003; Bennett, 1997):

- Lack of rigour;
- Lack of basis for generalisation; and
- Selection bias.

The details of these shortcomings are as follows:

- *Lack of rigour* - This is due to the lack of systematic procedures and approach in carrying out the case study (Yin, 2003). As a result, sometimes a case study approach is regarded as a time consuming approach which produces unreadable reports (Yin, 2003). This shortcoming can be addressed or reduced through better research design, and the execution of the case study in accordance to the design;
- *Lack of basis for generalisation* - The conclusion drawn by the case study approach is often criticised for the lack of representativeness as normally only a few cases are conducted for the study of a wide range of variables (Bennett, 1997). Hence, it is unable to be generalised to represent a wider and more diverse population. However, Bennett (1997) argues that the intention of conducting a case study is to seek only 'contingent' generalisations that apply to cases that are similar to those studied, rather than that apply to universes. Therefore, the validity of the findings of this approach is not affected; and
- *Selection bias* - Selection bias happens when researchers select cases that represent a truncated sample along the dependent variable of the relevant study of universe (Bennett, 1997). As a result, the conclusion drawn from the study may be bias and the views obtained may be truncated as well. To avoid this problem, the case study companies selected should comprise an appropriate mix of companies with different backgrounds or roles.

4.3 Methodology for Information Systems Development

An information system is 'an arrangement of people, data, processes, and information technology that interact to collect, process, store, and provide as output the information needed to support an organization' (Whitten et al., 2004, p.12). Avison and Fitzgerald (2003) define the IS development methodology as a collection of procedures, techniques, tools, and documentation aids which will help the system developers in their efforts to implement a new information system. A number of development methodologies are available, but the Information Systems Development Life Cycle (SDLC), which is also known as 'traditional systems analysis' and the waterfall model (see Figure 4.1), has been the general approach and basis for development of many IS since 1970s (Avison and Fitzgerald, 2003; Vidgen et al., 2002).

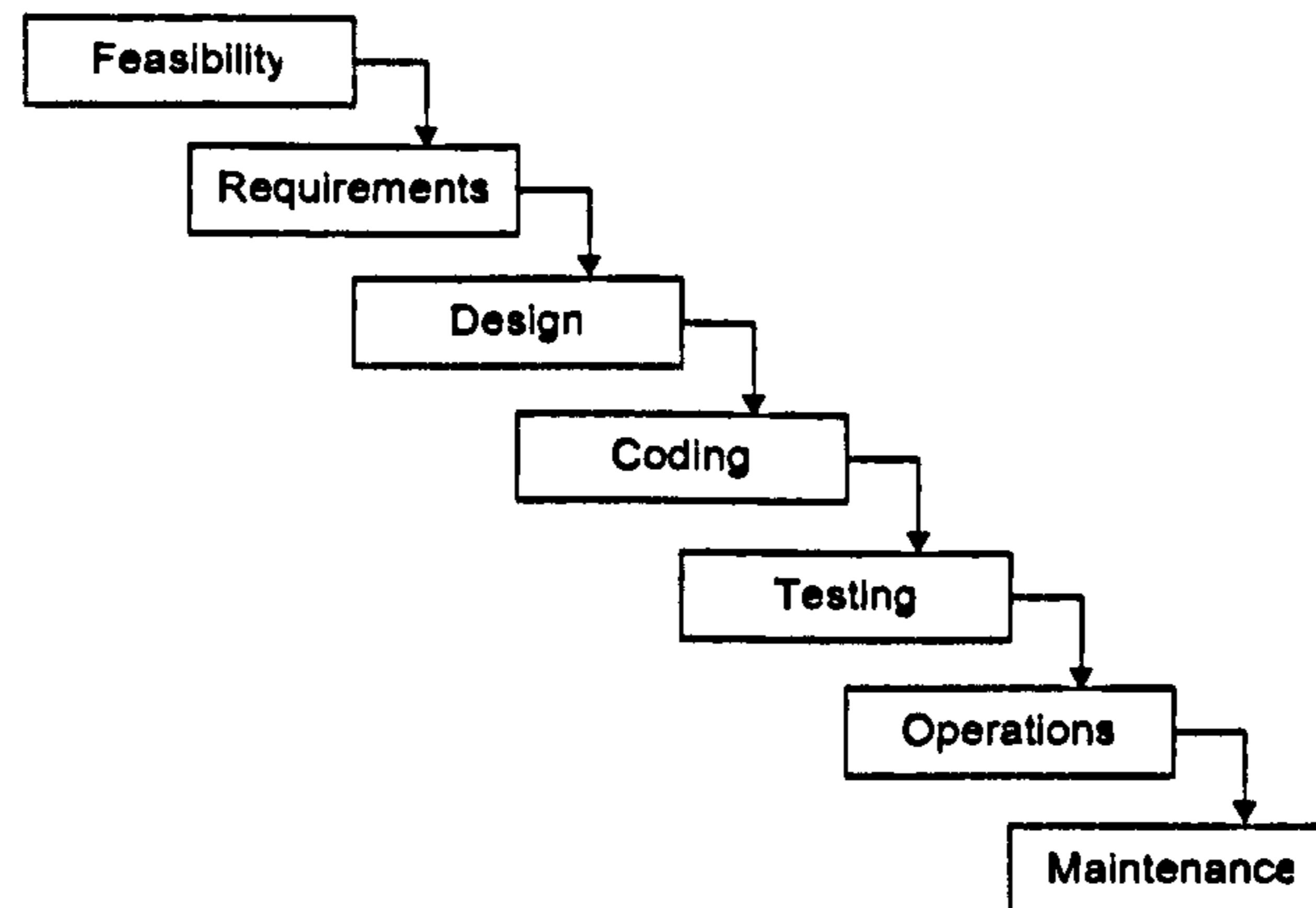


Figure 4.1: The waterfall life-cycle for information systems development (Vidgen et al., 2002)

The main weakness of SDLC is due to its staged nature. By the time the review stage comes, the information system may be found to be inadequate and it may not be long before the process starts again with a feasibility study to develop another IS to replace it (Avison and Fitzgerald, 2003). Vidgen et al (2002) also criticise SDLC as an inflexible, time-consuming and hence expensive methodology. Therefore, many new and adapted methodologies based on SDLC have emerged. Avison and Fitzgerald (2003) have grouped the methodologies into several categories. The features of these methodologies are shown in Table 4.2.

Table 4.2: Features and different types of IS development methodology

Category	Features (Avison and Fitzgerald, 2003)	Methodology
Object-oriented	<ul style="list-style-type: none"> It models objects, which represent something in the real world including people, data, and processes, and the interaction of objects 	Object-oriented Analysis (OOA)
		Rational Unified Process (RUP)
Organisational-oriented	<ul style="list-style-type: none"> Process Innovation (PI) for implementing new organisational structures and systems Information Systems Work and Analysis of Changes (ISAC) seeks to identify the fundamental causes of users' problems regarding IS within an organisation Renaissance aims to ensure that legacy systems can be adapted to reflect changes in the environment Project in Controlled Environments (PRINCE) is a structured and standard approach for project management 	Process Innovation (PI)
		Information Systems Work and Analysis of Changes (ISAC)
		Renaissance
		Project in Controlled Environments (PRINCE)
		Soft Systems Methodology (SSM)

	<ul style="list-style-type: none"> Soft Systems Methodology (SSM) addresses the 'fuzzy', ill-structured or soft problem situations of IS development 	
Process-oriented	<ul style="list-style-type: none"> Also called structured systems analysis approach. Main techniques used are process-oriented ones of functional decomposition, data flow diagrams, decision trees, and structured English 	Structured Analysis, Design, and Implementation of Information Systems (STRADIS) Yourdon Systems Method (YSM) Jackson systems development
People-oriented	<ul style="list-style-type: none"> Effective Technical and Human Implementation of Computer-Based Systems (ETHICS) adopts a people-oriented approach based on participation in research Knowledge Acquisition and Documentation Structuring (KADS) and CommonKADS are people-oriented as they attempt to capture the expertise and knowledge of people in the organisation 	Effective Technical and Human Implementation of Computer-Based Systems (ETHICS) Knowledge Acquisition and Documentation Structuring (KADS) CommonKADS
Blended methodologies	<ul style="list-style-type: none"> Being formed as parts of, or the 'best of', other methodologies, techniques, and tools (and applications in the case of Enterprise Resource Planning system) 	Structured Systems Analysis and Design Method (SSADM) Merise Information Engineering (IE) Weltri-ERP Development
Rapid Development	<ul style="list-style-type: none"> Oriented towards the speed of development based on evolutionary and prototyping techniques 	James Martin's RAD (JMRAD) Dynamic systems development method (DSDM) Extreme programming (XP) Web IS development methodology (WISDM)

These methodologies for IS development each have their own strengths and weaknesses, and may suit different types of IS of different nature and functional requirements.

4.4 Selection of the Methodology for Information System Development

For the purpose of this research, the most appropriate development methodology was selected through a process of elimination based on the following elements:

- The application domains*

Weltri-ERP development is for developing Enterprise Resource Planning systems (i.e. ERP); Knowledge Acquisition and Documentation Structuring (KADS) and CommonKADS are for expert systems; Renaissance is for system evolution and maintenance; Project in Controlled Environments (PRINCE) is for planning and management of time and resources required for an IS development project; and Process

Innovation (PI) is mainly related to Business Process Reengineering.

- *The target size of the organisations where the methodology is used*

Structured Analysis, Design, and Implementation of Information Systems (STRADIS), Yourdon Systems Methods (YSM), Object-oriented Analysis (OOA), Rational Unified Process (RUP), Structured Systems Analysis and Design Method (SSADM), Merise, and Information Engineering (IE) are mainly for use in situations where a large team of people are generally involved in an IS development project. Therefore, none of these were selected for the use in this project.

- *The existence of special requirements of the methodology that hinder its employment*

Effective Technical and Human Implementation of Computer-Based Systems (ETHICS) is eliminated as it requires an expert facilitator in order to use the methodology, whereas Extreme Programming (XP) is ignored as pair-programming (i.e. two people working together at a single computer) is required, which is not feasible in the research.

- *The coverage of the development phases*

Not all the methodologies cover all the development phases of an IS development project. For instance, Soft Systems Methodology (SSM), Information Systems Work and Analysis of Changes (ISAC), Process Innovation (PI), Yourdon Systems Method (YSM), Object-oriented Analysis (OOA), Jackson System Development, and Dynamic Systems Development Method (DSDM) only cover either testing or evaluation (but not both) of the IS developed. However, testing and evaluation are necessary for the purpose of this research as a means for ensuring the quality of the end product and refining the IS developed. Therefore, the aforementioned methodologies were not employed in this research.

The concept of RAD which allows the production of a prototype of the IS quickly for evaluation and refinements is promising. However, the prototype application to be developed is a Web-based IS, and RAD has known to struggle to meet the specific requirements of Web-based IS (Avison and Fitzgerald, 2003). Compared to non Web-

based IS, Web-based IS development emphasises on (Avison and Fitzgerald, 2003):

- Time pressure (i.e. fast delivery);
- Design and user-interface requirements;
- Security concerns; and
- Customer orientation.

If compared to RAD, Web IS development methodology (WISDM) addresses these requirements in its five aspects of the development process, and it also promises a fast delivery (Avison and Fitzgerald, 2003). Therefore, WISDM was selected for the development of the prototype application.

4.5 Web IS Development Methodology (WISDM)

WISDM consists of five aspects, i.e. organisational analysis, information analysis, technical design, human-computer interface and work design. There is no specific sequence for the five aspects or processes (Avison and Fitzgerald, 2003). The details of the five aspects of WISDM are summarised as follows (Avison and Fitzgerald, 2003):

- *Organizational analysis* represents value creation. It stresses strategy as relationship building and maintaining with a broad range of stakeholders. It also emphasises the adoption of the right strategy in the design and development of information systems for the success of a project;
- *Information analysis* represents a requirements specification. This is a formalised specification of the information and process requirements of the organisation;
- *Technical design* represents the software model. It is a formalised model of the software in terms of data structures and program design to support software development;
- *Human-Computer Interface (HCI)* represents the user-interface and is located as an overlapping space in technical design and work design. The interface design draws on the principle of the website design for page layout, navigation schemes, and usability in the context of work design. This aspect may also cover security issues and monitoring of the usage of the information systems; and
- *Work design* represents user satisfaction. WISDM assesses user satisfaction in terms of the usability, information, interaction, and convergence (i.e. overall view) of the

system.

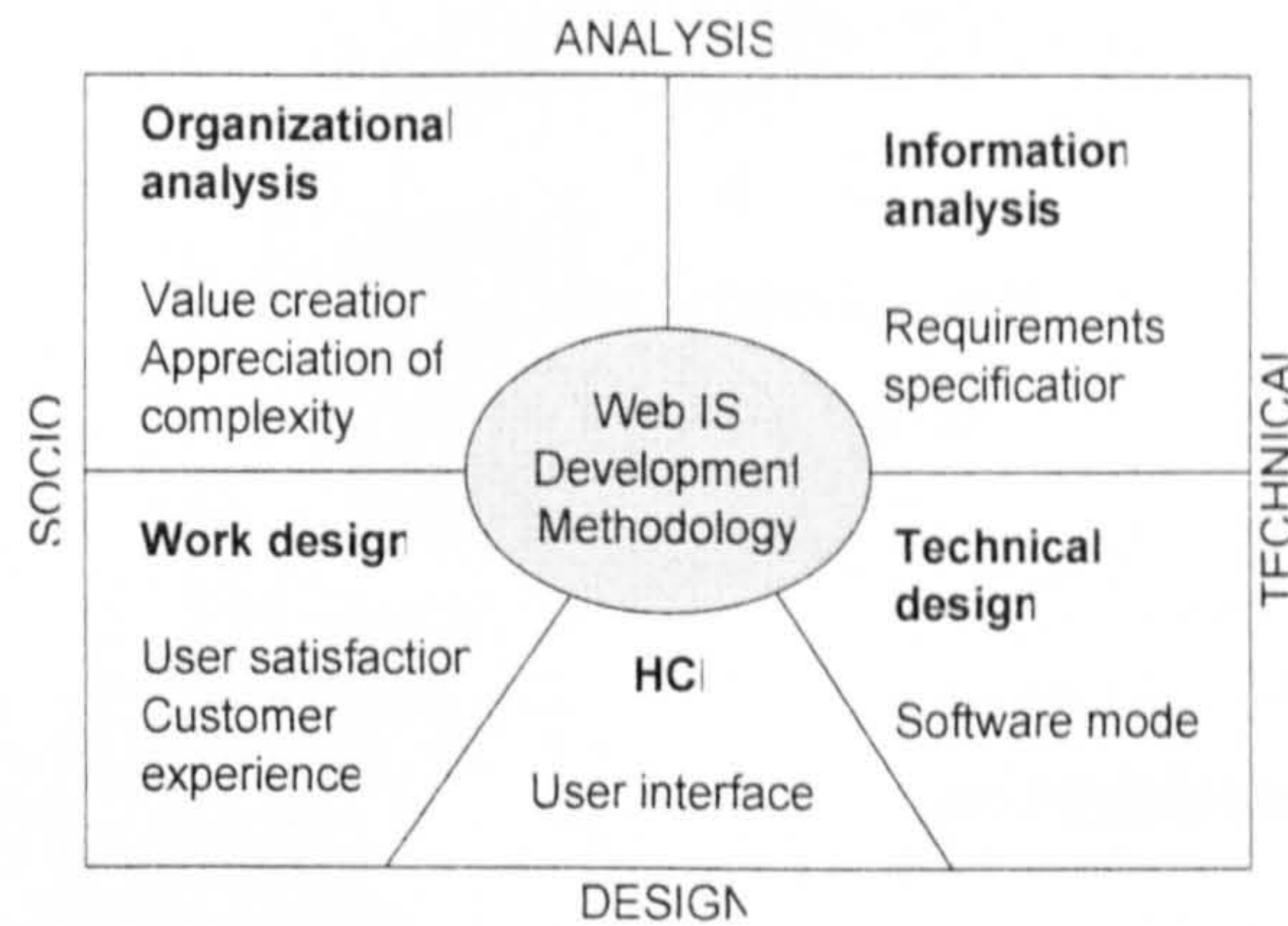


Figure 4.2: Web Information System Development Methodology (adapted from Avison and Fitzgerald, 2003)

4.6 Research Design

The research initially adopted a case study approach for data collection and analysis, and subsequently an appropriate IS development methodology (i.e. WISDM) was chosen based on the results of the case studies for the design of the IS. Therefore, for the purpose of this research the detailed information required for the development of the IS (i.e. the tasks covered by ‘organisational analysis’ and ‘information analysis’ processes of the WISDM) was obtained through the case studies. The research design, and the relationship between the case studies and the WISDM are depicted in Figure 4.3. The steps adopted to implement the research are as follows:

- Review of literature on the concept of knowledge management;
- Review of literature on the current knowledge management tools and concepts that may be useful for facilitating the ‘live’ capture and reuse of project knowledge;
- Conduct case studies;
- Develop the methodology; and
- Test and evaluate the methodology.

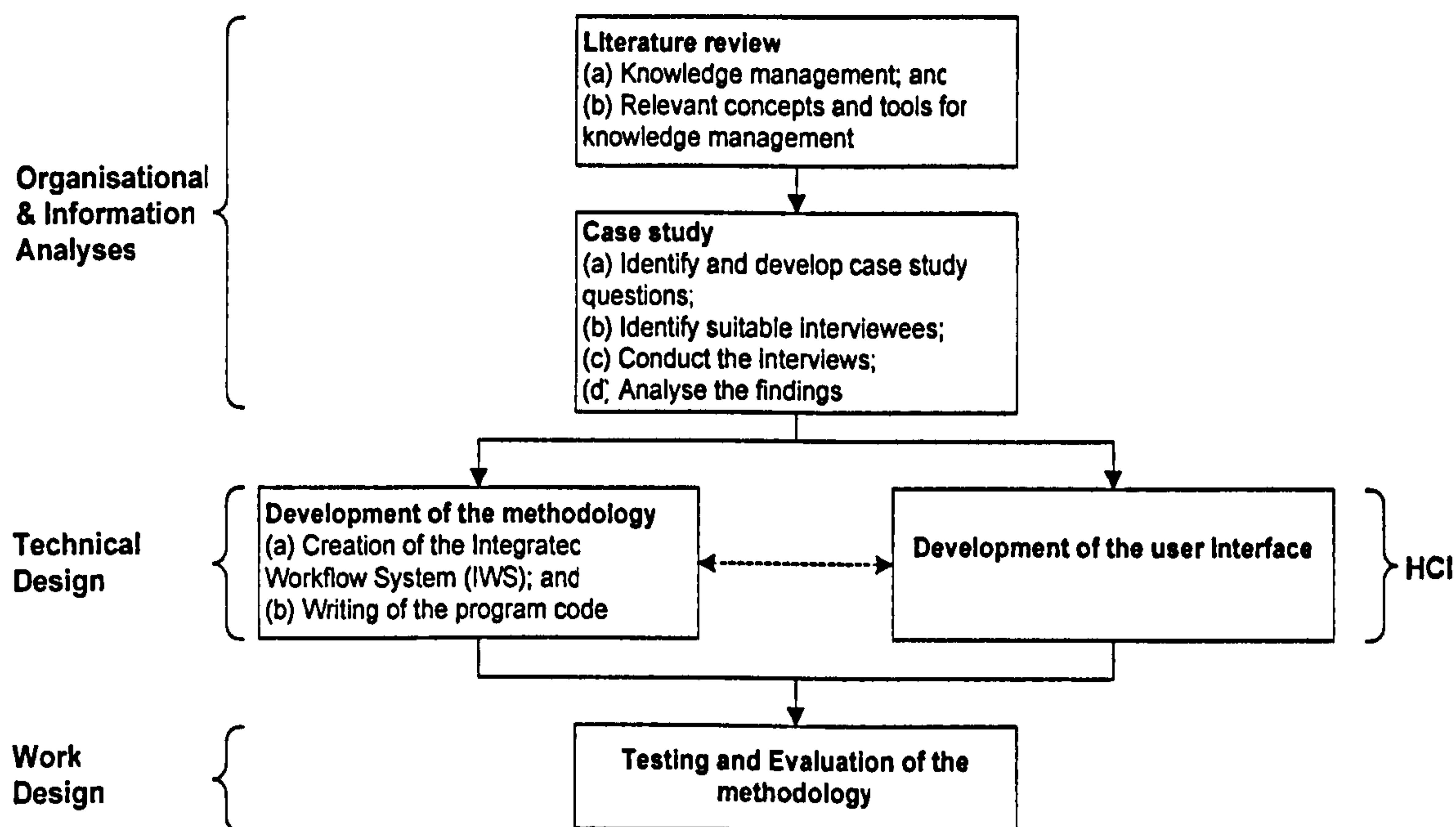


Figure 4.3: Research design adopted

The following sections describe each step in detail.

4.6.1 Literature Review

A review of the literature and existing studies is part of the ground-clearing and preparatory work in the initial stages of any empirical research (Hakim, 2000). It provides a synthesis of existing knowledge on a specific question (Hakim, 2000), which is an essential step towards the development of a theory prior to conducting a case study (Yin, 2003). The details of literature review conducted are as follows:

- *Review of the Concept of Knowledge Management*

A thorough review was conducted on the concept of knowledge management, the distinction of different types of knowledge, the learning situations where new knowledge is created, and the various knowledge management research projects in construction in particular. The literature review helped to establish the importance of the ‘live’ capture and reuse of project knowledge in construction and the lack of research in this area to justify the need for this research.

- *Exploring the Current Knowledge Management Tools and Relevant Concepts*

This involved extensive review of existing published literature on the current KM tools and concepts for the capture and reuse of knowledge both in construction and other industries. The various concepts and KM tools were also assessed in terms of their capability to help facilitate the 'live' capture and reuse of project knowledge. This provided essential background knowledge about the various KM tools available prior to conducting the semi-structured interviews for the case studies.

4.6.2 Gathering Detailed Information through Case Studies

Yin (2003) defines a case study as an empirical enquiry that investigates a contemporary phenomenon within real-life context. A number of categorisations are suggested by researchers to distinguish between various types of case study (see Yin, 2003; Hakim, 2000; Stake, 1994). The case studies in the context of this research fall under the categories of:

- Descriptive case study (Yin, 2003), as it attempts to present a complete description of a phenomenon (i.e. the study of various types of reusable project knowledge, the current practice and requirements for knowledge capture and reuse) within the context of construction organisations; and
- Collective case study (Stake, 1994), since each case study conducted covers several cases. This means that a 'multiple-case' design was adopted for the case study (Yin, 2003).

A multiple-case design is preferred to a single-case design as the views obtained from the latter is restricted to a single organisation or case (Galliers, 1985). In addition, this design is also more appropriate as the research involved the identification of various types of reusable project knowledge, learning situations, current practice and requirements for knowledge capture and reuse which cannot be obtained from a single organisation. Furthermore, analytical conclusions from more than one case study will be more substantial and powerful than those coming from a single case alone (Yin, 2003). The case studies involved semi-structured interviews with 18 senior staff from six companies to ensure that a comprehensive view was obtained. The details of the case studies are described in the following sections.

4.6.2.1 *Composition of Case Study Companies*

The six case study companies comprises:

- A project management consultant (i.e. Turner and Townsend Group);
- An engineering consultant (i.e. Arup);
- Two architects (i.e. Dewjoc and Simons Group);
- A client organisation (i.e. Thames Water); and
- A project extranet service provider (i.e. 4Projects).

These case study companies were part of the CAPRIKON (Capture and Reuse of Project Knowledge in Construction) project team. The composition of case study companies helps to ensure that the views obtained cover that of different parties in construction industry. The views of the quantity surveyor and contractor perspectives were obtained from the relevant staff of Turner and Townsend Group and Simons Group respectively. 4Projects was involved to contribute its view on the application of Information and Communication Technology (ICT) in the construction industry.

4.6.2.2 *Composition of Interviewees*

To avoid the truncation of information and bias, the case studies involved people of different positions and job functions. Their job titles included: Group Knowledge Manager, Director of Business Development, Knowledge Researcher, IT Manager, Procurement Manager, Project Director, Head of Research and Development, Company Partner and Managing Director.

4.6.2.3 *Interviews*

The questions asked were centred on:

- What are the nature and characteristics of reusable project knowledge?
- What are the various types of reusable project knowledge?
- What are the learning situations where new learning can be captured?
- What are the current practices for the capture and reuse of project knowledge?
- What are the end-users' requirements for knowledge capture and reuse?

To prevent misinterpretation of the questions by the interviewees, a short briefing

regarding the research project, key concepts (e.g. knowledge management processes) and the definition of terms used, was given to the interviewees before any question was asked. Each interview lasted one to two hours and was supplemented by presentations of the IT tools used for managing knowledge and sample documents showing the format used for capturing knowledge. The shortcomings of current practices and end-users' requirements identified were then analysed to formulate the methodology for the 'live' capture and reuse of project knowledge in construction.

4.6.3 Development of the Methodology

The basic structure of the methodology was first developed based on the findings of the case studies. The structure outlined the top-level processes of the methodology for the 'live' capture and reuse of project knowledge in construction. The methodology was subsequently detailed and represented in the form of a flowchart (i.e. the Integrated Workflow System) and relevant user interfaces were designed. The flowchart and the user interfaces were then reviewed by five of the case study companies in a mini-workshop conducted before they are encapsulated into a prototype application. This is because any amendments to the user interface after the prototype application is fully developed will lead to significant rework and extensive re-writing of the programme codes. The user interfaces and the Integrated Workflow System were refined based on the findings of the mini-workshop (see Section 6.5 for details).

The prototype application was then developed based on the user interfaces and Integrated Workflow System created. The combination of the Microsoft™ ASP.NET Visual Basic 2.0 and Microsoft™ SQL Server 2005 Express Edition was chosen for the development of the prototype application. This is because of the development tool's (i.e. Microsoft™ Visual Web Developer 2005 Express Edition) 'what you see is what you get' (WYSIWYG) development feature, the fully integrated development environment offered, its robust built-in security system, its rapid prototyping capability, and that it is available free of charge. During the course of development, the prototype application was also demonstrated to and tried by the research team members periodically. This collected feedbacks for fine-tuning the prototype.

An empirical study was also carried out to investigate whether the methodology (i.e. the capture of project knowledge in project meetings/reviews) would create significant additional workload to the people involved. The empirical study was conducted on a site meeting of a Simons Group's construction project. The Simons Group were very keen to implement the methodology and had required the project team to capture its project knowledge from weekly site meetings for a period of time prior to the empirical study. In accordance with the processes stipulated in the Integrated Workflow System, the project manager had included an agenda item called 'knowledge management' into the weekly site meetings for the capture of project knowledge. The project team members (consisting of a project manager, and the representatives of the architect, quantity surveyor, structural engineer and services engineer) would then discuss the knowledge learned since the previous meeting. The project manager was responsible for recording the details of the knowledge. The difference between the team's practice and the methodology developed was that the knowledge was recorded on the minutes of the meeting instead of a knowledge base because the knowledge base was not yet ready. The study covered:

- Recording the time required for discussing and capturing the knowledge learned; and
- Finding out from the project team members whether this practice would add significant additional workload to them and their acceptance of the idea of capturing knowledge in routine site meeting.

The study revealed that the project team only used ten minutes to discuss the knowledge learned since the previous meeting, and the project manager further confirmed that he only needed an additional 10-15 minutes to record the knowledge captured in the minutes of meeting (This excludes the time for data input into the system). None of the project team members (nine persons) saw this as a significant additional workload. Instead, they acknowledged the benefits of this method and that they were surprised to find out how much knowledge they could share and capture from the discussion. However, it is recognised that the result would be more conclusive if more similar studies are conducted.

Testing and evaluation were carried out after the prototype application was ready.

4.6.4 Testing and Evaluation of the Methodology

Two types of test (i.e. Acceptance Test and Entity-Life Histories Test) were conducted on the prototype application to examine its functionalities to ensure that it was free from error (see Section 7.2). An evaluation was conducted subsequently to obtain external views from potential users for making further refinements to the prototype application. For consistency, most of the people who participated in the evaluation were also involved in the interviews carried out for the case studies. The ten participants were first given a demonstration on how to use the prototype application. They were then allowed to use the prototype application. A questionnaire was given to the participants to collect their views of the prototype application in meeting the requirements identified from case studies. These include:

- The avoidance of creating significant workload to the users and organisations;
- The capability to facilitate the 'live' capture, sharing and reuse of project knowledge in construction; and
- The overall rating for the system.

Based on the findings of the evaluation, the prototype application was further refined.

The following chapter covers the case study findings and analysis, based on which the methodology for 'live' capture and reuse of project knowledge in construction was developed.

Chapter 5 Knowledge Reuse Requirements

Case studies were conducted to explore and obtain deeper insights into the areas investigated in this research. These include the nature and characteristics of reusable project knowledge, types of reusable project knowledge in construction, learning situations, end-users' requirements for knowledge capture and reuse, and the current approaches for knowledge capture. This chapter presents the findings and analysis of the findings of the case studies.

5.1 Background of Case Study Companies

Six case studies were undertaken, involving semi-structured interviews with eighteen representatives of the six companies whose positions ranged from Group Knowledge Manager to Company Partner. The six case study companies were partners of CAPRIKON (Capture and Reuse of Project Knowledge in Construction) research project. Background information about the companies is presented in Table 5.1.

Table 5.1: Background of case study companies

Company Name	Positions of Interviewees	Company Background	Number of Employees	Annual Revenue (£)
A	Partner, Associates & IT Manager	Design Consultant	80	£4.3M
B	Managing Director (Design), IT Manager, Systems Manager & Procurement Manager	Design Consultant, Developer and Contractor	850	£250M
C	Group Knowledge Manager & Knowledge Researcher	Engineering Consultant	7000	£403M
D	Group Knowledge Manager, Associate Director & Head of R&D	Management consultant	1200	£61M
E	Director of Business Development, Senior Account Manager & Customer Support Staff	Project Extranet Service Provider	31	£2M

F	Knowledge Manager	Water Company	18000	£1860M
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These companies are different in terms of their business nature and size, and play different roles in construction project. This helps to prevent bias and ensure that various perspectives were obtained from the case studies.

5.2 Findings from the Case Studies

The findings from the case studies represent the collective views of the companies involved in the areas investigated, where significant overlaps of information were observed. The findings from all case study companies are combined and structured into the following subheadings:

- Types of reusable project knowledge;
- Learning situations;
- End-users' requirements for knowledge capture and reuse, and
- Current approach for knowledge capture.

5.2.1 Types of Reusable Project Knowledge

Prior to the capture of reusable project knowledge, it is crucial to identify what the various types of reusable project knowledge are as well as their nature and characteristics. The main nature and characteristics of reusable project knowledge identified are as follows:

- It is borne out of a set of particular circumstances that exist on a recurrent basis;
- It is adaptable, i.e. the new application may not be identical but the knowledge is capable of adjustment to make it work;
- It is the amalgamation of industry's and a company's previous knowledge complemented by new research findings, new ways of working and new ideas which ultimately leads to innovation and improved best practice; and
- It is capable of being transferred across sectors for reuse (e.g. from construction to the business sector).

Through the case studies, a wide spectrum of reusable project knowledge were identified (see Appendix C). Different companies used different terms to describe similar type of

knowledge. The reusable project knowledge identified were therefore aligned and grouped into categories. It is possible to break some of the categories down into different types of reusable project knowledge. This list is by no means exhaustive but represents the main categories of the reusable project knowledge:

- *Process Knowledge* – This is the knowledge pertaining to the execution of various project stages of construction project. The types of reusable project knowledge belong to this category include design, tendering and estimating, planning, construction methods and techniques, and operation and maintenance knowledge. These knowledge are captured in the form of standard procedures (e.g. design manual for design knowledge) and mostly remain tacit;
- *Knowledge about Clients* – This covers the knowledge about clients' specific requirements, their internal procedures and business. This knowledge may exist in the form of standard procedures compiled based on the experience of dealing with client. It may also remain tacit and shared through interactions between people;
- *Costing Knowledge* – This knowledge is about the costs of alternative forms of construction and the whole life cost of an asset. This knowledge may remain tacit in the head of estimators, or be explicated and captured in custom-designed software;
- *Knowledge about Legal and Statutory Requirements* – Regulatory requirements change over time. This knowledge covers the requirements and responsibilities imposed by regulations, etc. and the best practice to address these requirements. This knowledge is available through subscription to the relevant Web services and in the form of CDs. It may also be captured in the head of people through experience or attending specific courses;
- *Knowledge about Reusable Details* – Reusable details comprises standard design details, specifications and method statements. These details may be reused with adaptations. They help to avoid recreating similar details from scratch and also lead to time and cost savings;
- *Knowledge of Best Practices and Lessons Learned* – These are the proven ways of working that contribute to the success of projects, and the mistakes made that must be avoided in future projects. This knowledge is often explicated and compiled as best practice guide and code of practice;

- *Knowledge of Performance of Suppliers* – The suppliers referred to are consultants, contractors, subcontractors, material suppliers, etc. who have contributed services or goods to a project. The capture of this knowledge facilitates better selection of suppliers for future projects. This knowledge is explicit in nature. It is captured in a custom-designed database which is accessible through intranet;
- *Knowledge of Who Knows What* – This is the knowledge on the skills, experience and expertise of each of the members of staff. It helps to locate the right people with the right knowledge for the sharing of knowledge, particularly the tacit knowledge which is difficult to codify. This knowledge is captured in organisation's staff profile or skills yellow pages; and
- *Other Types of Knowledge* – This knowledge category includes key knowledge about competitors, risk management, key performance indicators, and other sector-specific knowledge (e.g. knowledge about flood control and management of water networks).

The various categories of reusable project knowledge identified can also be classified according to project types (e.g. hospital project) and procurement routes (e.g. PFI or Private Finance Initiative) as appropriate. This can help the location of the relevant reusable project knowledge that is captured from projects that use a particular type of procurement route or fall under a particular project type. For the details of the reusable project knowledge, please see Appendix D.

5.2.2 Analysis of the Types of Reusable Project Knowledge

The nature and characteristics of reusable project knowledge identified from the case studies were consistent with its proposed definition, i.e. it can be adapted for reuse in different situations, and that it can lead to further improvement and innovation. Further insights obtained from the case studies are:

- The reuse of project knowledge is not limited to the same project or other similar projects, but also in other departments; and
- The finding that reusable project knowledge is borne out of a set of particular circumstances that exist on a recurring basis has indirectly proven the existence of learning situations at which knowledge is created. It also highlights the relationship between reusable project knowledge and the various stages of the construction project,

as well as the possibility of identifying and capturing the reusable project knowledge based on project stages. Existing literature on project stages which can be used for the purpose includes the RIBA Plan of Work, and Process Protocol Map developed by Kagioglou et al (1998).

Table 5.2 shows the possibility and attempts to identify and capture reusable project knowledge based on the Process Protocol phases. The four broad Process Protocol phases are pre-project, pre-construction, construction and post-construction. Different types of reusable project knowledge can be captured at the project reviews conducted at different project stages. However, some knowledge types may be captured throughout the duration of a project.

Table 5.2: Types of reusable project knowledge identified and the Process Protocol stages at which the knowledge can be captured

	Reusable Project Knowledge	Process Protocol Phases			
		Phase 1	Phase 2	Phase 3	Phase 4
1.	Process Knowledge				
	▪ Briefing	•	•		
	▪ Design	•	•		
	▪ Tendering and Estimating	•	•		
	▪ Planning		•	•	
	▪ Construction and Buildability			•	
	▪ Operation and Maintenance				•
2.	Knowledge about Client				
	▪ Clients' requirements	•	•		
	▪ Client organisations' internal procedures	•	•	•	
	▪ Background knowledge about client's business	•	•		
3.	Costing Knowledge				
	▪ Cost of alternative forms of construction			•	
	▪ Whole life cost (WLC)			•	•
4.	Knowledge of Legal and Statutory Requirements				
	▪ Health and Safety			•	•
	▪ Changes in regulatory requirements	•	•	•	•
	▪ Contract	•	•	•	•
5.	Knowledge of Reusable Details				
	▪ Standard design details	•	•	•	
	▪ Specifications	•	•	•	
	▪ Method statements	•	•	•	
6.	Knowledge of Best Practices and Lessons Learned	•	•	•	•
7.	Knowledge of Performance of Suppliers			•	•
8.	Knowledge of Who Knows What				•

9.	Other Types of Knowledge				
	▪ Risk management	•	•		•
	▪ Team working	•	•	•	•
	▪ Project management	•	•	•	•

The types of reusable project knowledge identified by the case study companies were found to be centred on their core activities. For instance, the key types of reusable project knowledge identified by a design consultancy are design knowledge, regulatory requirements knowledge and knowledge about the client's specific requirements which have a bearing on the design. For a management consultancy, its reusable project knowledge is wide ranging and covers the management knowledge of the various project processes. In the case of a water company, technical and engineering knowledge pertaining to the management of its water network were regarded as important reusable project knowledge. Therefore, although the list of reusable project knowledge presented is comprehensive, there might still be some other specific types of reusable project knowledge which were not identified in this research but perceived as important by other companies.

Further analysis revealed that the reusable project knowledge identified often exist as a mix of tacit and explicit knowledge, rather than as distinctive tacit or explicit knowledge alone. For instance, Companies A and C had externalised part of their design knowledge and knowledge about best practices into the form of a design manual and technical notes respectively. However, both companies acknowledged that there is still some knowledge which is difficult to externalise and hence remain tacit (in the head of people). The findings suggest that in addition to the tacit and explicit dimensions, there is an additional dimension of knowledge, i.e. the tacit knowledge which can be made explicit but have not yet been converted. This is depicted in Figure 5.1:

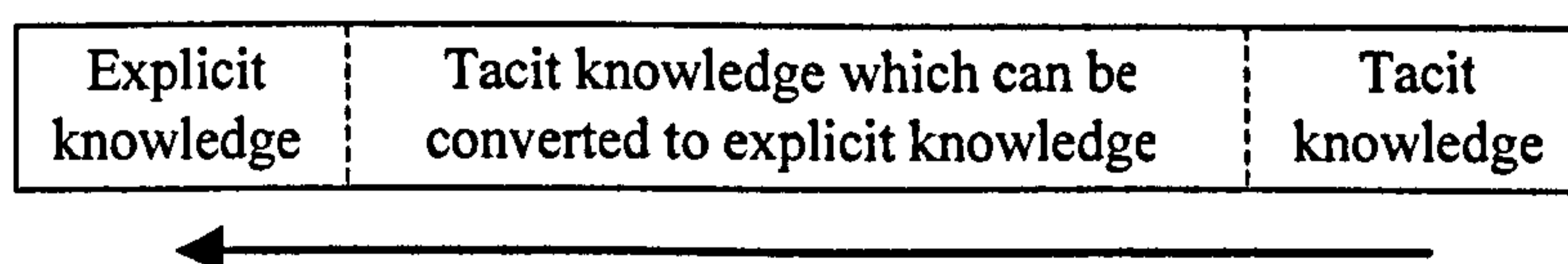


Figure 5.1: Three dimensions of knowledge

As explicit knowledge is comparatively easier to be transferred and shared for reuse, the methodology designed may attempt to explicate tacit knowledge into explicit knowledge as far as possible. For the remaining tacit knowledge which is really difficult to be explicated, means should be provided to connect the people with a particular type of knowledge and the people who need the knowledge. These findings will be reflected in the design of the methodology for the 'live' capture and reuse of reusable project knowledge.

5.2.3 Learning Situations

Learning situations are special events where new learning or knowledge are created. Identification of the various learning events in advance can help in the development of a methodology for the capture of reusable project knowledge.

Most of the interviewees found it difficult to identify specific learning situations where new learning were created and captured. This is because they asserted that every decision making process and 'every situation that emerges during the course of the project' has the potential to be a learning situation. Most of the learning situations presented below were actually identified by three companies. The learning situations identified are:

- **New Project Location/Market** - When a company has a new project in a new area or another country with a different set of regulations and local issues, this local knowledge must be captured;
- **New Type of Project** – A new type of project often has different and specific requirements or characteristics which necessitate the learning of new management practices, construction methods, and the use of new technology;
- **Change of End-user/Client** - There are circumstances where the ownership of a building which is originally designed for an end-user/client based on his/her specific requirements may be transferred to another party during the course of the contract for certain reasons. As a result, the building will have a new end-user or a new client and changes in design may be required in order to address the new requirements to suit the new purpose of use;
- **Problem in the Supply of Major Building Fabric/Material** - The desired building fabric or materials in the design, particularly those very specific items such as special types of

space frame from a particular manufacturer, can become unavailable during the course of the project in some instances. This will impose new problems to the project team;

- Undiscovered Condition of Project - Using a refurbishment projects as an example, during the course of the project some defects and faults which were not discovered initially may be identified. This can lead to a new set of problems, extension of project duration, additional work, and may even have an impact on the current job nature;
- Change in Political Climates – Change in government may lead to change in policy that may affect the construction industry;
- Political Problems – This could be potential objections to the construction of a new water treatment plant; and
- New learning can also be captured based on the project stages as delineated in the Process Protocol and RIBA Plan of Work.

5.2.4 Analysis of the Learning Situations

Two types of learning situations were identified from the literature, i.e. the formal and ad hoc learning situations. Corresponding to the findings from the literature review, formal learning situations such as project reviews, reporting and meetings conducted at different project stages were also identified as learning situations by Companies A, C and D. For the ad hoc learning situations, identifying it in advance was said to be difficult. According to the interviewees, this is because every decision making process and ‘every situation that emerges during the course of the project’ has the potential to be an ad hoc learning situation. Therefore, people may not realise that a particular situation is a learning situation. This is due to the fact that their attention is often concentrated on resolving the issues that have arisen in the learning situations.

However, it was found that this assertion might not be conclusive. For example, Boyd et al (2004) noted that site managers meet complex problems in their day-to-day work where their associated experience and solutions for the problems constitute valuable knowledge. When the site and project managers were requested to record their problems in an attempt to capture the knowledge, they had difficulties and asserted that ‘we have no problems on site. We only have solutions.’ However, as time passed, it was observed that most of the

managers had managed to identify and record the problems on site as required. This suggests that there is probably a learning curve both for identifying the problems on site as in Boyd et al (2004) and the learning situations in this research, which (with some practice) people will be able to identify with ease.

The ad hoc learning situations identified are centred on the management of change (e.g. the change in political climates and clients, involvement in new types of project in another country), problems (e.g. undiscovered condition of project and the supply of major building fabric) and the adaptation required in response to the changes and problems. Further research revealed that ad hoc learning situations are very similar to the 'triggers of knowledge production' identified by Egbu et al (2003) where knowledge is being produced and captured. Egbu et al (2003) grouped the triggers of knowledge production in construction organisations into three categories:

- Problem solving;
- Managing change; and
- Innovation.

Problem solving can be regarded as a learning situation as the process involved and lessons learned in solving major problems are reusable project knowledge. For change management, the industry and major clients have recognised the need to identify and manage the change properly (Lazarus and Clifton, 2001). Regarding innovation, Egbu et al (2003) note that it is the crucial driving force behind knowledge production in the construction industry and is hence the source of new learning from projects. More ad hoc learning situations are identified by identifying the major issues of concern within each of the three categories of triggers of knowledge production from the existing literature (See Appendix E). The learning situations identified from the case studies and existing literature are summarised in Table 5.3.

Table 5.3: Table summarising the ad hoc learning situations / triggers of knowledge production identified from this research

Ad Hoc Learning Situations		
a) Triggers of Knowledge Production (Egbu et al, 2003)		
Problem-solving	Managing Change	Innovation
<ul style="list-style-type: none"> • Dealing with complex projects • Managing team member interfaces (e.g. consultant-contractor) • Addressing value engineering issues to deliver best value • Addressing clients' needs • Identifying the knowledge gap • Dealing with contextual differences • Finding measures to increase company competitiveness • Dealing with lack of (design) information • Addressing the need to improve the quality of product/service • Addressing the need to improve efficiency • Addressing the need to recruit skilled people & retain them • Dealing with challenging site logistics • Dealing and coping with incompetent consultants 	<ul style="list-style-type: none"> • Managing changes to the project • Managing organisational change • Addressing the need to comply with standards (Quality Assurance, Health and Safety, etc.) • Addressing the changes to statutory regulations, technical standards • Dealing with contractual arrangements new to the respondent • Being enabled to make design choices • Working with new sub-contractors • Being assigned to a new role • Addressing the need to establish a data transformation system for the whole project team • Addressing the need to create a 'database' • Coping with Government initiatives (e.g. PFI, partnering) 	<ul style="list-style-type: none"> • Using new, innovative building materials, systems, services • Coping with the uniqueness of projects • Dealing with the need and willingness to be 'ahead of the game', 'move the market' • Addressing the pressure & need to innovate ('look at new ways of doing things')
b) Ad Hoc Learning Situations Identified From the Case Studies and Existing Literature		
Problem-solving	Managing Change	Innovation
<ul style="list-style-type: none"> • Supply of major building fabric/material • Undiscovered condition of project • Site condition change • Inflation or relative price rise • Difficulties with contractors • Termination & default • Projects behind schedule • Claims & disputes 	<ul style="list-style-type: none"> • New project location/market • New type of project • Change of end-user/client • Change in project scope • Professional errors and omissions • Design change • Change in client's requirements • Change in construction method etc proposed by 	<ul style="list-style-type: none"> • Fundamental and invasive technology improvements • New process that has benefits to the company • New approach to providing services to customers/clients • New procedures for obtaining goods/services • New product that provides competitive advantage for the company

<ul style="list-style-type: none"> • Budget related issues • Human resource issues • Political problems 	<ul style="list-style-type: none"> • contractor • Changing market requirements • Change in political climate 	<ul style="list-style-type: none"> • New external relations e.g. partnering and joint ventures • New administrative policy e.g. incentive schemes and bonuses
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Further analysis reveals that formal learning situation often involves a group of people for the capture of learning (e.g. project meetings), whereas the ad hoc learning situation may involve only individuals. However, formal and ad hoc learning situations are not mutually exclusive as the issues emerge from ad hoc learning situations may be raised for further discussion in the meetings and reviews with the aim of obtaining better solutions. The design of the methodology must be capable of capturing knowledge from a group of people and individuals so that the knowledge created in both types of learning situations will not be overlooked. The relationship between formal and ad hoc learning situations is depicted in Figure 5.2.

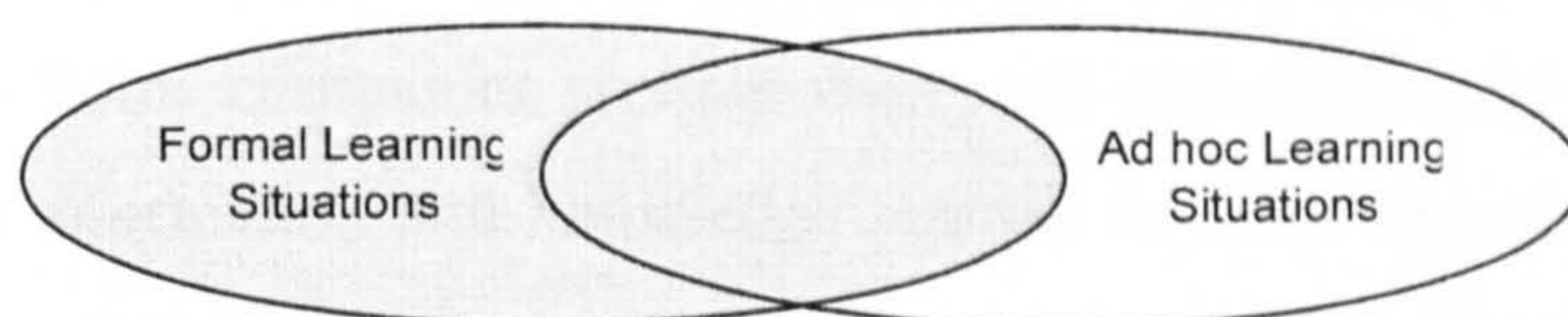


Figure 5.2: Relationship between formal and ad hoc learning situations

After the learning situations at which new learning can be captured are identified, the next section shows the findings on the end-users' requirements for knowledge capture and reuse.

5.2.5 End-users' Requirements for Knowledge Capture and Reuse

The main requirement for the development of the methodology is to facilitate the capture and access of project knowledge at any time (i.e. 'live') and at any place. The design of the methodology must reflect the fact that project team members are often pressed for time and not always collocated. The methodology must therefore allow individual project team member to share and access knowledge at any time without making it compulsory for all project team members to meet face-to-face for the purpose. The case study companies

acknowledged that the aforementioned requirements are critical, and identified the following requirements:

- a) **Cost** – The general consensus among the case study companies was that the methodology used for the capture and reuse of the reusable project knowledge should not incur significant additional cost to the companies. Furthermore, Company A noted that the cost incurred should also be justifiable by the benefits brought about through the reuse of the knowledge captured;
- b) **Workload** – The companies emphasised that any methodology developed should not create significant additional workload to members of staff in view of their existing heavy workload. They added that the additional workload created should be integrated into existing job functions and be carried out within normal working hours. They contended that this is the key to minimising rejection and securing acceptance from the people involved for the successful introduction of any new practice into an organisation. They also pointed out that the additional workload might not be covered by the worker's current job description or employment contract;
- c) **Legal Issues** – Some companies prohibit their staff and collaborating companies from disclosing the information and knowledge learned to other organisations that are not involved in the project. A solution is required to ensure that the sharing, capture and reuse of knowledge from a project is not in breach of copyright and the conditions of contract;
- d) **Accuracy** – Any methodology developed must be capable of capturing and representing the knowledge accurately; and
- e) **Representation of knowledge** – The case study companies' main requirements for knowledge representation are summarised as follows:
 - A standardised approach is required. The knowledge captured must be organised and represented in a logical and simple to understand way, and be readily accessible to others within the organisation;
 - Case studies or detailed explanation of the knowledge are to be provided and shared in a Web environment to help others to understand and hence reuse the knowledge. They suggested that this can be supplemented by video clips to capture the detailed explanation from the originator of the learning;

- A short description prepared to give the reader basic background information about a knowledge item, and the characteristics of the project that are related to the context for the reuse of the knowledge;
- The conditions for reusing the knowledge must be made clear to the users; and
- Establishing convenient means, such as people's personal profile and knowledge network aided by custom-designed IT-systems, for people to communicate with each other and share their knowledge.

See Appendix F for the individual company's requirements on knowledge representation.

5.2.6 Analysis of the End-users' Requirements for Knowledge Capture and Reuse

A methodology for the 'live' capture and reuse of project knowledge can be developed based on the various requirements identified from the case studies. The main requirements identified cover: (1) Cost and workload; (2) Legal issues; (3) Accuracy of knowledge captured; (4) Representation of knowledge; and (5) Facilitating the capture and reuse of project knowledge as soon as possible once it is created or identified. The measures taken to address the requirements are as follows:

5.2.6.1 Cost and Workload

There are three cost components of a KM system that have to be managed and taken into consideration in the development of a KM system/methodology (Robinson et al. 2004):

- The staff costs (KM team component) associated with the roles and skills required for knowledge transformation;
- The organisational or (re)organisational costs (KM process component) associated with core and supporting business processes enabled, affected or re-engineered; and
- The KM infrastructure component costs associated with information and communications technologies (hardware and software), and the setting up or maintenance of people sharing networks, systems or techniques.

The following recommendations can help to reduce and to prevent additional cost in the aforementioned cost components:

- To keep the staff cost low, the 'live' capture and reuse of reusable project knowledge

methodology should avoid the need for additional staff and the creation of significant additional workload for existing staff. Cost and workload are in fact interwoven as Robinson et al. (2004) have shown that staff cost is associated with the role or workload for knowledge transformation. Apart from contradicting with the end-users' requirement that significant additional workload is not desired, it may also reveal contractual issues as the additional workload created may not be covered by the current job description of the members of staff. Therefore, to resolve this matter it is suggested that most, if not all, of the relevant tasks and additional workloads created are handled by ICT (i.e. through the application software developed);

- To reduce the organisational or (re)organisational costs, the methodology developed should be built on existing practice if possible (i.e. integrated into something that people already do, such as meetings and reviews) for the capture of knowledge. This can help to prevent significant additional costs due to the need to re-engineer the current processes, and the creation of additional workload; and
- To reduce the KM infrastructure component costs, the application software developed as part of the 'live' knowledge capture and reuse methodology should be capable of running on the existing ICT systems and platforms which are commonly used by the construction organisations or are readily available in the market. Otherwise, it could lead to significant cost increase and render the plan to implement the system commercially unfeasible.

5.2.6.2 Legal Issues

To overcome the client's potential restriction on sharing information and knowledge with parties not involved in the project, the knowledge to be shared can be limited to those captured from the current project. The sharing of knowledge captured from other projects should be voluntary. An appropriate legal framework for 'live' knowledge capture and reuse needs to be developed and agreed between the project team members.

5.2.6.3 Accuracy

A validation mechanism is required to ensure that the knowledge entered is accurate, complete with all the details required in the specified format, important and reusable as a

means to prevent knowledge overload. Company F's practice can be used as a reference, as the new knowledge captured has to be validated by a panel of experts before it is published on the company's intranet for reuse.

5.2.6.4 *Representation of Knowledge*

The case studies revealed that reusable project knowledge often exists as a mix of tacit and explicit knowledge. Therefore, concentrating on either capturing explicit knowledge through codification of the knowledge or building a network of people for sharing tacit knowledge will fall short for managing reusable project knowledge effectively. To address this problem, the methodology was designed to explicate project knowledge into the tacit form as far as possible as well as providing links to connect the author of the knowledge with those who need it. The methodology may seem to incline towards a codification strategy, but it also caters for tacit-tacit exchanges. According to Hansen et al. (1999), this is the approach adopted by firms who have excelled in managing their knowledge.

The concept of a Project Knowledge File (PKF) is introduced which contains relevant project information and project knowledge that can be reused both during the execution (e.g. in subsequent phases) and after the completion of the project. The PKF covers:

- a) *Background information on the project* – These include project title, project location; start and completion dates, duration, companies involved, and date on which the knowledge is captured (which is included as an attempt to address the knowledge obsolescence issue).
- b) *Abstract* – This is a short description of the knowledge captured.
- c) *Details* – This is the detailed explanation of the knowledge so as to help others to understand and hence reuse the knowledge. Video clips, images and photographs can also be used to help explain the details about the knowledge.
- d) *Conditions for reuse* - This spells out the condition(s) for reusing a particular knowledge entry.
- e) *Reference* - This contains the reference to other relevant knowledge captured in the system, project documents, publications (e.g. books and reports), websites, where further details may be obtained. A hyperlink to Web pages showing the contact details

of the author (e.g. phone number, email and photo) to aid the transfer of tacit knowledge is also provided here.

There is a consensus between the findings from the literature review (Maier, 2002; Rollett, 2003) and case studies (i.e. Companies A and D) that knowledge has to be put into theme-specific categories to ease understanding and retrieval. The reusable project knowledge identified can be organised in the following hierarchy:

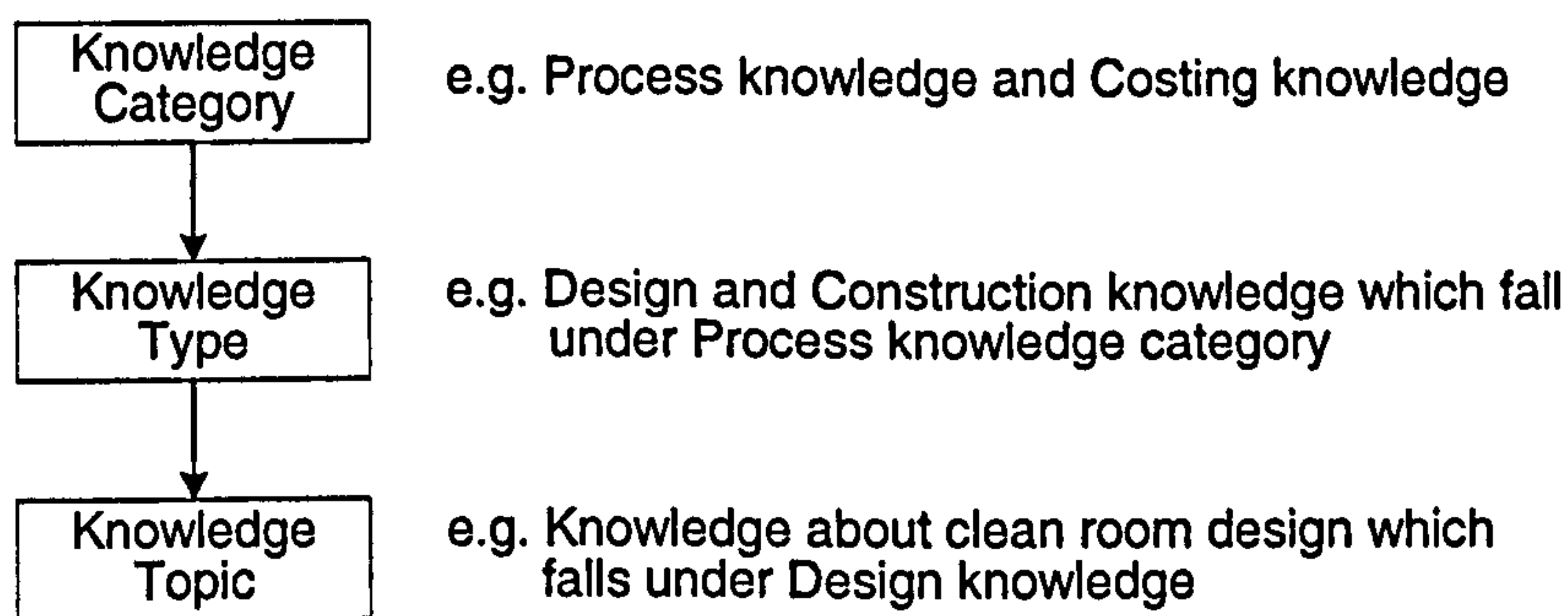


Figure 5.3: The hierarchy for the organisation of reusable project knowledge captured

In addition to the organisation of knowledge, a knowledge map and an index can be provided to give users an overview of the knowledge available as suggested by Maier (2002). This can be met through the creation of an index table as depicted in Table 5.4:

Table 5.4: Proposed knowledge map or index page depicting all the reusable project knowledge captured

	Reusable Project Knowledge	Example Knowledge Topics
1.	Process	
	• Briefing	Checklist for briefing
	• Design	Clean Room Design
	• Tendering & Estimating	e-Tendering – Do's and Don'ts
	• Planning	Charnwood Borough Council's Development Guidelines
	• Construction & Buildability	Damp-proof Problem in Basement
2.	Client	
	• Clients' requirements	Company M's special requirements
	• Client organisations' internal procedures	BAA's special internal procedures
	• Background knowledge about client's business	Company K's business plan for 2006/7

3.	Cost	
	<ul style="list-style-type: none"> • Cost of alternative forms of construction • Whole life cost (WLC) 	<p>Reduce waste with 'Dry Silo Mortar'</p> <p>How to reduce cost for lighting</p>
4.	Legal/Statutory	
	<ul style="list-style-type: none"> • Health & Safety • Changes in regulatory requirements 	<p>Some notes about Part-L Regulations</p> <p>Introduction of some new EU standards into the UK.</p>
	<ul style="list-style-type: none"> • Contract 	PFI contract – Important points
5.	Technical Details	
	<ul style="list-style-type: none"> • Standard design details • Specifications 	<p>Hospital R's standard design details</p> <p>Specifications for the design of air-conditioning system for an operation room</p>
	<ul style="list-style-type: none"> • Method statements 	Method statements for clean room construction
6.	Performance of Suppliers and KPIs	List of approved suppliers and their performance
7.	Who Knows What	Expert of siphon drainage
8.	Other	
	<ul style="list-style-type: none"> • Risk management 	Importance of careful selection of sub-contractors
	<ul style="list-style-type: none"> • Team working 	How we did it in 'City Walk' project – Our experience
	<ul style="list-style-type: none"> • Project management 	Some Do's and Don'ts

Further to the strategy that the methodology should be built on existing practice in the construction industry for the capture of reusable project knowledge, the next section focuses on the details and the capability of current practice in meeting the design requirements for the methodology identified.

5.2.7 Current Practice for the Capture of Reusable Project Knowledge

The development of a methodology for 'live' capture of reusable project knowledge in construction requires the understanding of the current practice for capturing project knowledge and the capability of current practice to help facilitate it.

The case studies revealed that Post Project Reviews (PPR) were still the single most important KM tool to capture project knowledge. It also revealed that there was no single KM technique or technology that could meet all the requirements for knowledge capture in construction organisations. A very pragmatic approach was therefore adopted by the construction organisations to capture and reuse project knowledge with a combination of KM techniques and technologies used. The details of the findings on each of the current

method for capturing reusable project knowledge are as follows:

5.2.7.1 Post Project Review (PPR)

The scope of knowledge to be captured in PPR is very wide as it covers almost all types of project knowledge. Company D conducts PPR within six months of the completion of its projects. PPR was chaired by project managers, and a report recording what went well and lessons learned was then prepared. The findings would be assessed to identify the learning which was reusable in other projects. PPR was made mandatory through the ISO 9000 system implemented by Company C. The PPR report was shared directly through its intranet and indirectly through its communities of practice. Company B's PPRs were conducted within one to three months of the end of a project, and took half or one full day depending on the complexity of the project and issues that emerged. The key learning was captured in point forms (i.e. do's and don't) which the company acknowledged as lacking in detail.

Adaptations to post project reviews (PPR) were made by Companies A and F to overcome the shortcomings related to time constraint and the loss of knowledge due to lapse of time in capturing the knowledge. The companies conducted technical reviews at key stages during the course of the project to capture the learning in addition to PPR. In Company A, the learning was first documented by the project leader, and then reviewed and disseminated by the quality manager. In Company F there were three phases of project review. For pre-project reviews, the project team members were required to gather information from other members of staff on the potential problems, issues, etc. that were likely to be encountered before the start of work on the project. Reviews were also conducted at pre-determined milestones, such as between the design and construction stages to capture the learning. This helped reduce the time pressure on capturing the learning after the completion of a project and before people lose the drive as "learning may no longer be seen as important after the event is over".

5.2.7.2 Custom-designed Software

Three case study companies used custom-designed software for the capture and reuse of

explicit project knowledge. In Company D, a custom-designed software was used to capture and analyse the cost information in order to identify the major elements that drive the cost of a particular type of building. Detailed and accurate estimates for a project could be provided by the software application based on basic information such as type of building, gross floor area and location of project. A custom-designed software was also used in Company B for the capture of the knowledge on performance of suppliers. Users can search for suitable suppliers based on the type of work (e.g. subcontractor for piping work) and geographical area with a view of their past performance. This facilitates better selection of suppliers for future projects. Company F created a knowledge base and provided each of its members of staff and suppliers with a log in name and password to access and contribute their suggestions on how to improve current working procedure, and the resultant time and cost savings into the knowledge base. The suggestions are reviewed by the company's panel of experts before it was shared in the knowledge base and the members of staff and suppliers rewarded based on the financial impact of the improvement suggested.

5.2.7.3 Groupware

Groupware referred to were Lotus Notes™ used by Companies B, D and F, and Company C's custom-designed tool to support its communities of practice. See Section 3.3.11 for the details of how groupware can facilitate the capture and reuse of reusable project knowledge.

5.2.7.4 Project Extranets

The 'Workflow and Approval Process' module of Company E's extranet allows for the approval routes for all the items on the extranet to be specified. The documents can either be Approved, Un-approved, Rejected or Under-review. Although not purposely designed for knowledge management, this feature can facilitate the peer-review process (i.e. validation) for the documented learning in order to seek for suggestions for improvement before it is formally tagged as 'best practices' or 'lessons learned'. See Section 3.3.12 for the details of how project extranets can facilitate the capture and reuse of reusable project knowledge.

5.2.7.5 Communities of Practice (CoPs)

There are two types of CoPs found from the case studies: the conventional CoPs without the aid of ICT and the CoPs aided by ICT such as intranet and Groupware. Company B had nine CoPs for nine disciplines: estimating, design management, admin secretarial and so forth, which fell into the former category. Knowledge was shared through people-to-people interactions within and across Company B's CoPs.

In Company C, its CoPs were called skills networks and were aided by ICT. The company assisted the setting up of emergent CoPs by providing them with in-house developed groupware to support group interactions and communication. To advocate CoPs, registration for joining was not required and there was no restriction over the number of CoPs that one can participate. In many instances, people belong to more than one CoPs. See Section 3.3.11 for the details of how groupware can facilitate the capture and reuse of reusable project knowledge.

5.2.7.6 Recruitment

Two companies (i.e. Companies C and F) stated that recruitment was used to capture the knowledge which is not available within the company. To achieve this, a detailed selection procedure was established in Company F to ensure that the recruits have very good command of the required knowledge and skills. Furthermore, the candidates would also be assessed on their willingness to share knowledge.

5.2.7.7 Forums

There were two types of forums identified from the case studies: the conventional and IT-aided. In Company A, a conventional forum is conducted on face to face basis at monthly intervals for the senior partners to share their knowledge with the associates of the company. The company argued that this allows the tacit knowledge residing in the head of the partners to be shared with and captured by others in the company. Company C's online forum allows members of staff to post questions and request for assistance from colleagues with the knowledge across the company's intranet. The online forum is a very powerful tool in locating and sharing knowledge, particularly when there is no formal record of

‘who knows what’ in a company.

5.2.7.8 Documentation of Knowledge

There were attempts in four out of the six case study companies to document their design knowledge and best practices. For the design knowledge, a handbook which spells out the standard procedures to be followed in design, key design issues need to be paid attention (e.g. health and safety), the forms to be filled and the reference or Web links to relevant information, was created and circulated within Company A. The handbook was accessible through the intranet. Company C created feedback notes to capture the industry’s best practices and lessons learned. It is also aimed at investigating how emergent issues are influencing the company’s current practice and to provide suggestions on how to deal with the issues. Feedback notes were written in a standard format and were subject to peer review for validation before they could be shared in the company’s intranet. Company D prepared case studies for each of the projects to record the roles of the company in the project, relevant background knowledge, programme and uniqueness of the particular project. The case studies prepared were accessible through intranet. For Company F, a knowledge base was created for the capture of knowledge in the format specified by the custom-designed software.

5.2.7.9 Expert Directory

Expert Directory refers to the Personal Profile, Divisionary Directory and staff appraisal report of Companies C, F and B respectively for the capture of the knowledge on ‘who knows what’. This knowledge covers details such as the skills, experience, expertise, contact details and job function of company staff. It is crucial in facilitating the connection of people with the right knowledge to the people who need the knowledge, particularly the more tacit knowledge which is notoriously difficult to codify. ‘Personal Profile’ was Company C’s intranet-based staff profiling system for capturing this knowledge. A standard procedure was established to ensure that members of staff keep their personal profiles up to date. Company B conducted staff appraisals at fixed intervals (normally annually) to capture this knowledge. However, the knowledge was recorded in paper form and there was no established means for other staff to access and hence to benefit from

reusing this knowledge. Company F's Web-based 'Divisionary Directory' was very similar to the Company C's 'Personal Profile'. The system facilitated the identification of the right people with the right knowledge by name and keywords (e.g. the type of expertise required) for knowledge sharing.

5.2.7.10 Research and Development Team (R&D team)

The R&D team within Company D was established to seek room for improvement and encourages members of staff to suggest new topics for research. The research carried out could be regarded as one of the practices to acquire new knowledge within the company. The team provided brochures on the outcome of its research, and made presentations to the various branches within the company to disseminate this knowledge.

5.2.7.11 Team Meetings, Road Shows, Presentations and Workshops

In Company D, road shows, presentations and workshops were held periodically and project teams from different sectors had monthly meetings to share knowledge. Although some knowledge was codified and made available in the documents disseminated at the meetings, most of the knowledge shared was captured in the heads of the people who attended the meetings.

5.2.7.12 Training

Companies A, D and F identified training as a practice for the capture of project knowledge. Training was provided to members of staff at fixed intervals (e.g. every three weeks) covering a range of topics. In Company A, training sessions were integrated with lunch time CPD (Continuous Professional Development) sessions. Documented knowledge was disseminated in Company D's training, and tacit knowledge could be shared through the interaction between the trainers and trainees. External knowledge might also be captured as external experts were invited by Company A to give presentations.

5.2.7.13 Knowledge Teams

Company D set up knowledge teams, which were led by key persons or experts in the respective business areas, to identify and capture the knowledge imperative to their fields.

The company argued that this would allow other teams to tap into the knowledge captured for reuse in their respective fields. In addition, the knowledge gained could also be reused for training purposes.

5.2.7.14 Collaboration with Other Companies

Company D collaborates with other companies including its competitors in research and construction projects for the sharing of knowledge and information on benchmarking and best practices. Some of the knowledge was captured through observation and attempts made to replicate or innovate based on others' practices. Company F encourages and rewards its suppliers for contributing useful knowledge into its knowledge base. In addition, Company B also acknowledged the imperative of capturing knowledge through collaboration with other companies.

5.2.7.15 Preparation of the Standard Reusable Details

Company B's project teams conducted special sessions to identify areas where standard details on design and specifications can be created, and to identify existing standard details for reuse. The standard details were created in electronic form and were made available to the team for reuse in other similar projects with the same client, or even for projects with other clients. This helped avoid the reinvention of the wheel and the need to start from scratch for each of the new projects. It had indirectly led to the savings both in term of time and costs.

5.2.7.16 Reassignment of People

The study revealed that reassignment of people was the most direct method used by the case study companies to reuse the knowledge captured from one project in another project. This is particularly for the tacit knowledge which is notoriously difficult to capture. Besides reassigning people to other projects, Company C allocated members of staff who were experienced in similar type of project to provide assistance to other project teams. Whilst, Company B also moved its members of staff from one discipline to work for a short period of time in another discipline. The company contended that bringing people from different disciplines together could help people to understand where the bits and

pieces of knowledge were being stored within the company. In addition, the company also felt that more ideas could be generated through the interactions of people from different disciplines.

5.2.7.17 External Sources of Knowledge

Companies A and B identified tapping knowledge from external sources as one of the practices for the capture of reusable project knowledge. Company B noted that some of the project knowledge could be obtained by subscribing to the relevant service providers, such as Whole Life Cost Forum (www.wlcf.org.uk) for the knowledge on whole life costing and Building Cost Information Service (<http://www.bcis.co.uk>) for knowledge on building costs. According to Company A, the publications of government departments and other professional organisations such as the GLC (Greater London Council) Detailing for Building Construction and Architect Metric Handbook (a design guide) and product presentations by manufacturers or suppliers, which cover knowledge on a variety of problems, issues and their recommended solutions are amongst the other external sources of knowledge. The external sources of knowledge may lead to time and cost savings for the capture of knowledge, particularly those require a relatively long time for its capture such as knowledge on whole life costs.

5.2.7.18 Succession Management and Mentoring

Only Companies A and C identified succession management and mentoring as the practice for the capture of reusable project knowledge respectively. Company A's succession management covers the identification of young architects to learn (or capture) the specialist design knowledge for pharmaceutical facilities from the experts. Company D's mentoring closely resembled the practice outlined in the existing literature, where junior staff was assisted in their work by attaching them to a mentor.

5.2.8 Analysis of Current Practice for the Capture of Reusable Project Knowledge

Various KM techniques and technologies were being used by the case study companies for the capture of reusable project knowledge (see Table 5.5). ICT was found to play a significant role in facilitating 'live' capture and reuse of project knowledge. All of the KM

techniques (e.g. Communities of Practice and forum) and technologies that can partially satisfy the requirements identified for facilitating 'live' capture and reuse of project knowledge were either aided by ICT or are ICT tools themselves. The companies' current practices to capture the reusable project knowledge are summarised in Table 5.5.

Table 5.5: KM techniques and technologies adopted by the case study companies

KM technique	Facilitating Live Capture and Reuse of Knowledge?	Case Study Companies Using This Practice for Knowledge Capture					
		A	B	C	D	E	F
Post project reviews	No	√	√	√	√	√	√
Communities of Practice	Partially		√	√			√
Documentation of knowledge	Partially	√		√	√		
Training	No	√			√		√
Forum	Partially	√		√			
Recruitment	No			√			√
External source of knowledge	No	√	√				
Reassignment of people	No		√	√			
Research collaboration	No				√		√
Partnership-like arrangements	No					√	
Preparation of standard reusable details	No		√				
Research & development	No				√		
Team meetings, road shows, presentations and workshops	No				√		
Knowledge team	No				√		
Succession management & mentoring	No	√					
KM technology		A	B	C	D	E	F
Groupware	Partially		√	√	√		√
Custom-designed software	Partially		√		√		√
Expert Directory	Partially		√	√			√
Project extranet	Partially		√				

The shortcomings of current approach in terms of the capability to facilitate the 'live' capture and reuse of project knowledge are as follows:

- **Post Project Reviews (PPR)**

PPR are normally time-consuming and slow. The time lapse between the discovery and creation, and the capture and sharing of knowledge leads to the loss of important insights (Kamara *et al.*, 2003) and hence fails to facilitate 'live' capture of project knowledge. Two other major shortcomings of current PPR practice were identified in the case studies: first, in three out of the five cases, the learning captured was not being shared effectively and there was no established way to locate the learning embedded in reports for reuse. Secondly, the current practice of distilling the key learning captured in PPR into point form is too brief for understanding and efficient sharing of the knowledge captured.

However, despite unable to facilitate the 'live' capture of project knowledge, existing literature reveals that PPR is important for capturing the collective learning of different parties involved in a project. What could possibly be done to improve is to shorten the intervals or increase the frequency for such project reviews to be conducted. This can help to reduce the knowledge loss problem. In fact, the practice of Companies A and F to conduct project reviews at each of the key project stages for capturing project knowledge is a better alternative than PPR. This can even be further extended to capturing project knowledge at the routine weekly or bi-weekly project meetings, which is the shortest intervals possible for the capture of collective learning from a project team. Therefore, it is recommended that project reviews should be made part of the methodology for 'live' capture and reuse of project knowledge.

- **Communities of Practice (CoPs), Groupware and Forums**

Without the aid of ICT, it was found that the conventional CoPs and forum fail to facilitate 'live' sharing of project knowledge across geographical dispersed offices. Moreover, Company A's practice to restrict the participation of its forum to senior staff had made others failed to benefit directly from the practice.

The online CoPs and forums have overcome the geographical constraints for sharing knowledge through the use of groupware and other custom-designed software. In addition, the knowledge shared and the threads of correspondences can be archived or saved by the

ICT applications. This allows knowledge to be retrieved and reused in the future. However, online CoPs and forums still fall short in meeting all the end-user requirements due to their passive nature. This is because if a question is not asked in the online CoPs or forum, the knowledge pertaining to the question is less likely to be shared. A more pro-active approach is required.

In addition, there was no standard format created to represent the knowledge shared in the groupware used by the case study companies, which is one of the end-users' requirements identified in this study. Furthermore, developing the methodology for 'live' capture and reuse of project knowledge in a groupware can be a very expensive option due to the licensing fees, etc. required. Therefore, groupware is not considered as a suitable option for the purpose.

- **Recruitment**

Correspond to the findings from existing literature, it was observed that recruitment was more for filling the case study companies' existing knowledge gap rather than as a practice for the capture of knowledge from its ongoing projects. Other than this, existing literature also reveals that it is a lengthy process undermined by the difficulties in finding and assessing experts with the required knowledge (Harman and Brelade, 2000) and the scarcity of experts (Maier, 2002).

- **Training, Team Meetings, Road Shows, Presentations and Workshops**

The time lapse between the capture of knowledge from a project to the sharing of the knowledge through these knowledge sharing mechanisms also suggests that they do not adequately facilitate the 'live' capture and reuse of project knowledge. Furthermore, the scope of knowledge available for sharing through the aforementioned practices are also constrained to those captured by the trainers and participants, and are normally topic-specific. Other than this, there was no established means observed from the case studies for the sharing of the knowledge captured with those who are not involved in the trainings, etc.

- Succession Management and Mentoring

Succession management and mentoring are time consuming processes and hence cannot facilitate 'live' capture and reuse of project knowledge. Furthermore, succession management was only used to transfer a specific type of project knowledge in the case studies. According to Company A, its succession management was not very successful due to the reluctance of people to confine their learning to a specific area. Young architects prefer to be involved in different types of project instead of being restricted to one specific sector.

For mentoring, it is very efficient in the transfer of knowledge (particularly tacit knowledge). However, its efficiency is constrained by the number of protégés that the mentor can handle at any point in time, the distance between the mentor and potential protégé, issues related to cross gender mentoring (Clawson and Kram, 1984), time constraints (Tabbron et al, 1997) and the ability of the mentor to transfer his/her knowledge to the protégé (Megginson, 2000).

- Documentation of Knowledge

Companies A and D's checklist-based design handbook and case studies of project undertaken were criticised by their employees for lack of detail and reuse value. Companies C and F's practices (i.e. the creation of feedback notes which were accessible online and the maintenance of a knowledge base) were very mature and tested tools of documenting knowledge. However, there is no mechanism to ensure that the knowledge is captured 'live' or within a short time frame after its creation or generation. Such mechanisms, if created, may make a Web-based knowledge base the closest practice to meet the requirements for 'live' capture and reuse of project knowledge in construction. Furthermore, the knowledge captured by Company C's feedback notes is limited to that created or identified by the company while the views of other project team members are not captured.

- Partnership Arrangement and Research Collaboration

Partnership arrangements and research collaboration are more a strategic arrangement for

knowledge sharing rather than a practice for knowledge sharing by itself. Furthermore, these methods cannot guarantee that critical or key knowledge will be shared. This is because:

- a) The construction organisations collaborating in one project may actually be competing in another project (Kamara *et al.*, 2003); and
- b) Corporate security restrictions imposed on posting of information/knowledge have further added to the problem (Ardichvili *et al.*, 2003). People have been indirectly discouraged from sharing their knowledge especially where the boundary of such restrictions is not made clear.

- Knowledge and R&D teams

The nature of work done by the knowledge and R&D teams seemed to be more relevant to knowledge creation and innovation than the capture of reusable project knowledge. Furthermore, the establishment of the knowledge and R&D teams entails additional resources which does not meet the requirements that significant additional workload or cost is undesirable.

- Preparation of the Standard Reusable Details

It must be noted that this practice is probably only economically viable for companies with a high proportion of similar projects. In the case of Company B, this was justified by the fact that 80% of its projects are from 30 key clients. Furthermore, for people other than the creator of the documents or drawings, the reuse may pose some problems as the rationale for the design and changes made might not always be clear to them.

- Reassignment of People

The success of reassignment of people for knowledge capture and reuse depends heavily on: (1) the staff turnover rate (Kamara *et al.*, 2003), and (2) the individual's ability to capture the learning from his/her previous project and then reuse the knowledge in another project or share the knowledge with others. The fact that people are only reassigned to another project after the completion of existing project also suggests that this practice does not facilitate 'live' capture and reuse of project knowledge.

- External Sources of Knowledge

The external sources of knowledge may lead to time and cost savings for the capture of knowledge, particularly those that require a relatively long time to capture (such as knowledge on whole life costs). However, what the companies obtained from the external sources was general project knowledge, rather than detailed reusable project knowledge. This is also not a practice for 'live' capture of project knowledge.

- Project Extranets

Currently, the role of project extranets is more significant in the sharing of documented or explicit knowledge (such as the reusable project documents) rather than tacit knowledge. In addition, there is no specific template or mechanism specifically designed for the capture of project knowledge. However, project extranet can be a suitable medium to facilitate 'live' sharing of information and knowledge than intranet. This is because it can provide access to different organisations involved in a project for the purpose of capturing and accessing reusable project knowledge. By comparison, an intranet's access is restricted to a single organisation only.

- Expert Directory

Web-based expert directory helps to facilitate the 'live' identification of the right people with the right knowledge, which in turn assists in the 'live' sharing and reuse of project knowledge. However, expert directory captures only the knowledge on 'who knows what', and is not appropriate for the capture and creation of other types of knowledge.

- Custom-designed Software

Tan *et al.* (2004) have identified various types of reusable project knowledge in construction, which need to be managed. Custom-designed software used for the capture of project knowledge were, however, narrow in scope and focused on specific types of project knowledge only. For instance, Companies B and D's custom-designed software targeted only costing knowledge and knowledge about the performance of suppliers. It was noticed that the Web-based nature of the custom-designed software could greatly enhance the sharing and reuse of knowledge. This points out the importance of Web-based technology

in facilitating the 'live' capture and reuse of project knowledge.

The findings from the case studies revealed that although there are various KM techniques and technologies available, none of the KM technologies or techniques represents a complete solution. The findings further revealed that both KM techniques and technologies have their strengths and shortcomings, and may in fact complement each other. Therefore, a combination of KM technique and technology is more likely to meet the various end-user requirements for the development of a methodology for 'live' capture and reuse of project knowledge identified from this research. This is further investigated in the next section.

5.2.8.1 Enabling Technologies and Techniques

The essence of the 'live' capture and reuse of project knowledge methodology lies in allowing users at different locations to enter and access the knowledge captured in real-time. The strength of Web-based KM technologies (such as groupware, expert directories and knowledge bases) is an integral element of the methodology for the 'live' capture and reuse of project knowledge. This is due to their capability to connect distant offices together, provide fast access and location of knowledge captured, facilitate sharing of knowledge, and provide huge knowledge storage space,. Among the KM technologies available, a Web-based knowledge base seems to be the current practice closest to meeting the requirements identified. The reasons are as follows:

- *No significant additional cost:* The pervasive use of intranets by companies to connect their offices together nowadays has laid the necessary foundation for implementing a Web-based knowledge base. A Web-based knowledge base can run on the existing intranet/internet systems and platforms commonly used by most of the construction organisations. This eliminates the chances of incurring significant additional cost for the implementation of the methodology;
- *No significant additional workload created:* The only requirement is the need to enter project knowledge into the knowledge base;
- *Accuracy of knowledge ensured:* A mechanism can be built into the knowledge base for monitoring the validation of knowledge submitted as a means of ensuring its accuracy; and

- *Allowing a standard format for representing project knowledge to be specified:* Another built-in mechanism can be created to ensure that project knowledge is entered in accordance with the format developed.
- It can provide the necessary platform for the access and sharing of knowledge which is captured in the form of video clips and other formats of multimedia files;
- It may be used in conjunction with other Web-based applications (e.g. Groupware and video conferencing tools) to enhance the sharing of knowledge, particularly the tacit knowledge; and
- It can be integrated with 'skills yellow pages' which captures the knowledge about 'who knows what' within an organisation. This helps in the location of the author of the knowledge and the people with the right knowledge.

The case studies had recognised that the methodology must be designed to capture knowledge from both individuals and in a group setting so that useful knowledge generated in various learning situations will not be overlooked. Capturing knowledge in a group setting also helps to ensure a more holistic and more complete set of knowledge is captured than through individuals alone. Therefore, in addition to allowing individuals to submit knowledge into a knowledge base, the Web-based knowledge base will be supplemented by PPR and project meetings/reviews.

Chapter 6 investigates this in further detail and also presents the details on the development of the 'live' capture and reuse of project knowledge methodology.

Chapter 6 Development and Operation of a 'Live' Capture Methodology

This chapter presents the structure of the 'Live' capture and reuse of project knowledge framework, the system architecture of the prototype application, the development of the prototype application using ASP.NET 2.0 and Microsoft™ SQL Server Express 2005, and the operation of the prototype application.

6.1 Structure of the 'Live' Capture and Reuse of Project Knowledge Methodology

Based on the findings from the case studies, a methodology for the 'live' capture and reuse of project knowledge has been developed. The methodology comprises:

- A Web-based knowledge base – This is where the Project Knowledge File of a project is stored. A Project Knowledge File (PKF) contains relevant project information and project knowledge that can be reused both during the execution (e.g. in subsequent phases) and after the completion of the project. A PKF is similar to the Health and Safety File (HSF) under the Construction (Design and Management) (CDM) Regulations in the UK. The difference being that HSF is a project record which focuses on health and safety (HSE, 1997), whereas the PKF targets reusable project knowledge;
- A Project Knowledge Manager (PKM) – This is a role, normally charged to a project manager or other designated person, to manage the knowledge base (i.e. the development of a Project Knowledge File for a project) and the Integrated Workflow System (IWS); and
- An Integrated Workflow System (IWS) – This delineates, executes and monitors the mechanism for the capture, validation and dissemination of the project knowledge captured. A Project Knowledge Manager (PKM) may configure the IWS to suit individual requirements of the project.

The proposed methodology is designed to capture reusable project knowledge generated from the various learning situations once the knowledge is created or identified (i.e. 'live') through project reviews/meetings (i.e. group of people) and individuals. Users have to enter reusable knowledge in accordance with the format specified. The knowledge

captured from individuals needs to go through a validation process to verify its accuracy. However, the validation process can be omitted for knowledge captured from a group (e.g. meetings and reviews) as the knowledge captured is deemed to have been reviewed and validated in the meetings or reviews. All the knowledge captured from a project is grouped together and stored as the Project Knowledge File of the project in the knowledge base. Knowledge will be shared 'live' soon after knowledge is captured in the system. Email notification will be sent to users when knowledge is entered into the system. In addition, routine email reminders will be sent to request users to submit their knowledge. Registered users are able to access the knowledge captured in the system.

6.2 System Architecture of Prototype Application

To automate the methodology, a prototype application which consists of a Web-based knowledge base is developed. The system architecture of the prototype application is shown in Figure 6.1. For accessibility and security reasons (as the knowledge base provides access to more than one organisations involved in a project), the knowledge base will run in the project extranet environment where only designated users from collaborating organisations can gain access into the system. The data layer or the database is the core of the Web-based knowledge base where all the knowledge are stored. The application logic/code automates the Integrated Workflow System (IWS) and helps to reduce potential workload of the users in submitting reusable knowledge. A standard Web browser is used for users to interact with the knowledge base (i.e. for submitting or retrieving knowledge).

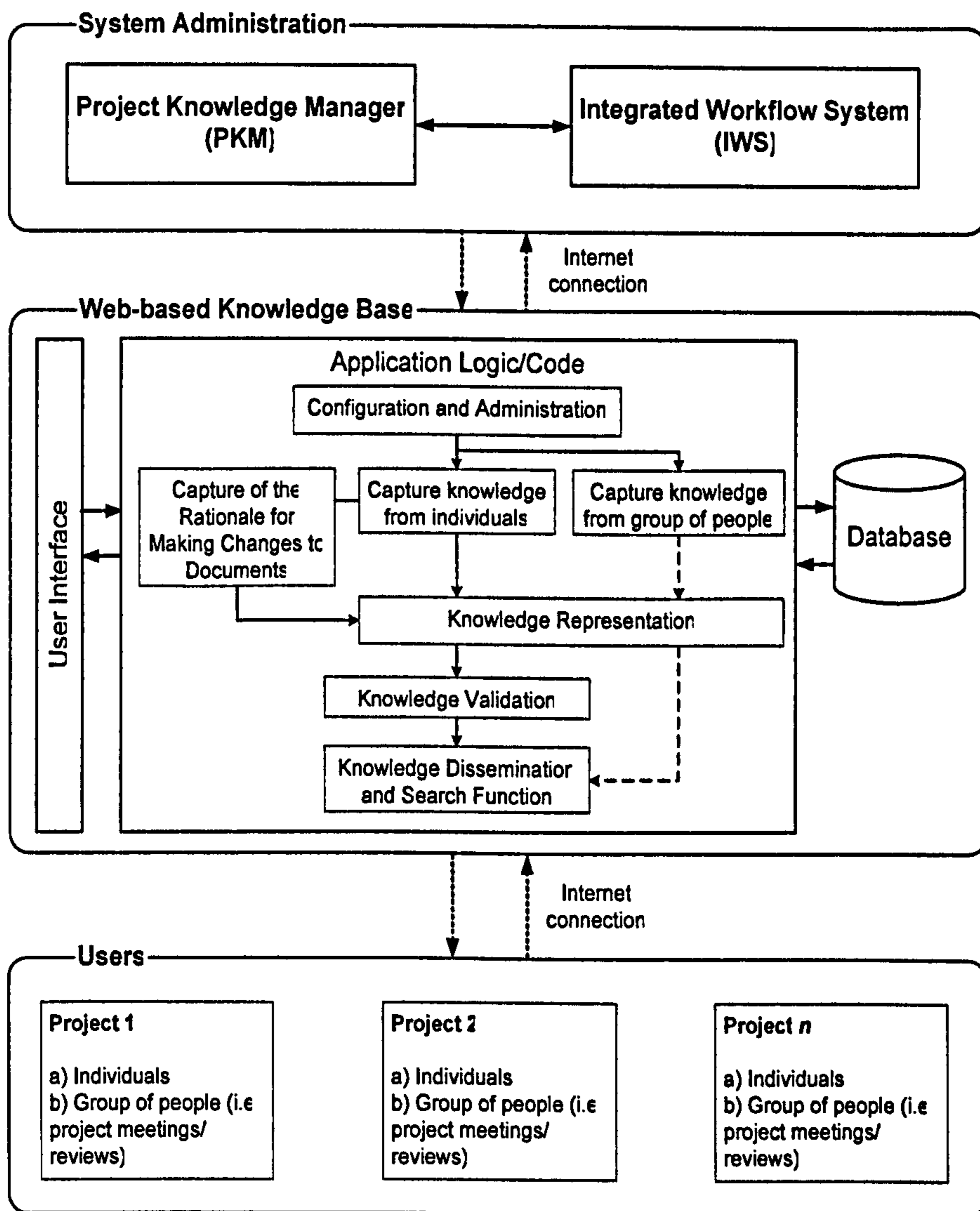


Figure 6.1: System architecture of the methodology for the 'live' capture and reuse of project knowledge in construction

6.3 Development of the Integrated Workflow System (IWS)

The development of the methodology started with the development of the Integrated Workflow System. This is because it dictates how the computer programme (i.e. the Web-based knowledge base) and the users (including PKM) work together in the methodology for the 'live' capture and reuse of project knowledge. Part of the IWS was also encapsulated into the programme logic/codes of the Web-based knowledge base.

The IWS covers five areas of the 'live' knowledge capture and reuse methodology. These are:

- System configuration;

- Capture of knowledge from individuals;
- Capture of knowledge from project meetings and reviews (i.e. group of people);
- Capture of the rationale for making changes to documents;
- Knowledge validation; and
- Dissemination of knowledge captured.

The details of each of the areas are developed and represented in the form of a flow chart (see Figure 6.2).

6.3.1 System Configuration

The Web-based knowledge base needs to be configured to suit the individual requirements and details of a project. System configuration is a process to:

- Set up an account for a new project, where the details about a project and the ways that the knowledge captured are to be organised are entered into the system;
- Create accounts for various users, which includes specifying the level of access of different users;
- Specify the preferred method for validating reusable project knowledge captured (see Section 6.3.3 for the various options for knowledge validation);
- Configure whether individual user would like to receive email notification when knowledge is entered into the system and when the status of the knowledge entered has been updated;
- Configure the system for sending out email reminders to the PKM to include knowledge capture into the agenda of coming project meeting or review; and
- Configure the system for sending out routine email reminders to users to add new knowledge into the system.

This is a one-off process. It helps to avoid the need for re-entering similar information in the knowledge capture process. It is also needed in order for some features of the system to function, such as the automated email notification when a new knowledge item is added into the system.

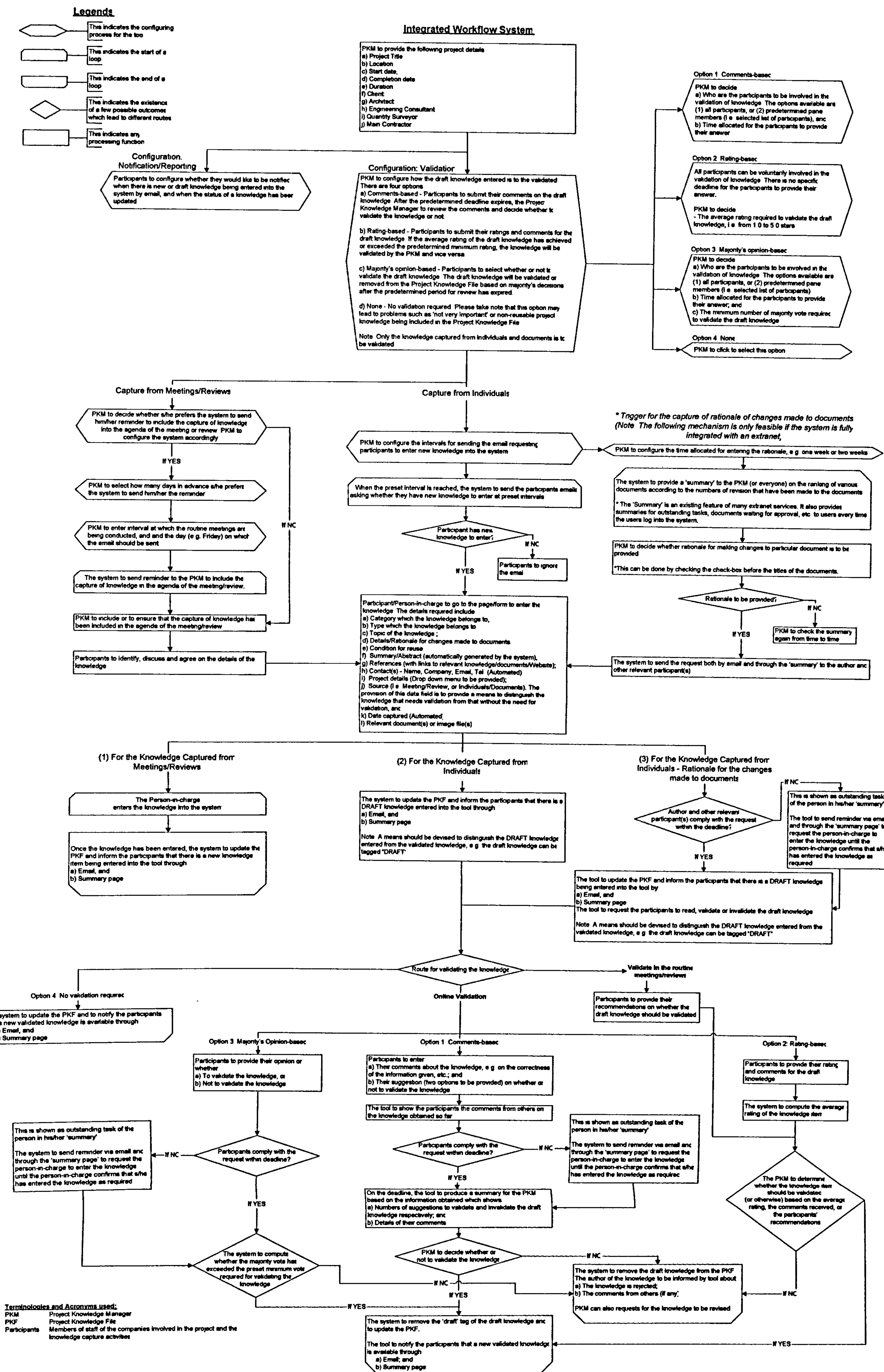


Figure 6.2: Integrated Workflow System (IWS)

6.3.2 Knowledge Capture

This process indicates how reusable project knowledge can be captured 'live' from ongoing construction projects. Three sources of reusable project knowledge were identified from the case studies, i.e. the individuals involved in a project, project meetings/reviews, and the rationale for making changes to documents such as drawings.

6.3.2.1 Capture of Knowledge from Project Meetings/Reviews

The PKM will be responsible for including the capture of reusable project knowledge as an agenda item in the routine project meetings/reviews. The system will send the PKM an email reminder for this purpose. During the meetings/reviews, the learning captured since the previous meeting/review is discussed and the details agreed. If the system is accessible during the meeting/review, the designated person (who is normally the PKM) may enter the approved knowledge directly into the knowledge base in the specified format. Otherwise, the designated person may transfer the record into the system at a later time.

6.3.2.2 Capture of Knowledge from Individuals

All knowledge workers involved in the project will be assigned a login name and password to access the system. This allows them to enter their knowledge into the software tool once knowledge is created or identified (i.e. 'live'), or at anytime which is convenient to them. The system will send routine email reminders to the users who have opt to receive them.

6.3.2.3 Capture of the Rationale for Making Changes to Documents

The findings of the case studies revealed that the rationale for making changes to project documents (such as engineering drawings) is important reusable project knowledge. The system will provide a summary of the number of changes made to the project documents which the PKM can check at predetermined intervals. If there is a project document for which the number of changes made to it is well above average, a procedure for the capture of the rationale for making the changes to the document can be invoked by the PKM. The author of the project document will be requested to provide the necessary details into the system. Similar to the knowledge submitted by individuals, the rationale of changes made to document will be subject to validation before it can be disseminated.

6.3.3 Knowledge Validation

This process describes the options provided for the validation of knowledge captured in the system. The knowledge captured from a group (i.e. meetings and reviews) is deemed to have been validated in the meetings or reviews, whereas the knowledge submitted by individuals may need to be validated prior to reuse. However, at the organisation's discretion, the validation process may be omitted for the knowledge submitted by their experts and very experienced staff. The validation mechanism of the system is triggered once new knowledge is submitted into the system by individuals. Two knowledge validation routes are devised:

- a) To validate the knowledge submitted in the routine meetings or reviews. The knowledge submitted by individuals since the last meetings/reviews will be discussed at the current meeting/review. The PKM will be responsible for deleting or removing the knowledge from the system if the knowledge is rejected, or updating the status of the knowledge from 'draft' to 'validated' knowledge in the system if the knowledge is approved; and
- b) Online validation. All the project participants or designated people/experts will be requested by the system to take part in the process within the predetermined deadline. The system will monitor of the progress and reminders will be sent if there is any delay in response on part of the users. Four options for validating knowledge are provided. These include:
 - i. Semi-automated;
 - ii. Rating-based;
 - iii. Majority's opinion-based; and
 - iv. No validation required.

The details of the above four options are provided in following section.

6.3.3.1 Online validation – Comment-based

Users submit their comments on the draft knowledge and their opinions on whether the knowledge should be validated or not. After the predetermined deadline expires, the PKM reviews the comments and decides whether to validate the knowledge or not.

6.3.3.2 Online Validation – Rating-based

This is a variant of the comment-based option. In addition to allowing users to submit their comments, ratings (ranging from 1 to 5 stars) are to be provided by the users for the draft knowledge. The PKM then decides whether or not to validate the knowledge based on the average rating and the comments given by other users for the draft knowledge. The PKM can also request for the content of a knowledge item to be revised. The comments given are accessible to others.

6.3.3.3 Online Validation – Majority's Opinion-based

Users select whether or not to validate the draft knowledge. The draft knowledge will be validated or removed from the Project Knowledge File based on the majority's opinion after the predetermined period for review has expired.

6.3.3.4 Online Validation – No Validation Required

The system will bypass the validation mechanism. There is no distinction between draft knowledge and validated knowledge.

For the first three options, the author(s) of the knowledge will be informed about the status of the knowledge submitted (i.e. rejected or accepted) together with the rating and comments (if any) given by others.

6.3.4 Dissemination of Knowledge Captured

This section describes how the 'live' sharing of project knowledge is to be achieved. It requires an email notification to be sent instantly to the users to notify them about the addition of the new knowledge item. The users should be notified of the changes made to the status of a knowledge item in the system. In addition, knowledge is also made available for access once it has been added into the system.

6.4 Development of the Web-based Knowledge Base

This section covers the selection of the most appropriate development environment and tool, and the development of the Web-based knowledge base using Web Information Systems Development Methodology (WISDM). The development started with the design of the various user interfaces, followed by the creation of the databases and the writing of associated programme codes. However, it must be noted that the development process was also iterative to an extent. The details of the development process are described in respective sub-sections.

6.4.1 Selection of Suitable Development Environment

The selection of the suitable development environment for the Web-based knowledge base impacts on the speed of development, and the cost for developing and running the end product. A number of options are available for the development of the Web-based knowledge base. However, the most appropriate options are:

- The development of the prototype on the Lotus QuickPlace;
- The development of the prototype using PHP and MySQL combination; and
- The development of the prototype using ASP.NET 2.0 and Microsoft™ SQL Server Express 2005 Combination.

The details of the suitability of these options are as follows:

6.4.1.1 The Development of the Prototype on the Lotus™ QuickPlace

Lotus™ QuickPlace is a software application for running intranet/extranet service. Some companies use Lotus™ QuickPlace to create their Web-based database. However, this option was eliminated due to the high cost involved (e.g. the annual licensing fees for Lotus QuickPlace, which is over £10000 p.a.). In addition, this option was also discarded due to the need for a dedicated Web server to host or run the prototype application developed.

6.4.1.2 The PHP and MySQL Combination

PHP is an open source scripting language used mainly for developing server side applications and websites, which include Web-based database (Wikipedia, 2006a). MySQL

is a free SQL Database Management System which is often combined with PHP for the development of Web-based database (Wikipedia, 2006b).

The PHP engine and MySQL database server can be downloaded free-of-charge from internet. The PHP programme codes can be written using any word processor (e.g. Microsoft Windows's built-in Notepad). However, writing the PHP codes using a word processor is less efficient, slow and difficult to identify the errors in the codes. Using an integrated development environment (i.e. Zend Studio) for the development of PHP applications is advisable to address the aforementioned issues. However, it comes with a cost and offers less functions if compared to the Visual Web Developer Express (VWD) used for the development of ASP.NET 2.0 and Microsoft™ SQL Server Express 2005 applications. Furthermore, the PHP-MySQL option also has a longer learning curve than the ASP.NET 2.0 option. This is described in detail in subsequent section.

6.4.1.3 ASP.NET 2.0 and Microsoft™ SQL Server Express 2005 Combination

This combination is one of the latest Web-based database development technology offered by Microsoft™. ASP.NET 2.0 is the equivalent of PHP, but more powerful in terms of the range of functionalities offered. An integrated development environment (i.e. Visual Web Developer Express (VWD) for the development of ASP.NET 2.0 applications) is freely available from Microsoft™. In addition, VWD also comes with a free Microsoft™ SQL Server Express 2005 (i.e. the equivalent of MySQL). Compared to Zend Studio used for developing PHP applications, VWD offers the following advantages:

- a) It offers a drag and drop feature for the creation of various controls on a Web page, such as the user log in, log out, forgot the password controls. Associated codes for the controls can be generated automatically by VWD. This helps to reduce the development time;
- b) It comes with a built-in security system. Different roles of users with different access authentications can be created easily without the need for writing complicated programme codes. This again helps to accelerate the development of the Web-based knowledge base; and
- c) It offers a fully integrated development environment. The management of the

database, development of the programme codes and the debugging of the application can be done through VWD.

This option was chosen for the purpose of developing the Web-based knowledge base for the aforementioned reasons.

6.4.2 User-Interface and Programme Codes Development

User interface (i.e. Human-Computer Interface) design is critical in the development of the Web-based knowledge base. This is because it affects the user-friendliness of the system and also impinges on the design of the database structure. In the ASP.NET 2.0 environment, the development of user interfaces and programme codes are often carried out in parallel. This is because ASP.NET 2.0 uses a code-behind structure where the programme codes associated with the functions/features of an user interface are saved as part of the interface's source codes. This causes some of the features/functions on an user interface are not visible until the associated programme codes are written. This may slow down the progress of the prototype development as the user interface cannot be shown to the potential users for feedbacks before the associated programme codes are fully developed. Furthermore, at that stage it is likely to be too late to introduce any changes to the interface design due to the extensive rewriting of the programme codes or the redesign of the database structure required.

To address these issues, draft mock-up user interfaces were first designed using Microsoft™ Visio. Microsoft™ Visio allows mock-up user interfaces to be created quickly without needing the associated programme codes to be completed. The IWS and mock-up user interfaces were used to demonstrate graphically to the potential users (i.e. the collaborators) in a mini workshop how the prototype application operates. The mini workshop involved only the research team members and five representatives of the case study companies. This was done before the real user interface and programme codes were developed (see Section 6.5 for details of the workshop and the feedbacks received). The user interfaces were then refined based on the feedbacks received. Subsequently, the working versions of the interface were developed using VWD. The user interfaces and associated programme codes were developed for the following tasks:

6.4.2.1 Capturing Knowledge

Challenge: The focus of the design of the knowledge capture user interface and associated functions is on the avoidance of the need for re-entering duplicate information. This is critical in order to reduce the creation of additional workload to the users. A file upload function was also to be created for users to upload relevant documents and image files. Related to this, the programme codes written also must be able to prevent the accidental overwriting of existing file with a similar file name.

Solution: A number of dropdown menus were created on the user interface for capturing knowledge to avoid the need for re-entering information, such as project details, and different categories and types of knowledge (see Figure 6.3). These dropdown menus were linked to the respective tables in the database. They will be automatically updated with the changes made to the information in the database. Furthermore, the programme codes were written to automatically capture information such as the date of submitting a knowledge entry, the author's details, the calculation of duration of a project, etc. To prevent the accidental file overwriting problem, the programme codes was designed to examine whether there was an existing file with the similar file name in the system before a new file was uploaded (see Excerpt 6.1). If yes, a number (which is auto-incremental) will be added to the end of the file name. The newly uploaded file will then be saved with a different and unique file name.

The screenshot displays a web-based knowledge capture interface with three main sections, each featuring a dropdown menu and an associated information box:

- Project Title:** The dropdown menu is set to "Astra Zeneca". The information box below it lists project details:
 - Project Title: Astra Zeneca
 - Location: Loughborough
 - Start Date: 12/10/2005
 - Completion Date: 12/11/2006
 - Duration: 57 weeks
 - Client: Astra Zeneca R&D Charnwood
 - QS: Simons Construction
 - Engineering Consultant: Simons Design
 - Main Contractor: Simons Construction
- Knowledge Category:** The dropdown menu is set to "Process Knowledge". The information box states: "This knowledge is concerned with the various processes involved in a typical construction project. It includes knowledge about design, bidding, construction, facility management, etc."
- Knowledge Type:** The dropdown menu is set to "Design Knowledge" and is open, showing a list of options:
 - Design Knowledge
 - Tendering & Estimating
 - Planning
 - Construction methods and techniques
 - Buildability
 - Operation & maintenance
 The information box for this category describes: "knowledge and specialist design use of standard approach in design to consideration the issues like health and regulations. For the specialist design on a particular type of unique facility such".

Figure 6.3: Dropdown menus for knowledge capture


```

Private Function GetFileName(ByVal filename As String) As String
    Dim i As Integer = 0
    Dim path As String = Server.MapPath("~/Documents/") & "" & filename
    Dim fname As String = path.Substring(0, path.IndexOf("."))
    Dim ext As String = path.Substring(path.IndexOf("."))

    Do While File.Exists(path)
        i += 1
        path = fname & i.ToString() & ext
    Loop

    Return path
End Function

Protected Sub uploadButton_Click(ByVal sender As Object, ByVal e As
System.EventArgs) Handles uploadButton.Click
    If (DocFileUpload1.HasFile) Then
        Try
            Dim fileName As String = GetFileName(DocFileUpload1.FileName)
            DocFileUpload1.SaveAs(fileName)
            docFile1 = fileName.ToString()
        Catch ex As Exception
            Response.Write("Failed because: <br/>" & ex.Message)
        End Try
    End If
End Sub

```

Excerpt 6.1: Codes for overcoming similar file name problem

6.4.2.2 Representing Knowledge

Challenge: The details of a knowledge item are scattered across various tables in the database. The challenge is to retrieve the relevant information of a knowledge item such as the details of project and author from the tables and display them on two user interfaces: the 'Summary' page and 'Knowledge Details' page. The programme codes must be written to pre-render the information into required formats prior to displaying them on the user interfaces.

For the 'Summary' page, the main challenges include:

- Highlighting the latest five knowledge entries in the system;
- The automatic creation of an abstract based on the details of a knowledge item. This is to eliminate the need for the author to prepare an abstract and to reduce the additional workload created; and
- Highlighting the knowledge items which are tagged as 'Draft' or 'To Be Reviewed' for validation purpose.

For the 'Knowledge Details' page, the main challenges are:

- The automatic rendering of URL in the knowledge details to a hyperlink; and
- The automatic creation of download links to the uploaded files.

Solution: For the 'Summary' page, the abstract of knowledge items were created by writing the programme code that extracts only the first 200 characters of the details of the latest five knowledge items entered (see Excerpt 6.2). The programme code was also amended to retrieve only the list of knowledge items which were tagged as 'Draft' or 'To Be Reviewed' only on to the 'Summary' page.

```
CREATE PROCEDURE mysp_Get_LatestTop5
AS
    SELECT TOP (5) KnowledgeDetailsTable.KnowledgeID,
    KnowledgeDetailsTable.KnowledgeTopic, ProjectDetailsTable.ProjectTitle,
    SUBSTRING(KnowledgeDetailsTable.KnowledgeDetails, 1, 200) AS Expr1,
    KnowledgeDetailsTable.DateEntered
    FROM KnowledgeDetailsTable INNER JOIN ProjectDetailsTable ON
    KnowledgeDetailsTable.ProjectID = ProjectDetailsTable.ProjectID
    ORDER BY KnowledgeDetailsTable.KnowledgeID DESC
    RETURN
```

Excerpt 6.2: Stored procedure for creating abstract of a knowledge item

On the 'Knowledge Details' page, all the contents sections with http:// will be rendered as a hyperlink. This was made possible by creating programme codes that automatically identify these sections and then enclose them with the hyperlink's syntax before storing into the database (see Excerpt 6.3).

```
Dim knowledgeDetails As String = detailsTextBox.Text
Dim find As String = "(?<url>http://(?:[\w-]+\.)+[\w-]+(?:/[\w-./?%&=]*)?)?"
Dim Result As String = Regex.Replace(knowledgeDetails, find, "<a
    href=""${url}"">${url}</a>")
e.Command.Parameters("@knowledgeDetails").Value = Result
```

Excerpt 6.3: Programme codes for hyperlink conversion

The download link to the uploaded file is essentially a hyperlink. It will navigate to the location of the uploaded file in the system when clicked. Codes are written to create the relevant download link automatically (see Excerpt 6.4).


```
<asp:Label ID="Doc1Label" runat="server" Text='<%# Bind("Doc1") %>'></asp:Label>
<asp:HyperLink ID="doc1DownloadLink" runat="server" NavigateUrl='<%# Eval("Doc1",
"~\Documents\{0}") %>' Text="Download"></asp:HyperLink>
```

Excerpt 6.4: Programme codes for creating document download links automatically

6.4.2.3 Validating Knowledge

Challenge: It must be noted that only the rating-based validation mechanism was built into the Web-based knowledge base as the proof of concept. First of all, there was a need for a mechanism to distinguish between the knowledge captured from individuals (which has to be validated) and the knowledge captured from meetings/reviews (which is deemed to have been validated). A mechanism for managing the users' comments and ratings for a knowledge item was required. Furthermore, the PKM should be provided with an additional function for validating and deleting a rejected knowledge item from the system.

Solution: No specific page was created for the purpose of knowledge validation. The programme codes and features for knowledge validation function were built into and scattered in the user interfaces for capturing and representing knowledge (i.e. the 'Add Knowledge' and 'Knowledge Details' page). On the 'Add Knowledge' page, a drop down list was provided for the users to specify the source of knowledge (i.e. individual or meeting/review. See Figure 6.4). If the source of the knowledge is 'individual', then the default status of that knowledge will be stored as 'Draft' in the database. If the source of knowledge is 'meetings/reviews', the default status of that knowledge will be stored as 'Validated'.

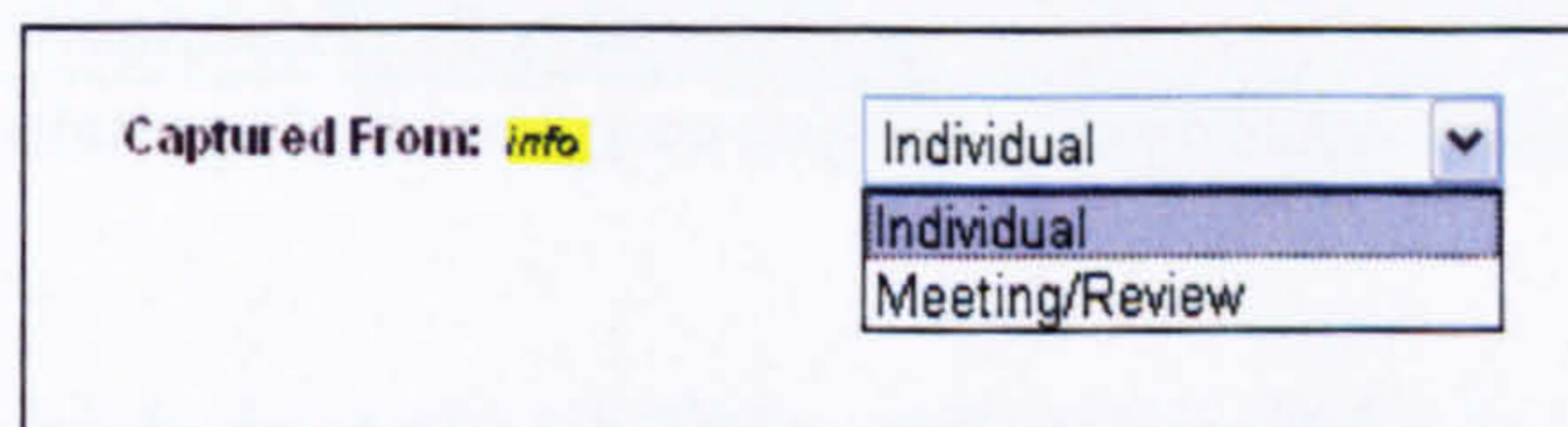


Figure 6.4: Dropdown menu for selecting the source of knowledge

In the user interface for representing the details of a knowledge item (i.e. the 'Knowledge Details' page), a text box and a drop down list were provided for collecting users' comments and ratings for a 'draft' knowledge item respectively (see Figure 6.5). A

database table was created for storing these information. Programme codes were then written to automatically retrieve the ratings given, calculate, update and display the average rating for the 'draft' knowledge item (see Excerpt 6.5).

Figure 6.5: Function for entering comment and rating for a knowledge item

```

While rdr.Read()
    TotalRating += Convert.ToInt32(rdr("Rating"))
    If rdr("Rating") IsNot Nothing Then
        NumOfComment += 1
        Average = Convert.ToDouble(TotalRating / NumOfComment)
    End If
End While

If NumOfComment = 0 Then
    noCommentLabel.Text = "No comment received so far. Why don't you be the 1st
person to give your comment?"
    NumOfCommentsLabel.Text = "0"
Else
    NumOfCommentsLabel.Text = NumOfComment.ToString()
    noCommentLabel.Text = ""
End If

Dim AvgResult As String
Dim NFI As NumberFormatInfo
NFI = New CultureInfo("en-US", False).NumberFormat
AvgResult = Average.ToString("N", NFI)
AvgRatingLabel.Text = AvgResult.ToString()

```

Excerpt 6.5: Codes for calculating the average rating for a knowledge item

A separate function, which is only visible and accessible by the Project Knowledge Manager, (PKM) was also created at the bottom of the user interface for representing knowledge details (see Figure 6.6). The function allows the PKM to edit/change the status of a knowledge item in the main database from 'Draft' to 'Validated' based on the comments and average rating received. The changes made to the status of a knowledge item will then trigger the system to send out email notifications to the users.

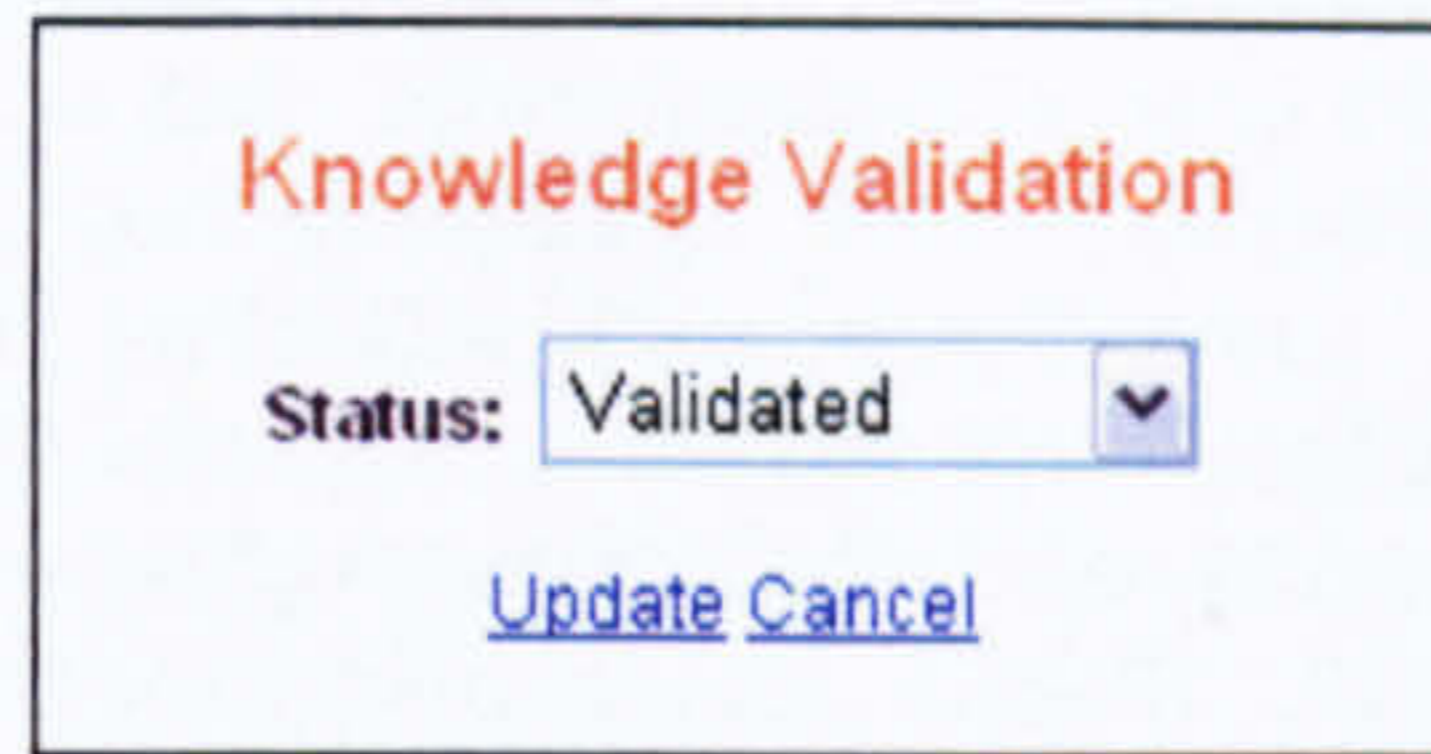


Figure 6.6: Function for PKM to validate a knowledge item

6.4.2.4 Searching Knowledge

Challenge: Two types of search function need to be created in the Web-based knowledge base: a simple Google™-like search function and an advanced search function. The Google™-like search function should be able to perform a search of a keyword across all the data fields in the database. The advanced search function should provide some additional features to filter or narrow down the results returned. This will help to obtain a more relevant set of search results.

Solution: Search textboxes were created for the Google™-like search function on the Index Page. A complex SQL query was written to compare the text entered into the textbox with all the data in the main database using the LIKE ‘%’ syntax . The results returned by the LIKE ‘%’ syntax will include the knowledge items that contain the particular text, as well as the text which closely resemble the text searched. For example, if the word ‘door’ is searched, the results returned will include the knowledge items that contain the words ‘indoor’ and ‘doors’.

An ‘Advanced Search’ page was specifically created for the advanced search function. It can perform a search by combining a variety of terms (e.g. project title, knowledge category, knowledge type and keyword) to help construction a more detailed search. Its SQL query for searching was written using the same principle as that of the Google™-like search function (see Excerpt 6.6). However, a number of new search criteria (e.g. project title and knowledge category) were created to allow the search results to be restricted to the knowledge entries, for instance, that contain a particular keyword and fall under a particular knowledge category in a particular project.


```
SelectCommand="SELECT KnowledgeDetailsTable.KnowledgeID,
KnowledgeDetailsTable.KnowledgeTopic, KnowledgeDetailsTable.userName,
KnowledgeDetailsTable.DateEntered, KnowledgeDetailsTable.CapturedFrom,
KnowledgeCategoryTable.KnowledgeCategory, KnowledgeTypeTable.KnowledgeType,
MemberInfo.email, ProjectDetailsTable.ProjectTitle, KnowledgeDetailsTable.status,
KnowledgeDetailsTable.KnowledgeDetails FROM KnowledgeDetailsTable INNER JOIN
KnowledgeCategoryTable ON KnowledgeDetailsTable.KnowledgeCategoryID =
KnowledgeCategoryTable.KnowledgeCategoryID INNER JOIN KnowledgeTypeTable ON
KnowledgeDetailsTable.KnowledgeTypeID = KnowledgeTypeTable.KnowledgeTypeID INNER
JOIN MemberInfo ON KnowledgeDetailsTable.userName = MemberInfo.userName INNER
JOIN ProjectDetailsTable ON KnowledgeDetailsTable.ProjectID =
ProjectDetailsTable.ProjectID WHERE (ProjectDetailsTable.ProjectTitle LIKE '%' +
@ProjectTitle + '%') AND (KnowledgeCategoryTable.KnowledgeCategory LIKE '%' +
@KnowledgeCategory + '%') AND (KnowledgeTypeTable.KnowledgeType LIKE '%' +
@KnowledgeType + '%') AND (KnowledgeDetailsTable.status LIKE '%' + @status + '%')
AND (KnowledgeDetailsTable.KnowledgeTopic LIKE '%' + @KnowledgeTopic + '%') AND
(KnowledgeDetailsTable.KnowledgeDetails LIKE '%' + @KnowledgeDetails + '%') ORDER
BY KnowledgeDetailsTable.DateEntered DESC"
```

Excerpt 6.6: SQL query for advanced search function

6.4.2.5 Configuring the System

Challenge: Certain information is required each time a knowledge item is entered into the system (e.g. project title, knowledge category and knowledge type). To avoid the need to re-enter similar information, a mechanism that allows such information to be entered once but retrievable over and over again was required. This feature was crucial to help reduce the additional workload created and to make the system as user friendly as possible.

A mechanism was also required for:

- The PKM to configure when the system should send email reminders to him/her to include knowledge capture into the agenda of the coming project meeting/review; and
- The PKM to configure the intervals at which the system should send email reminders requesting all users to add new knowledge into the system.

Solution: Before the system is ready for uploading reusable project knowledge, it needs to be configured. This includes adding information such as the project details, various categories and types of reusable project knowledge and user details. Various user interfaces were created for these information to be added into the database. These information were then linked to the various dropdown menus on the 'Add Knowledge' page (see Section 6.4.2.1 and Figure 6.3 for details). This enables the users to click to select the required option from the dropdown menus without the need to re-enter the

information. The various information required and associated user interfaces created are depicted in Table 6.1:

User Interface	Information Captured
'Add New Project' Page	Project details, i.e.: <ul style="list-style-type: none"> • Project title; • Project location; • Client; • Quantity surveyor; • Engineering consultant; • Architect; • Main contractor; • Start and completion dates; and • Duration (automatically calculated and added by the system)
'Knowledge Category and Type' Page	<ul style="list-style-type: none"> • Various knowledge categories and associated definitions; and • Various knowledge types and associated definitions.

Table 6.1: User interfaces for capturing repetitive information

The mechanism for the PKM to configure the intervals for sending email reminders to users was achieved through writing an email script for the purpose, and then use the Windows built-in 'Scheduled Tasks' function to execute the email script at the required intervals. The procedures are as follows:

1. Add a new scheduled task through the 'Scheduled Tasks' function;
2. Configure the new scheduled task to execute this command: "C:\Program Files\Internet Explorer\IEXPLORE.EXE" "http://localhost:2795/CaprikonRI1/reminder.aspx". Check the option to enable the scheduled task to run at specified time (see Figure 6.7); and
3. Configure the 'Schedule' to run the command on certain day, time and intervals (see Figure 6.8);
4. Configure the 'Setting' to stop the task if it runs for one minute (see Figure 6.9). This is to close the window that pops out after the task is executed.

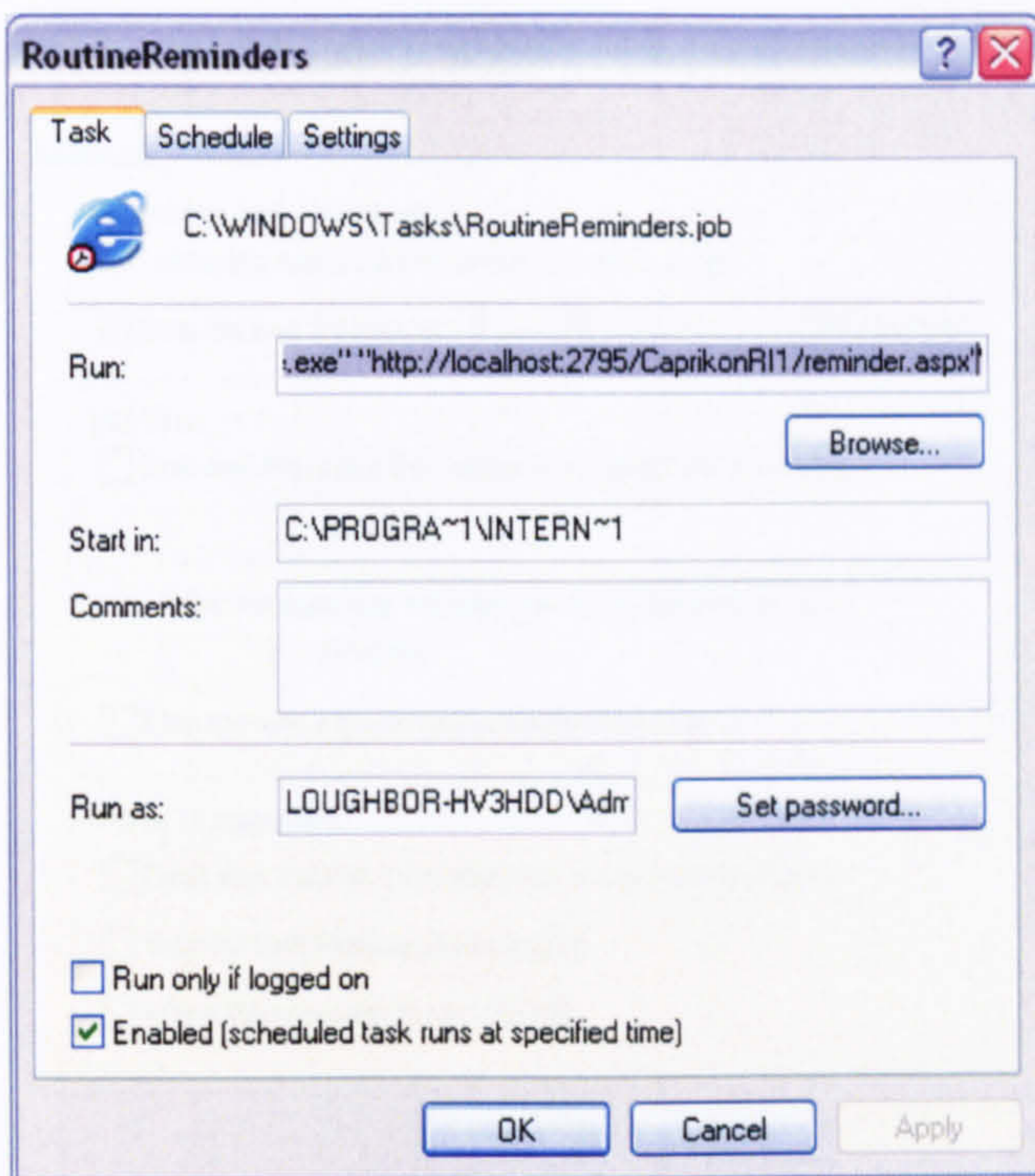


Figure 6.7: Configure the 'Scheduled Tasks' to execute the email script

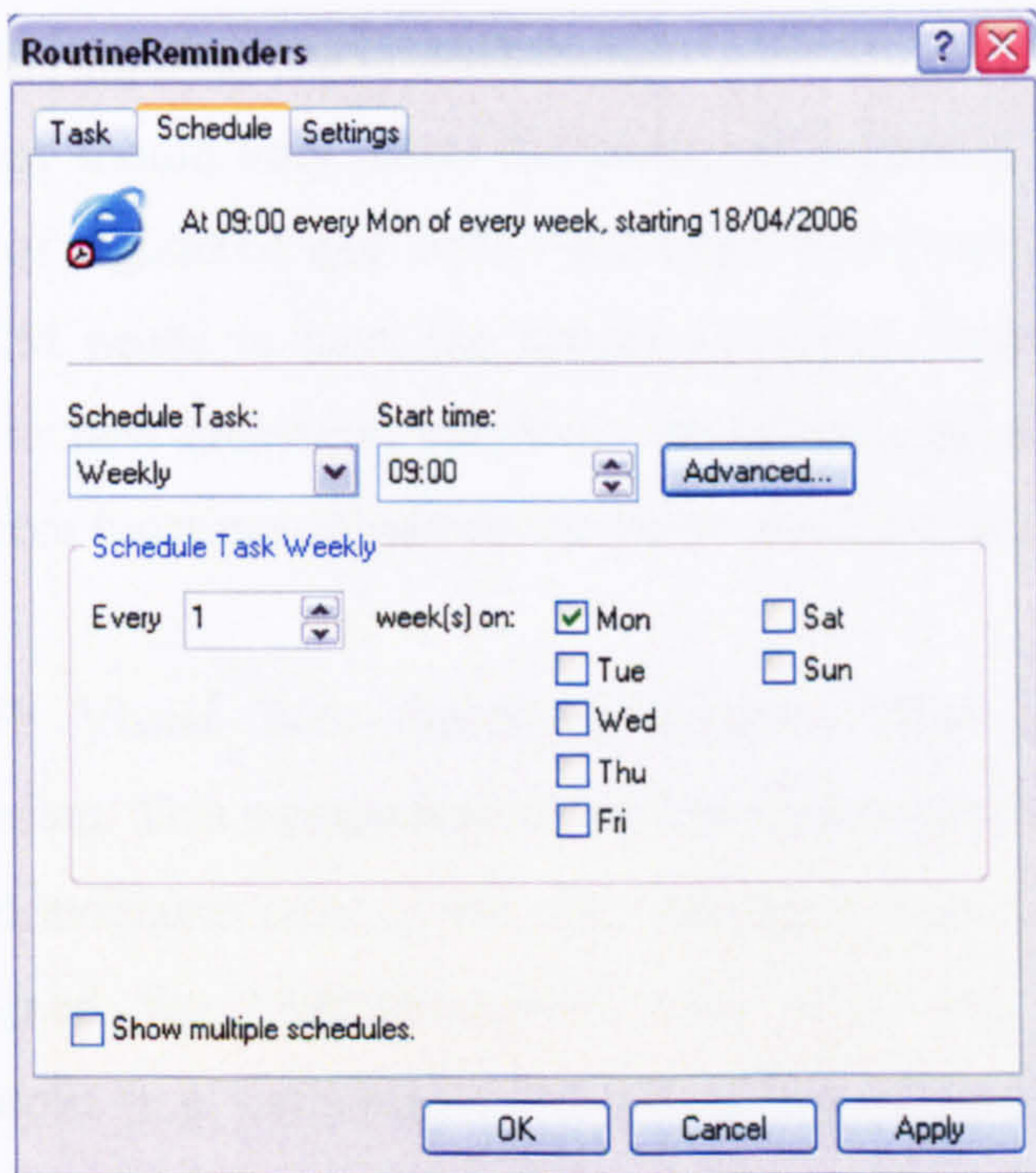


Figure 6.8: Configure the date, time and interval at which the email script will be executed

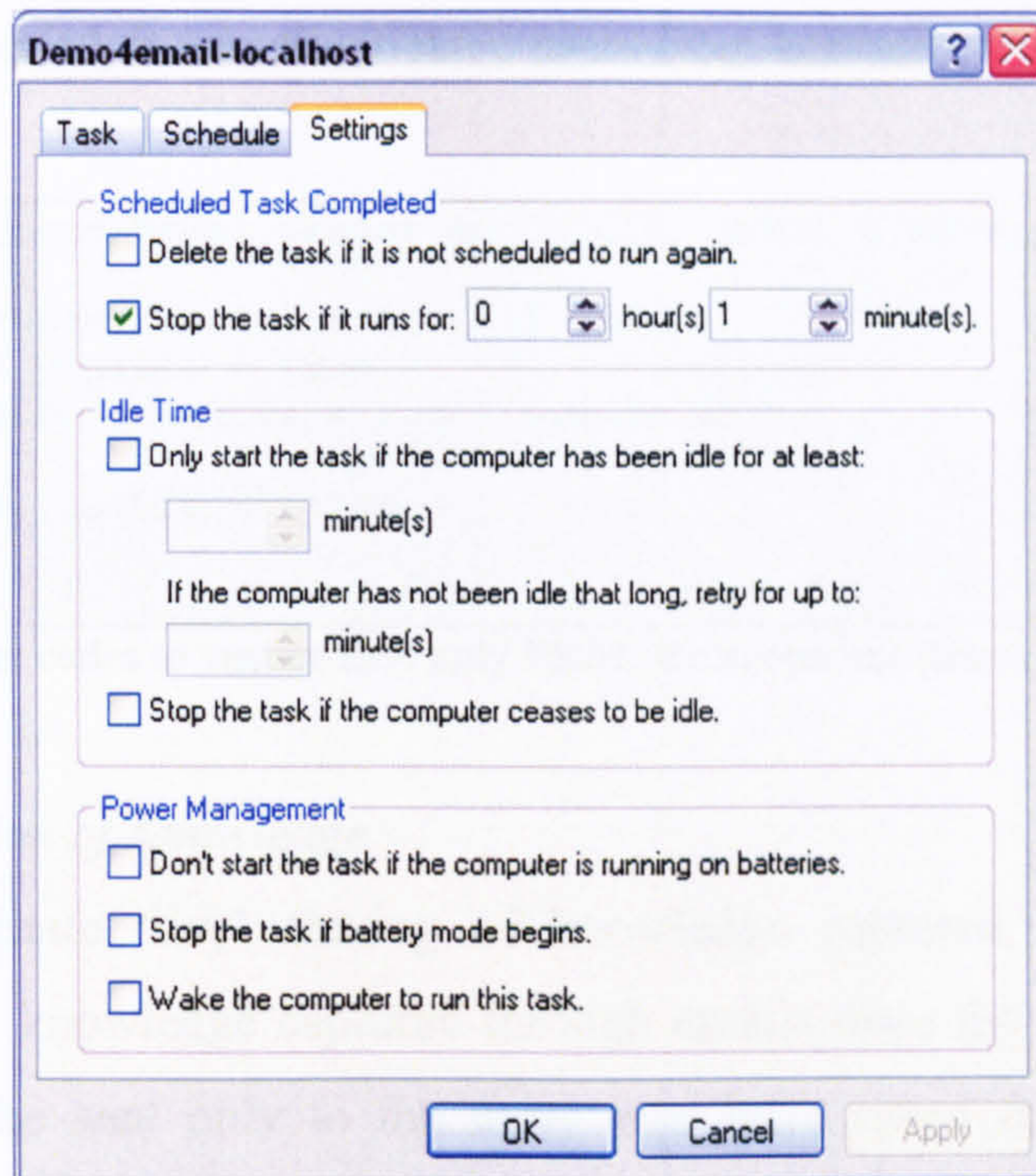


Figure 6.9: Configure the 'Scheduled Tasks' to close the pop out window after the task is executed

6.4.2.6 Managing User Information in the System

Challenge: The system should only allow the access of registered and authorised users. There are two types of registered and authorised users in the system (i.e. the PKM and other users). The PKM needs to have the access to certain functions, such as that for adding new projects or new members, validating knowledge, deleting a knowledge item from the database. These functions should not be made available to the other users.

Solution: Microsoft™ Visual Web Developer Express 2005 provides a role-based authentication mechanism. This mechanism allows the customisation of certain parts of the system to make them available only to the users assigned with certain roles. All of the PKM will be assigned the 'Administrators' role, who will have access to the aforementioned functions (e.g. validating knowledge). Programme codes were written to distinguish the users with different roles when they attempt to access the restricted functions. For instance, before the function for validating knowledge (i.e. referred to as FormView4 in Excerpt 6.7) is made available to the user, the associated programme will check to ensure that the user is in 'Administrators' role. The authentication mechanism can

also prevent unauthorised or unauthenticated users from accessing the system.

```
Protected Sub Page_Load(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Me.Load
    If User.IsInRole("Administrators") Then
        FormView4.Visible = True
        FormView4.DefaultMode = FormViewMode.Edit
    Else
        FormView4.Visible = False
    End If
End Sub
```

Excerpt 6.7: Programme codes to ensure that only PKM can access the knowledge validation function

6.4.2.7 Dissemination of Knowledge

Challenge: To facilitate 'live' sharing of knowledge captured, the system needs to disseminate the new knowledge captured through emails once the knowledge is entered. The emails should be sent only to the users who have opted for receiving the email notifications.

Solution: A 'bit' data field (i.e. for storing "True" or "False" value) was first created in a data table to store user's preference on whether they would like to receive email notifications. Programme codes were then written to send email notification to the users who have opted to receive email notifications when a knowledge item is added into the system. The programme codes will also attach a copy of the knowledge submitted together with its topic to the recipients in the email (see Excerpt 6.8).

```
Dim conn As New SqlConnection(ConfigurationManager.ConnectionStrings
"ConnectionString").ConnectionString)
Dim sqlquery As String = "SELECT email from MemberInfo Where ([inMailingList] =
1) "
Dim cmd As New SqlCommand(sqlquery, conn)
Dim topic As String = topicTextBox.Text
Dim details As String = detailsTextBox.Text
Dim find As String = "(?<url>http://(?:[\w-]+\.)+[\w-]+(?:/[\w-./?%&=]*)?) "
Dim Result As String = Regex.Replace(details, find, "<a
href=""${url}"">${url}</a>")
Dim objreader As SqlDataReader
Dim myVar As String

conn.Open()
objreader = cmd.ExecuteReader(System.Data.CommandBehavior.CloseConnection)
myVar = ""
While objreader.Read()
myVar += objreader("email") & ", "
End While
```



```

myVar = myVar.Substring(0, (myVar.Length - 1))

Try
  Dim mail As New MailMessage()
  mail.From = New MailAddress("h.c.tan@lboro.ac.uk")
  mail.To.Add(myVar)
  mail.Subject = "New Knowledge Item Added: " & topic
  mail.Body = Result & "<font face=Arial> You can access the details of the
knowledge through this link: <a href=http:www.caprikon.org.uk>CAPRINET</a>
</font>"
  mail.IsBodyHtml = True
  Dim smtp As New SmtpClient("ispstaff-mailout.lboro.ac.uk")
  smtp.Credentials = New NetworkCredential("user name", "password")
  smtp.Send(mail)
  Catch ex As Exception
    Trace.Warn(ex.Message)
  End Try

```

Excerpt 6.8: Programme codes for sending email notification instantly when a new knowledge item is added

6.4.3 Database Design

The Web-based knowledge base comprises two Microsoft™ SQL Server 2005 Express databases, i.e. the ASPNETDB database and the main database.

The ASPNETDB database contains the information about the membership, identity and authentication of users. It plays an important role in the security of the Web-based knowledge base. It helps to ensure that only the user with the correct user name, password and authorisation can access the stipulated sections of the knowledge base. This database is generated automatically by Visual Web Developer Express Edition when the knowledge base is configured.

The main database stores all the details pertaining to reusable project knowledge. In the database, the details of a knowledge item are divided into six tables where each of the tables stores only one topic of information (see Figure 6.10). The data stored in the tables are linked by relations. This type of database structure (i.e. a normalised relational database) ensures that a non-primary key data is only stored in one table in a database. This helps to eliminate the potential of data update and deletion anomalies. Data update and delete anomalies may happen if similar data is stored in two tables but the programme code only updates or deletes the data in one table. Details of the tables are as follows:

- Project details are stored in 'ProjectDetailsTable';

- Details of reusable project knowledge are stored in 'KnowledgeDetailsTable';
- Details of the different categories of reusable project knowledge are stored in 'KnowledgeCategoryTable';
- Details of the different types of reusable project knowledge are stored in 'KnowledgeTypeTable';
- Comments for each of the reusable project knowledge are stored in 'CommentTable';
- and
- The users' personal contact details and preference are stored in 'MemberInfo' table.

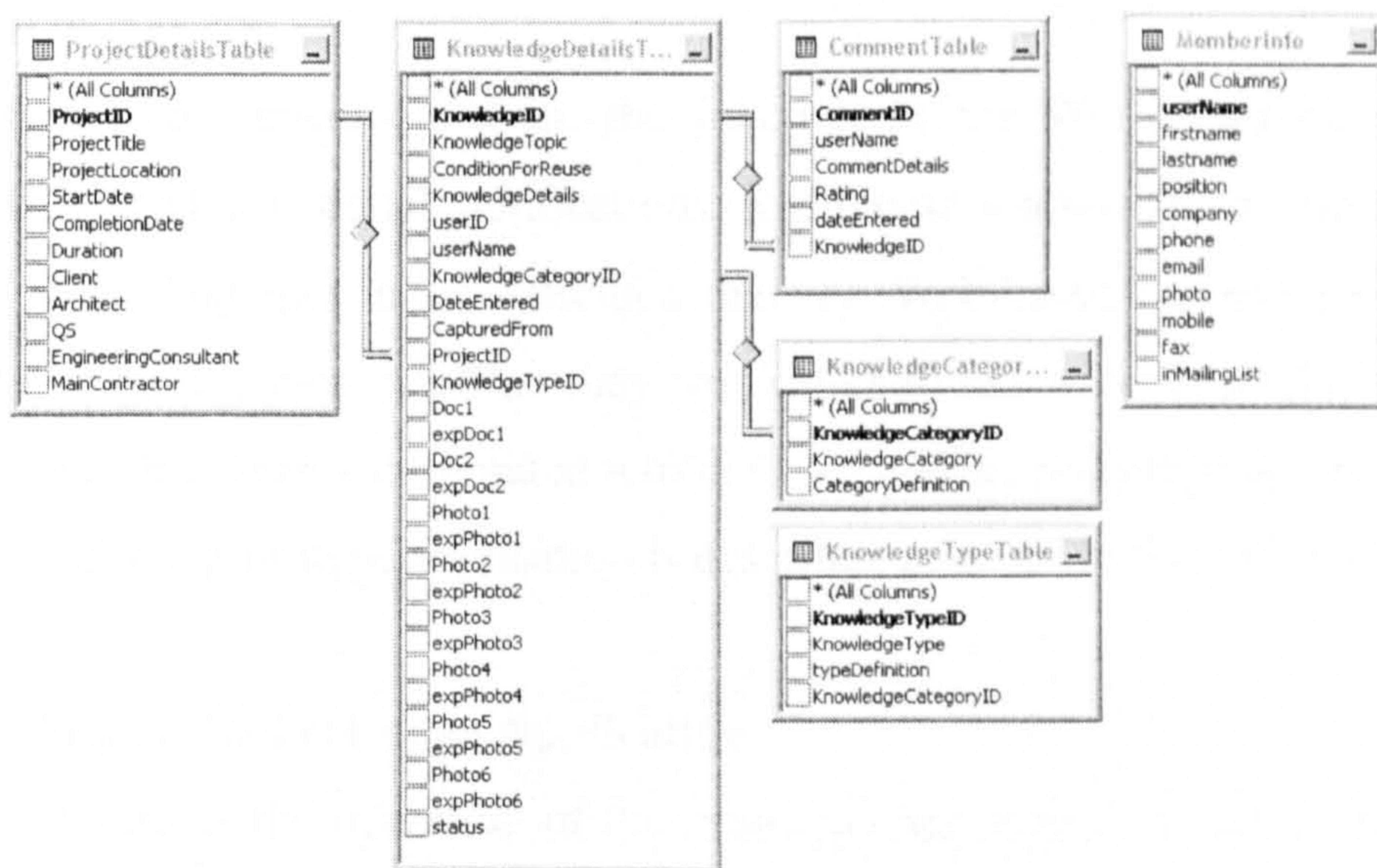


Figure 6.10: The main database's schema

6.5 Refinement of the Integrated Workflow System (IWS) and User Interface

The IWS and mock-up user interfaces were presented and reviewed by the case study companies in a mini-workshop conducted in a CAPRIKON Project Meeting. The user interfaces and the Integrated Workflow System were subsequently refined based on the findings of the mini-workshop. The prototype application was then developed based on the mock-up user interfaces and Integrated Workflow System created. The main outcomes of the mini-workshop include:

- The idea of capturing reusable project knowledge from project meetings/reviews, and individuals were accepted. Simons Group offered to use one of its projects to test the idea of capturing knowledge from the routine project meetings;

- The idea of capturing the rationale for making changes to documents was seen as crucial. However, it was decided that this feature would not be implemented in this prototype. This is because it requires the full integration of the software prototype with an existing project extranet (i.e. one used for managing project documents), which is not feasible at the point in time;
- Companies suggested that the validation of knowledge captured in the Web-based knowledge base could be conducted in the project meetings/reviews. This suggestion had been incorporated into the IWS as another option for knowledge validation. In addition, only the rating-based option would be incorporated into the prototype tool as the proof of concept; and
- Companies were concerned about the function of the Web-based knowledge base which will send out email notifications when new knowledge is entered into the system. Regarding this, it was decided that the Web-based knowledge base should allow the users to choose whether they would like to receive the email notifications or not. This also had been incorporated into the IWS and the prototype application.

The operation of the prototype application is described in detail in the next section.

6.6 Operation of the Prototype Application

This section describes the operation of the prototype application with the aid of relevant screen shots.

6.6.1 Logging In

When the prototype is started, the login page is displayed (see Figure 6.11). All the hyperlinks found on that page (except the 'Forgot Password?' link) will not function before the identity of the user is verified. The users can log into the system by entering their user name and password. In case they forgot their password, they can click on the 'Forgot Password?' link. This brings up the 'Forgot Password Page' where the user will be requested to provide their login name and the answer to a secret question (see Figure 6.12). The password will then be sent to the user's registered email address in the system.

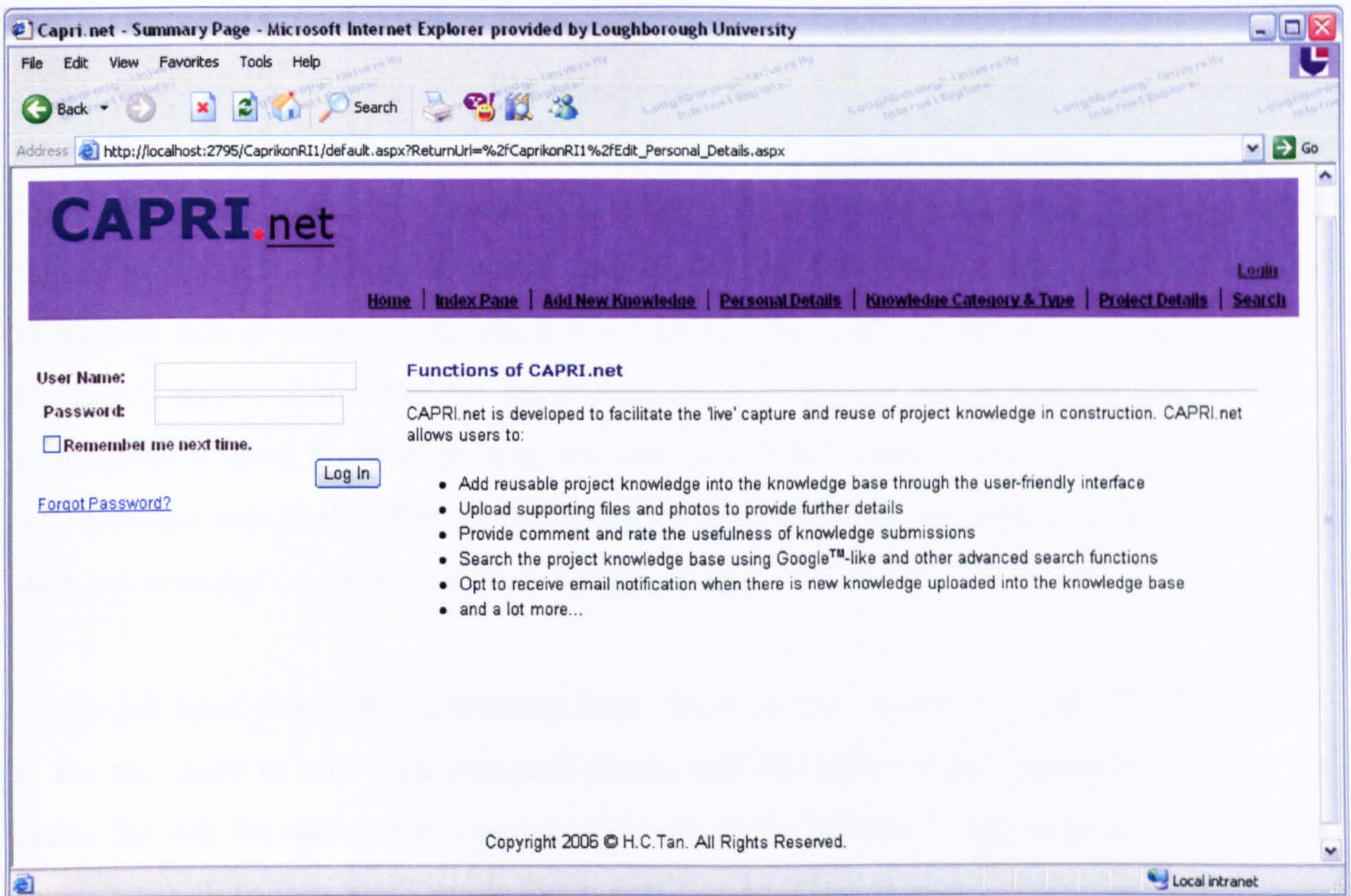


Figure 6.11: Login page

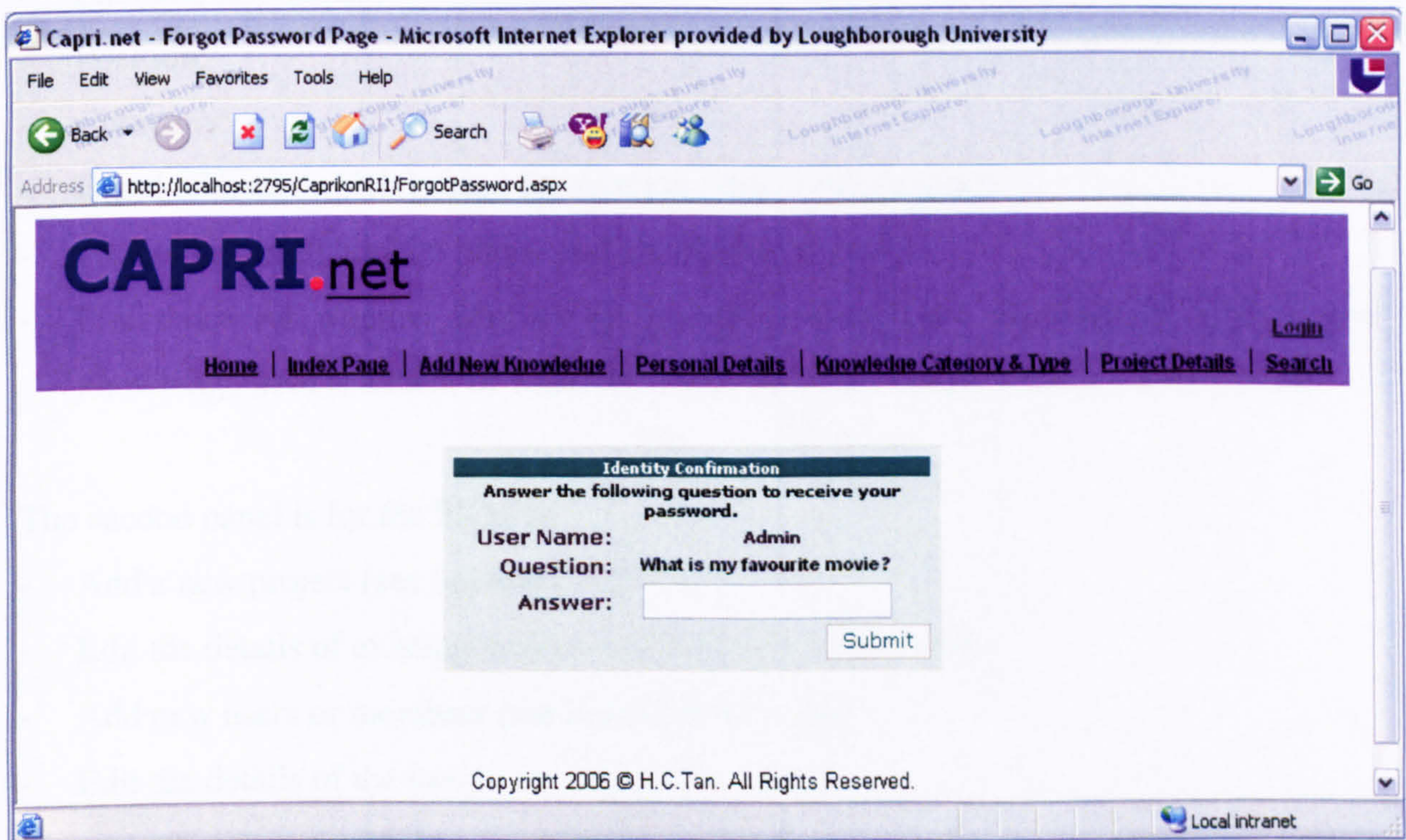


Figure 6.12: Forgot Password Page

6.6.2 Browsing the Summary Page

After successfully logging into the system, the user will be redirected to the 'Summary Page' (see Figure 6.13). On the 'Summary Page', a list of the latest five additions of knowledge items in the system and a list of knowledge items pending validation (i.e. either tagged as 'Draft' or 'To Be Revised') are shown. The knowledge's topic, date on which it is entered, title of project from which it is captured, its current status (i.e. 'Draft' or 'To Be Revised') and an abstract of the knowledge are provided. If the user would like to know more about a listed knowledge item, the user can click on the 'read more' hyperlink. This will lead the user to the 'Knowledge Details Page' where all the details of the knowledge item are revealed (see Figure 6.20 and Figure 6.21).

At the left hand side of the 'Summary Page' there are two coloured panels. The first panel is for the users to edit their personal details and to change their password. Clicking on either the link for editing one's personal details or the link for changing password will take them to the 'Edit Personal Details Page' (see Figure 6.14). In addition to allowing the user to change his/her password, the user can also edit the following personal information:

- First and last names;
- Position;
- Company;
- Email address (which is used for sending email notifications);
- Phone (landline), mobile phone and fax numbers; and
- Preference for whether s/he would like to receive email notifications when a new knowledge item is added, or when the status of a knowledge item has been changed.

The second panel is for the PKM to:

- Add a new project (see Section 6.6.5);
- Edit the details of existing project (see Section 6.6.5 as well);
- Add new users or members (see Section 6.6.7); and
- Edit the details of the users.

If users other than the PKM attempt to access the functions, they will be informed that the functions are only accessible to the PKM (see Figure 6.15).

Capri.net - Summary Page - Microsoft Internet Explorer provided by Loughborough University

File Edit View Favorites Tools Help

Address <http://localhost:2795/CapriKonRI1/Default.aspx> Go

CAPRI.net

Welcome back Admin! [Logout](#)

[Home](#) | [Index Page](#) | [Add New Knowledge](#) | [Personal Details](#) | [Knowledge Category & Type](#) | [Project Details](#) | [Search](#)

Hello Admin:
 If you want to EDIT your personal details, please [click here](#).
 If you want to CHANGE YOUR PASSWORD, please [click here](#).

For Project Knowledge Managers ONLY
 As a PKM, you can:
 (a) Add New Project by [clicking here](#)
 (b) Edit existing projects' details by [clicking here](#).
 (c) Add new member by [clicking here](#).
 (d) Add/Edit member's details by [clicking here](#).

Latest 5 Additions

Topic: Work on the foreshore
Date Entered: 13/04/2006
Project Title: Non Project Specific
Abstract: Be aware that if piling on the beach a licence is required from Defra for the works and this requires a substantial lead in period and fee. ...
[read more>>](#)

Topic: Room Ceiling Tiles
Date Entered: 06/04/2006
Project Title: The Teleport
Abstract: Better to use 600x600 ceiling tiles rather than 600x900 ...
[read more>>](#)

Topic: Scaffold Rules
Date Entered: 06/04/2006
Project Title: Non Project Specific
Abstract: Must make sure scaffold has adequate bracing! ...
[read more>>](#)

Topic: external glazing
Date Entered: 04/04/2006
Project Title: dewjoc
Abstract: Large areas of external glazing increase energy costs...
[read more>>](#)

Topic: Early age strength assessment of concrete on site
Date Entered: 03/04/2006
Project Title: Non Project Specific
Abstract: Knowledge of concrete strength at an early age: • Allows significantly increased efficiency of in-situ concrete frame construction. • Enables early striking of formwork and its economic re-use. This...
[read more>>](#)

To view all, please [click here](#).

Knowledge Pending Validation

Topic: Health and Safety Statistics - Cuts to hands a major contributor
Status: Draft **Date Entered:** 23-02-2006
Project Title: Asda - ASC4 (Project Sandal)
Abstract: David Mason of the HSE Department reports statistics relating to accidents this year. If we could eliminate cuts to the hand we could nearly halve our incident rate. Summary of our accidents stats for...
[read more>>](#)

Topic: Improving rebar information and supply
Status: Draft **Date Entered:** 14-03-2006
Project Title: Non Project Specific
Abstract: Improving the flow of information between all parties involved in the rebar design, supply and construction chain will: • Speed up the design process, and reduce the amount of re-working. • Reduce d...
[read more>>](#)

Topic: Prefabricated punching shear reinforcement for reinforced concrete flat slabs
Status: To Be Revised **Date Entered:** 16-03-2006
Project Title: Non Project Specific
Abstract: 1. Proprietary prefabricated punching shear reinforcement systems are between three and ten times quicker to fix than traditional loose links. 2. In most cases, the design approaches are relatively s...
[read more>>](#)

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Local intranet

Figure 6.13: Screen shot of the Summary Page

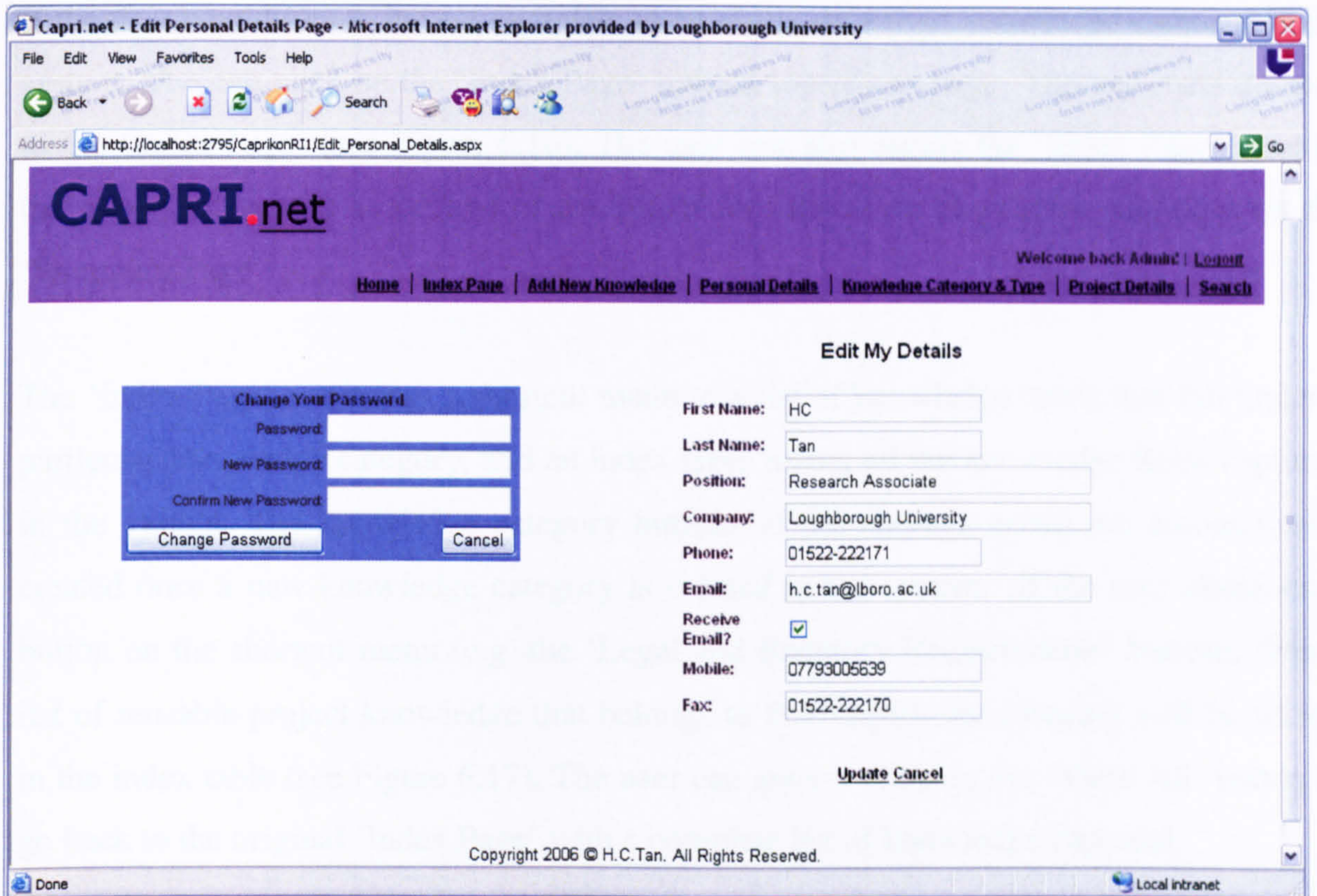


Figure 6.14: Template for editing personal details

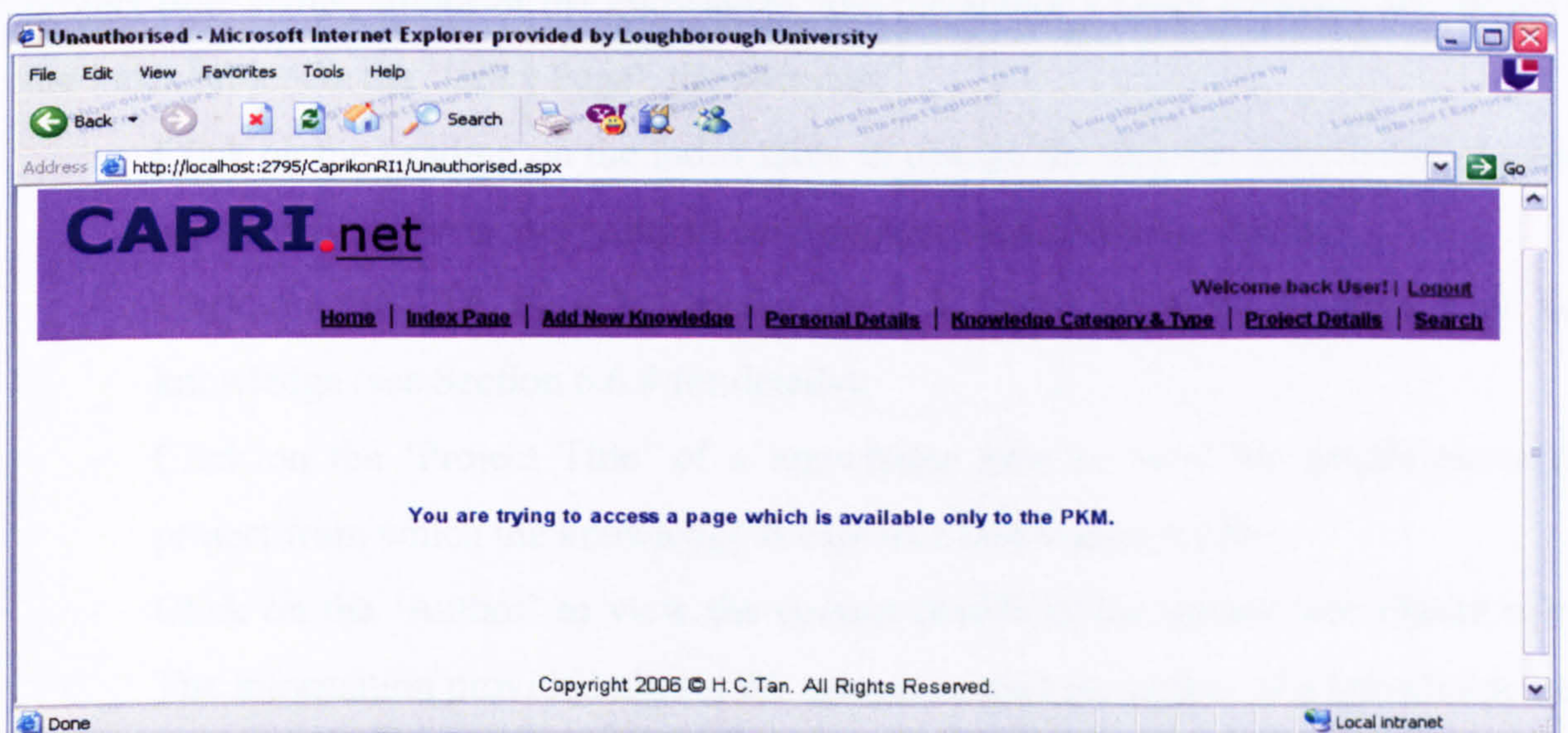


Figure 6.15: Screen shot of the Unauthorised Page

6.6.3 Exploring the Content of the System through the 'Index Page'

If the user would like to have a complete view of the list of the knowledge captured in the system, s/he can click on the 'Index Page' link on top of any page. This redirects the user to the 'Index Page' (see Figure 6.16). The user can also access the 'Index Page' through the hyperlink located at the end of the list of the latest five knowledge additions on the 'Summary Page'.

The 'Index Page' comprises a shortcut menu to a list of knowledge items that fall under a particular knowledge category, and an index table listing all the knowledge items captured in the system. The knowledge category buttons of the shortcut menu are automatically created once a new knowledge category is created in the system. If the user clicks on a button on the shortcut menu (e.g. the 'Legal and Statutory Requirements' button), then a list of reusable project knowledge that belongs to that knowledge category will be shown in the index table (see Figure 6.17). The user can always click on the 'View All' button to go back to the original 'Index Page' with a complete list of knowledge captured.

The details of knowledge items (i.e. topic, knowledge category and type, date entered, project title, status, author of the knowledge, and the author's email address) are shown in the index table. On the 'Index Page', the user can:

- Click on the heading on the index table to change the way the knowledge captured are sorted (i.e. from ascending to descending order, and vice-versa);
- Click on the 'ID' of a knowledge item in order to view the details of that knowledge (see Section 6.6.4 for details);
- Click on the 'Project Title' of a knowledge item to view the details about the project from which the knowledge is captured (see Figure 6.18);
- Click on the 'Author' to view the contact details of the author (see Figure 6.19). The information provided allows the user to contact the author of a knowledge item for further details; and
- Click on the 'Click Here' email link to send an email to the author of the knowledge.

Capri.net - Index Page - Microsoft Internet Explorer provided by Loughborough University

File Edit View Favorites Tools Help

Address http://localhost:2795/CapriNetR11/Index_Page.aspx

CAPRI.net

Welcome back Admin! [Logout](#)

[Home](#) | [Index Page](#) | [Add New Knowledge](#) | [Personal Details](#) | [Knowledge Category & Type](#) | [Project Details](#) | [Search](#)

Knowledge Category

- [Process Knowledge](#)
- [Knowledge About Client](#)
- [Costing Knowledge](#)
- [Legal & Statutory Requirements](#)
- [Reusable Details](#)
- [Best Practices & Lessons Learned](#)
- [Performance of Suppliers](#)
- [Who Knows What](#)
- [Health and safety](#)

[View All](#)

ID	Knowledge Topic	Knowledge Category	Knowledge Type	Date Entered	Project Title	Status	Author	Email
Delete 115	Roof mounted plant and the acoustic issues	Process Knowledge	Planning	14/04/2005	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 114	The use of the MEP system (pre-assembled pipework) has provided better quality and speedier installation.	Process Knowledge	Construction methods and techniques	17/02/2005	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 113	The use of suction lifting device for the handling of glazed panels	Process Knowledge	Construction methods and techniques	17/02/2005	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 112	Lift - Separate synchronisation issues	Process Knowledge	Planning	20/01/2005	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 111	Health and Safety vs. influx of foreign labour	Health and safety	-	22/12/2004	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 110	The use a tower crane is not always beneficial	Process Knowledge	Construction methods and techniques	22/12/2004	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 109	The use of fibrous mesh reinforcement in lieu of steel.	Process Knowledge	Construction methods and techniques	25/11/2004	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 108	WC considered the decision to use a tower crane to be of considerable benefit	Process Knowledge	Construction methods and techniques	25/11/2004	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 107	Need to consult HSE at soon as possible regarding site establishment and vehicle deliveries	Health and safety	-	04/11/2004	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 106	Development of design procurement programme to eliminate any misunderstandings on the status of design.	Process Knowledge	Design Knowledge	04/11/2004	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 105	The Use of a cassette delivery system and modular prefabricated mechanical installation system to speed up progress	Process Knowledge	Construction methods and techniques	04/11/2004	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 104	How planning affects access issues on site	Process Knowledge	Planning	30/09/2004	2 City Walk, Sweet Street	Validated	Admin	Click Here
Delete 103	Curtain Walling to Accelerate Progress	Process Knowledge	Construction methods and techniques	13/03/2006	2 City Walk, Sweet Street	Validated	APalmer	Click Here
Delete 69	Mobile Tower Cranes	Legal & Statutory Requirements	Regulatory requirements	23/02/2006	Astra Zeneca	Validated	Admin	Click Here
Delete 68	Health and Safety Statistics - Cuts to hands a major contributor	Best Practices & Lessons Learned	-	23/02/2006	Asda - ASC4 (Project Sandal)	Draft	Admin	Click Here
Delete 67	A New Solution to Japanese Knotweed	Best Practices & Lessons Learned	-	23/02/2006	BnQ Cheltenham	Validated	Admin	Click Here
Delete 66	Be prepared for the new Part C Regulation	Legal & Statutory Requirements	Regulatory requirements	23/02/2006	GlaxoSmithKline	Validated	GDickinson	Click Here

1 2

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Local intranet

Figure 6.16: Screen shot of the 'Index Page'

The screenshot shows the CAPRI.net index page in Microsoft Internet Explorer. The browser title is "Capri.net - Index Page - Microsoft Internet Explorer provided by Loughborough University". The address bar shows "http://localhost:2795/CaprikonRI1/Index2_Page.aspx?Category=6". The page features a purple header with the CAPRI.net logo and navigation links: Home, Index Page, Add New Knowledge, Personal Details, Knowledge Category & Type, Project Details, and Search. A search bar is located in the top right. Below the header, there is a "Knowledge Category" section with buttons for: Process Knowledge, Knowledge About Client, Costing Knowledge, Legal & Statutory Requirements (selected), Reusable Details, Best Practices & Lessons Learned, Performance of Suppliers, Who Knows What, Health and safety, and View All. A table displays knowledge items:

ID	Knowledge Topic	Knowledge Category	Knowledge Type	Date Entered	Project Title	Status	Author	Email
Delete 66	Be prepared for the new Part C Regulation	Legal & Statutory Requirements	Regulatory requirements	23/02/2006	GlaxoSmithKline	Validated	GDickinson	Click Here
Delete 69	Mobile Tower Cranes	Legal & Statutory Requirements	Regulatory requirements	23/02/2006	Astra Zeneca	Validated	Admin	Click Here

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Figure 6.17: Screen shot of the index page showing list of knowledge about legal and statutory requirements

The screenshot shows the CAPRI.net project details page in Microsoft Internet Explorer. The browser title is "Capri.net - Microsoft Internet Explorer provided by Loughborough University". The address bar shows "http://localhost:2795/CaprikonRI1/Projects_Details.aspx?ID=%202%20City%20Walk,%20Sweet%20Street". The page features a purple header with the CAPRI.net logo and navigation links: Home, Index Page, Add New Knowledge, Personal Details, Knowledge Category & Type, Project Details (selected), and Search. A search bar is located in the top right. Below the header, the "Project Details" section is displayed in a table:

Project ID:	29
Project Title:	2 City Walk, Sweet Street
Project Location:	Leeds, UK
Start Date:	05/04/2004 00:00:00
Completion Date:	20/10/2005 00:00:00
Duration:	80 weeks
Client:	Simons Development
Architect:	Simons Design
QS:	Leslie Clark
Engineering Consultant:	John Allen Consulting
Main Contractor:	Wrights Construction Ltd

Below the table is a "View All Projects" link. Copyright 2006 © H.C.Tan. All Rights Reserved.

Figure 6.18: Screen shot of a project's details

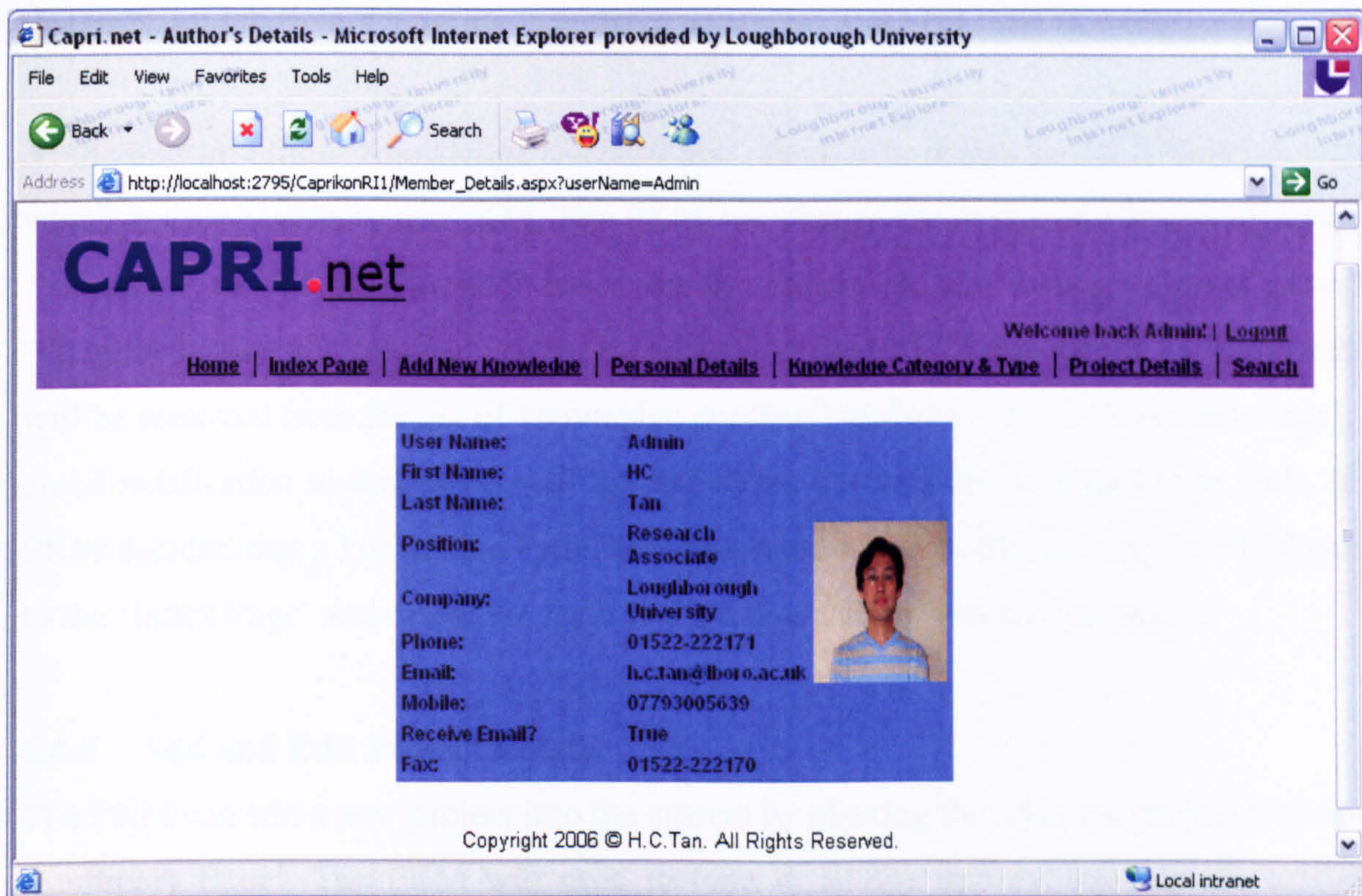


Figure 6.19: Screen shot of the page showing the author's contact details

6.6.4 Exploring and Validating the Details of a Knowledge Item

The details of a knowledge item is revealed on the 'Knowledge Details Page' (see Figure 6.20 and Figure 6.21) when the user clicks on the 'ID' of that knowledge on the 'Index Page' or other pages. Full details about the knowledge (including relevant image files) and the project from which the knowledge is captured from are displayed on the page by default. There are also hyperlinks that can lead the user to the contact details of the author and other relevant Websites. By clicking on the download links, the user can download and view the relevant documents. If the default size of the images displayed on the page are too small, the user can also click on the image to view the full-size image. Short descriptions are provided to give the users details about the document and image files uploaded.

The user can view the average rating, as well as the individual rating and comment given by other users to a knowledge item at the bottom of the 'Knowledge Details Page'. The user can add his/her own comment in the textbox provided, and select the rating to be given from the dropdown list. By clicking the 'Insert' button, the comment and rating will

be added into the system. The comment and rating given are available for viewing instantly, and the average rating is updated accordingly in real-time as well.

At the bottom of the 'Knowledge Details Page', there is a section for validating knowledge which is only visible to the PKM. The PKM can change the status of a knowledge item to 'Validated' or 'To Be Revised' based on the comments and average ratings provided. When the status of a knowledge item is changed by the PKM from 'Draft' to 'Validated', it will be removed from the list of knowledge pending validation on the 'Summary Page'. An email notification to that effect will be sent to the users in the mailing list as well. If the PKM decided that a knowledge item should be removed from the system, the PKM can go to the 'Index Page' and delete the record of the knowledge item on that page.

6.6.5 Add and Edit Project Details

The PKM can add a new project into the system by clicking the add new project link on the 'Summary Page'. The PKM will need to type in all the information into the textboxes provided, except the duration of the project which will be calculated automatically by the system from the start and completion dates entered (see Figure 6.22).

Occasionally, the PKM may need to edit or update the details of a project (e.g. changes in the start or completion date). In this case, the PKM can click to access the 'Administer Project Details Page' through the 'Project Details' hyperlink on top of every page. On that page, the PKM can click on the 'Edit' button which is only visible to PKM for editing the details of a project (see Figure 6.23).

Capri.net - Knowledge Details - Microsoft Internet Explorer provided by Loughborough University

Address: http://localhost:2795/CapriKonRII/KnowledgeDetails.aspx?KnowledgeID=186

CAPRI.net Welcome back Admin! [Logout](#)

[Home](#) | [Index Page](#) | [Add New Knowledge](#) | [Personal Details](#) | [Knowledge Category & Type](#) | [Project Details](#) | [Search](#)

Project Title: GlaxoSmithKline	Project ID: 20
Location: Gethouse	Completion Date: 10/03/2006
Start Date: 05/09/2005	Architect: PACE Partnership/Simons Design/Dewjoc
Duration: 27 weeks	OS: The Davidson Partnership, Pritchard Williams and Hunt
Client: GlaxoSmithKline	Main Contractor: Simons Construction
Engineering Consultant: ROSS Partnership/Bettridge Turner PTRS	

Knowledge ID: 186	Date Entered: 03/04/2006	Status: Validated
Knowledge Topic: Early age strength assessment of concrete on site	Knowledge Category: Process Knowledge	Captured From: Individual
Knowledge Type: Construction methods and techniques	Author: SMajor	Please click here for contact details

Knowledge Details:

Knowledge of concrete strength at an early age:

- Allows significantly increased efficiency of in-situ concrete frame construction.
- Enables early striking of formwork and its economic re-use. This is further explained in a companion Best Practice Guide, Early striking for efficient flat slab construction.
- Enables early prestressing with safety.
- Can give an indication of long-term strength, enabling early confirmation of the quality of the concrete as placed.

Best practice

- Use pull-out inserts cast into the concrete to determine early age strength.
- Horizontally cast members (e.g. slabs) - locate inserts, using a floating cup, on the top surface of the slab near the end of the pour.
- Vertically cast members (e.g. walls, columns) - locate inserts on the formwork, with provision for early access before striking.

Please refer to the files attached for further details.
Source: <http://www.bca.org.uk>

Condition For Reuse:

The use of pull-out tests involving pre-planned inserts is the method recommended in this Guide. However there may be situations where such testing is not appropriate e.g. where special finishes are used, where the planned inserts have not been installed, or where increased confidence is required from using a range of techniques. Whatever techniques are employed, it is important that an attempt is made to determine a lower bound estimate of the concrete's strength.

Relevant Documents

Doc 1: 'BPG_Early_Age[1].pdf' [Download](#)
This Guide provides recommendations for determining the strength of concrete on site at early ages (less than three days).

Doc 2: 'BPG_Early_Striking[1].pdf' [Download](#)
Best Practice Guide: Early striking for efficient flat slab construction.

[Click Here To Go Straight To See The Comments](#)

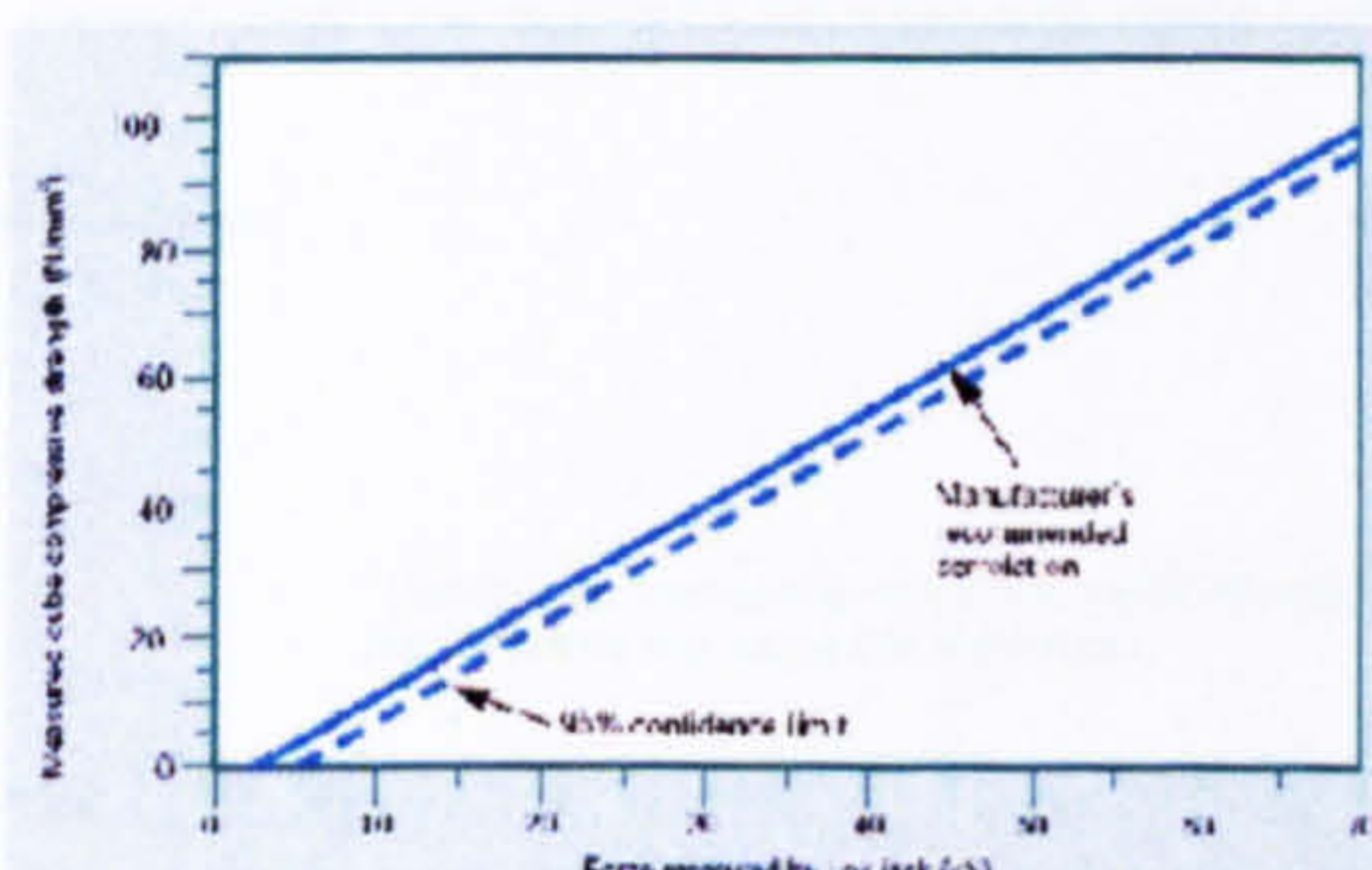


Photo 1: 'age11.JPG
Illustrative correlation between strengths determined by the Lok-test and by conventional cube testing.

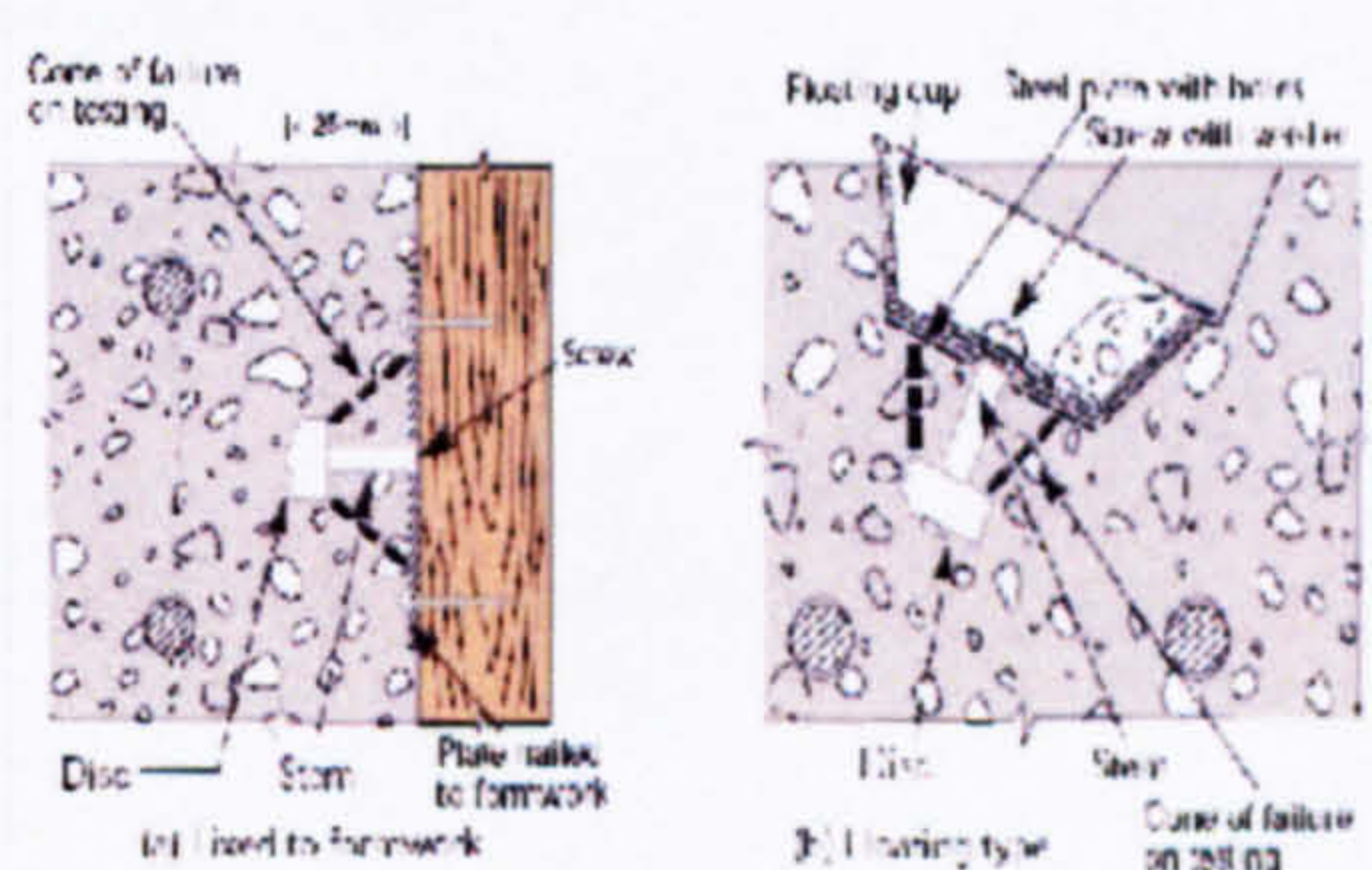


Photo 2: 'age21.JPG
Lok-test inserts.

Figure 6.20: Screen shot displaying the details of a knowledge item (Part 1 of 2)

Capri.net - Knowledge Details - Microsoft Internet Explorer provided by Loughborough University

File Edit View Favorites Tools Help

Address: http://localhost:2795/CapriKonR11/KnowledgeDetails.aspx?KnowledgeID=186

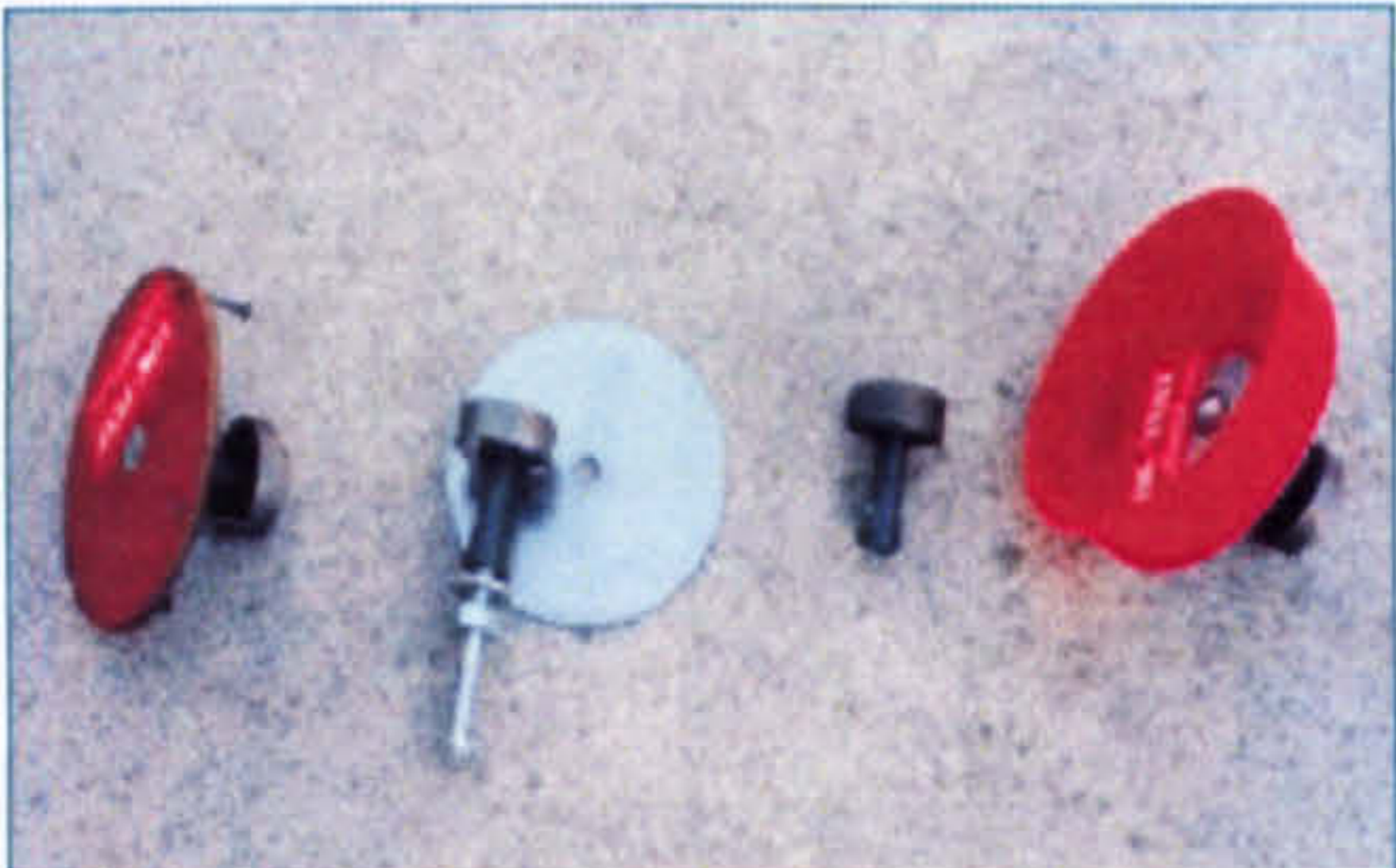


Photo 3: 'age31.JPG
Lok-test inserts for formwork (left) and floating cup (right)

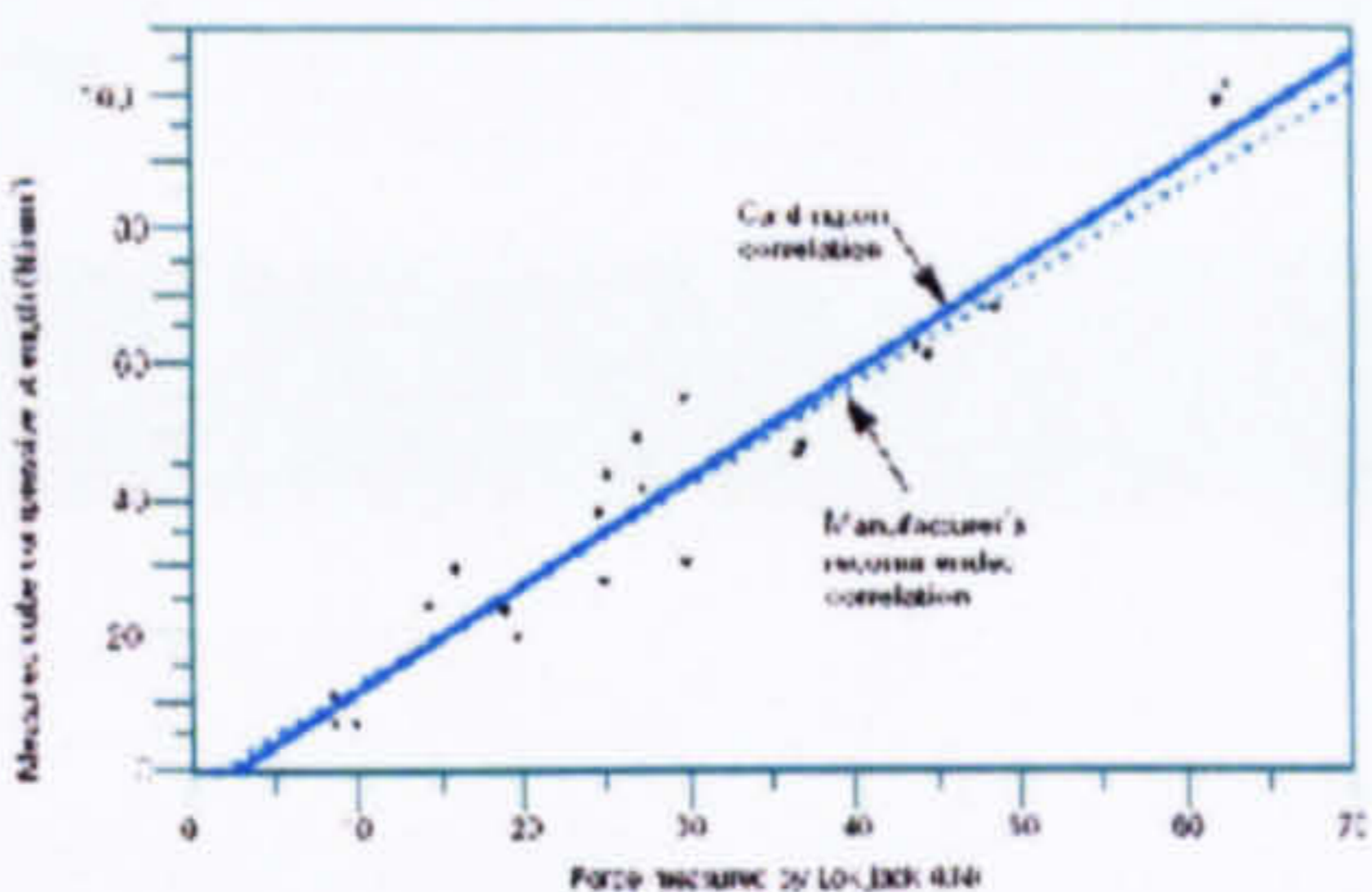


Photo 4: 'age41.JPG
Correlation of Lok-tests and cube tests carried out at Cardington.

Test Method	Procedure	Advantages	Disadvantages
Compression
Flexure
Split Tensile
Modulus
Beam Deflection

Photo 5: 'age51.JPG
Comparison of test methods.




Photo 6: no photo.jpg

Reader(s)'s Comments For This Knowledge
Average rating: **4.33 Stars**, based on **3 comments**

Rating: 4 Stars **Date Entered:** 08/04/2006
Author: JHaynes [Contact Details](#)
Comment: Well-written and useful knowledge. Recommended!

Rating: 4 Stars **Date Entered:** 12/04/2006
Author: APalmer [Contact Details](#)
Comment: Should consider disseminating this knowledge to all project teams.

Rating: 5 Stars **Date Entered:** 15/04/2006
Author: PWalker [Contact Details](#)
Comment: Would like to see more this kind of high quality knowledge being shared. Good work, Steve.

Your Comment:

* Constructive comment is welcomed, whilst offensive comment is not allowed. Person who has given offensive comment may be barred from using this application.

Rating: 1 Star 2 Stars 3 Stars 4 Stars 5 Stars

[Insert](#) [Cancel](#)

Knowledge Validation

Status:

[Update](#) [Cancel](#)

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Figure 6.21: Screen shot displaying the details of a knowledge item (Part 2 of 2)

Capri.net - Add New Project - Microsoft Internet Explorer provided by Loughborough University

File Edit View Favorites Tools Help

Address: http://localhost:2795/CaprikonRI1/Adm2_Projects_Details.aspx

Welcome back Admin! | [Logout](#)

[Home](#) | [Index Page](#) | [Add New Knowledge](#) | [Personal Details](#) | [Knowledge Category & Type](#) | [Project Details](#) | [Search](#)

Insert New Project Details

Project Title:

Project Location:

Client:

OS:

Engineering Consultant:

Architect:

Main Contractor:

Start Date

April 2006						
Mo	Tu	We	Th	Fr	Sa	Su
27	28	29	30	31	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
1	2	3	4	5	6	7

Completion Date

April 2006						
Mo	Tu	We	Th	Fr	Sa	Su
27	28	29	30	31	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
1	2	3	4	5	6	7

[Insert](#) [Cancel](#)

[Back](#)

Done Local intranet

Figure 6.22: Screen shot of the page for adding new project into the system

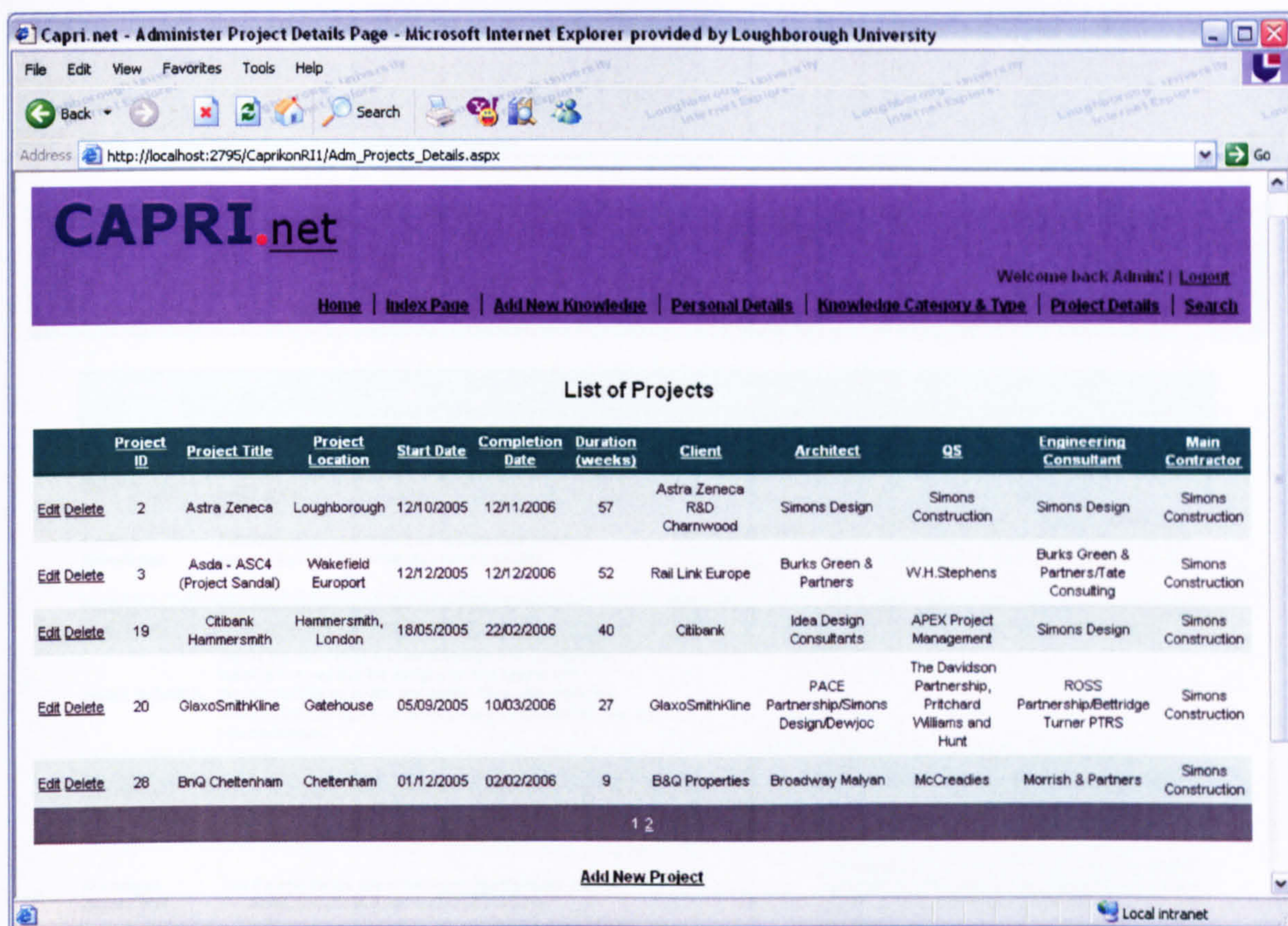


Figure 6.23: Screen shot for the Administer Project Details Page

6.6.6 Adding New Knowledge Category and Type

Only the PKM is allowed to add new knowledge categories and knowledge types into the system. To access this feature, the PKM needs to click on the 'Knowledge Category & Type' link at the top of every page. This redirects the PKM to the page for adding new knowledge category and type (see Figure 6.24). The procedures for adding a new knowledge category and type are as follows:

- The PKM enters a new knowledge category name and the associated definition. After the 'insert' button is clicked, the new knowledge category is created in the system; and
- The PKM provides a name and definition for the new knowledge type. The PKM must select a knowledge category which the knowledge type belongs to from the dropdown list. The PKM can now click on the 'insert' button to add the new knowledge type into the system

The details of the knowledge categories and types available in the system are revealed on the table on top of the page.

Capri.net - Knowledge Category and Type Page - Microsoft Internet Explorer provided by Loughborough University

File Edit View Favorites Tools Help

Back Forward Stop Home Search

Address http://localhost:2795/CapriKonR11/Knowledge%20_CateNType.aspx

CAPRI.net

Welcome back Admin! | Logout

[Home](#) | [Index Page](#) | [Add New Knowledge](#) | [Personal Details](#) | [Knowledge Category & Type](#) | [Project Details](#) | [Search](#)

Knowledge Category	Category Definition	Knowledge Type	Type Definition
Best Practices & Lessons Learned	Best practices and lessons learned are the proven ways of working that contribute to the success of projects and the mistakes made that must be avoided in future projects respectively.	-	-
Costing Knowledge	This knowledge covers the cost of alternative forms of construction and the whole life cost of a project	Cost of alternative forms of construction	This is the knowledge on the cost of alternative forms of design and construction methods with respect to the project location and the way that the project is being financed.
Costing Knowledge	This knowledge covers the cost of alternative forms of construction and the whole life cost of a project	Whole Life Cost (WLC)	Whole Life Cost is the total cost of procuring, operating and maintaining an asset throughout its lifespan.
Health and safety	This is the knowledge on how to design and construct the building in a way that the designers' and contractor's responsibilities on health and safety, especially under the Construction (Design and Development) Regulations 1994, are fully discharged.	-	-
Knowledge About Client	This the knowledge about the client organisations' internal procedure, specific requirements and business.	Client organisations' internal procedure	Public and private sectors clients may have their individual working procedures which can be so rigid until in some circumstances they are regarded as organisational red-tapes that affect the progress of the project.
Knowledge About Client	This the knowledge about the client organisations' internal procedure, specific requirements and business.	Clients' business	This knowledge covers who are the people working for the client, the availability of new projects from the client and the background knowledge about his/her business activities.

1 2 3

Add New Knowledge Category

New Knowledge Category:

Definition of the Knowledge Category:

[Insert](#) [Cancel](#)

Add New Knowledge Type

New Knowledge Type:

which falls under this Knowledge Category:

Definition of the Knowledge Type:

[Insert](#) [Cancel](#)

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Local intranet

Figure 6.24: Screen shot for the add new knowledge category and type page

6.6.7 Create Account for New User

For security reasons, ordinary users are not allowed to create accounts for themselves in the system. Only the PKM has the authority to add new users. This function is accessible through the PKM-only section on the 'Summary Page' (see Figure 6.13). There are two steps for the creation of new user accounts:

- Step 1: After clicking on the "Add new member" link provided, the PKM will be redirected to the 'Add Member Page' (see Figure 6.25). The PKM needs to provide the required details for the new user. New user account is created after the PKM clicks on the 'Create User' button; and
- Step 2: The PKM needs to go to the 'Add Member Details Page' (see Figure 6.26) for entering further details about the users. These include the first and last names of the user, company, position, telephone and mobile phone numbers, fax number, email address, the preference on receiving email notification, and a personal photo of the new user.

The new user can now access the system using the user name and password obtained from the PKM. The user can also update his/her personal details in the system (see Section 6.6.2 for details).

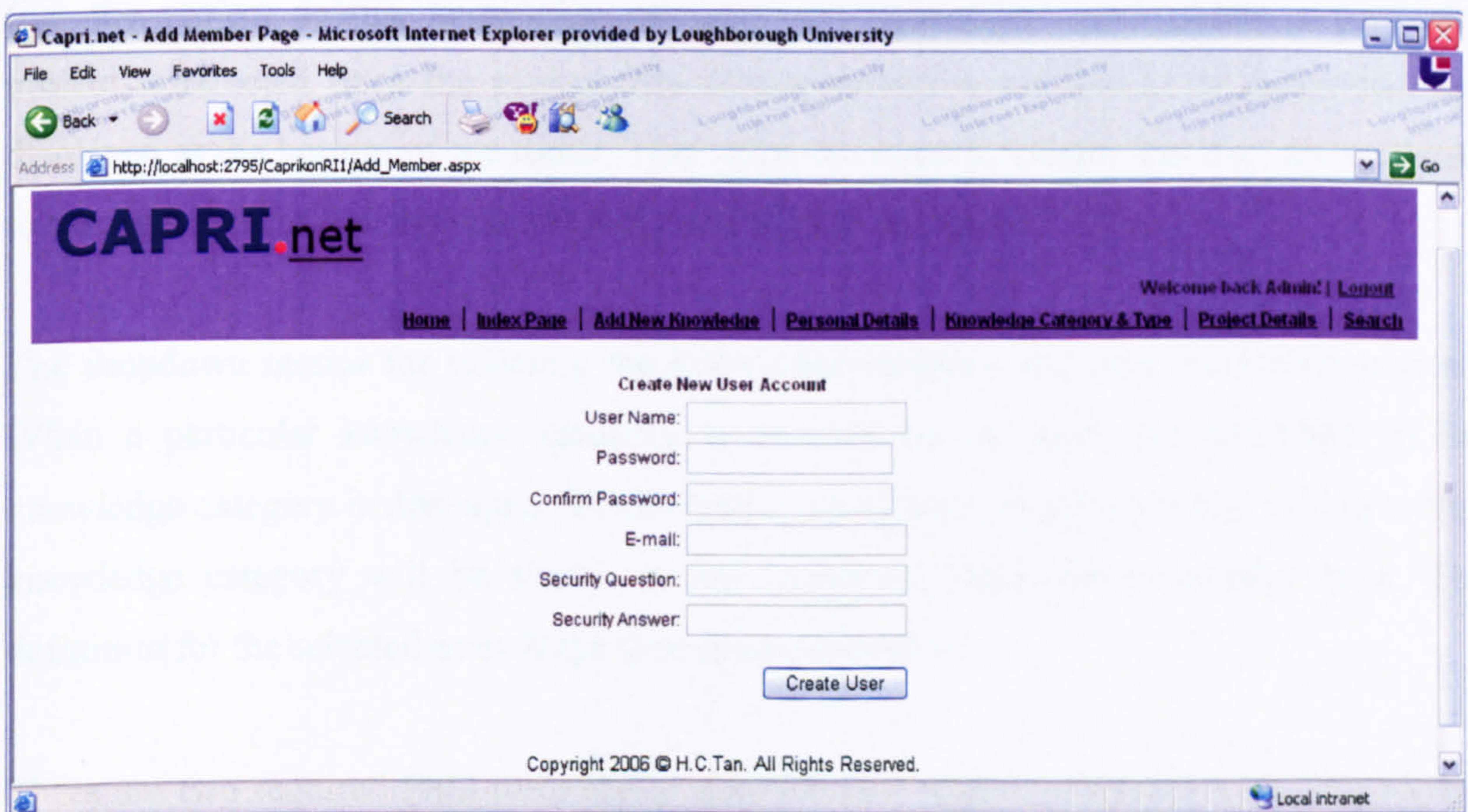


Figure 6.25: Screen shot of the Add New Member Page

The screenshot shows a Microsoft Internet Explorer window titled 'Capri.net - Add Member Details - Microsoft Internet Explorer provided by Loughborough University'. The address bar contains 'http://localhost:2795/CaprikonRI1/Add_Members_Details.aspx'. The main content area displays a form titled 'Add New Member's Details' with the following fields and controls:

- User Name:
- First Name:
- Last Name:
- Company:
- Position:
- Tel:
- Mobile:
- Fax:
- Email:
- Receive Email?:
- Photo:
-

At the bottom of the page, there is a copyright notice: 'Copyright 2006 © H.C.Tan. All Rights Reserved.' and a 'Local intranet' indicator in the bottom right corner.

Figure 6.26: Screen shot for adding further details of a new member

6.6.8 Add New Knowledge

The 'Add New Knowledge Page' is accessible through the hyperlink available at the top of every page (see Figure 6.27). The page is characterised by three dropdown menus which provide a user friendly means for entering repetitive information about a knowledge item (i.e. the project details, knowledge category and knowledge type). When a particular project is selected from the project title dropdown menu, the details of the project are displayed at the bottom of the menu. This helps the users to ensure that they are referring to the right project (i.e. the one where the knowledge is captured from).

The dropdown menus for selecting the knowledge category and type are interconnected. When a particular knowledge category is selected by the user, the definition of the knowledge category is displayed. Meanwhile, a list of knowledge types that belong to that knowledge category will be shown in the dropdown menu for knowledge type. The definition for the selected knowledge type is also displayed.

There are two required field information that the user must complete (i.e. the knowledge topic and knowledge details) before clicking the upload button. Otherwise, a warning

message will be shown (see Figure 6.28). Occasionally, there is some restriction as to the usage of a knowledge captured. For instance, a knowledge item which is captured from a PFI hospital project may be only valid in the context of the PFI hospital projects. Therefore, the user should stipulate the restriction or condition for reusing a knowledge item in the section provided. If no condition for reuse is specified, this section will be tagged as 'Not Available' by the system. The user also needs to specify where the knowledge is captured from, i.e. either from project meetings/reviews or personal experience (individual).

Two upload functions are provided: one for uploading non-image files and another for image files. The user can click to select relevant images and other non-image files to upload into the system using the appropriate upload functions. The user can also provide a short description on the content of the document or image files in the textbox provided. If the user is in doubt about what information should be provided in the various sections, a screen tip will pop out when the mouse cursor hovers over the respective yellow 'info' tag. After providing all the details, the user can click on the upload button to enter the knowledge into the system. An email notification will be sent instantly to all users who have opted to receive it.

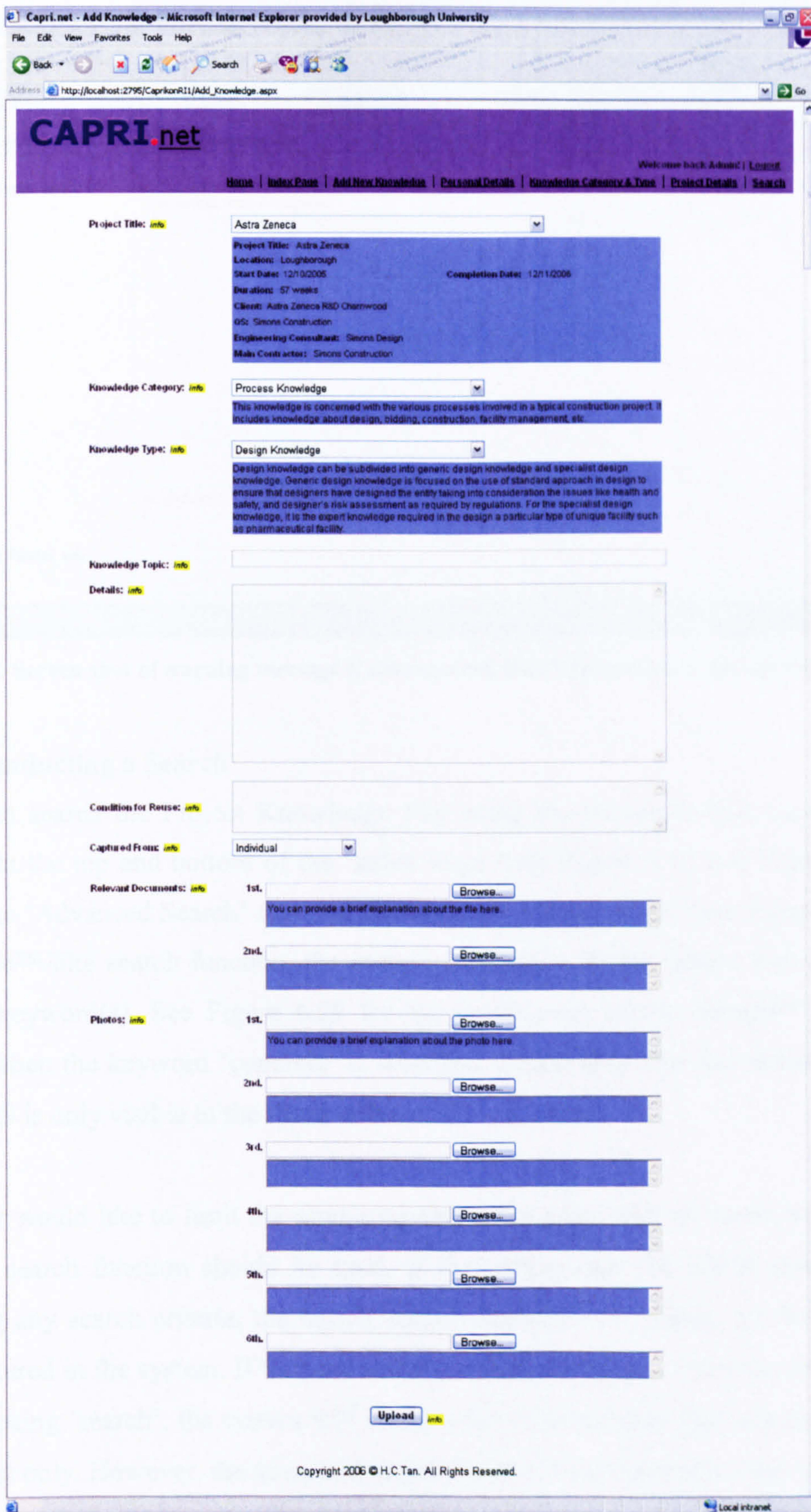


Figure 6.27: Screen shot of the 'Add Knowledge Page'

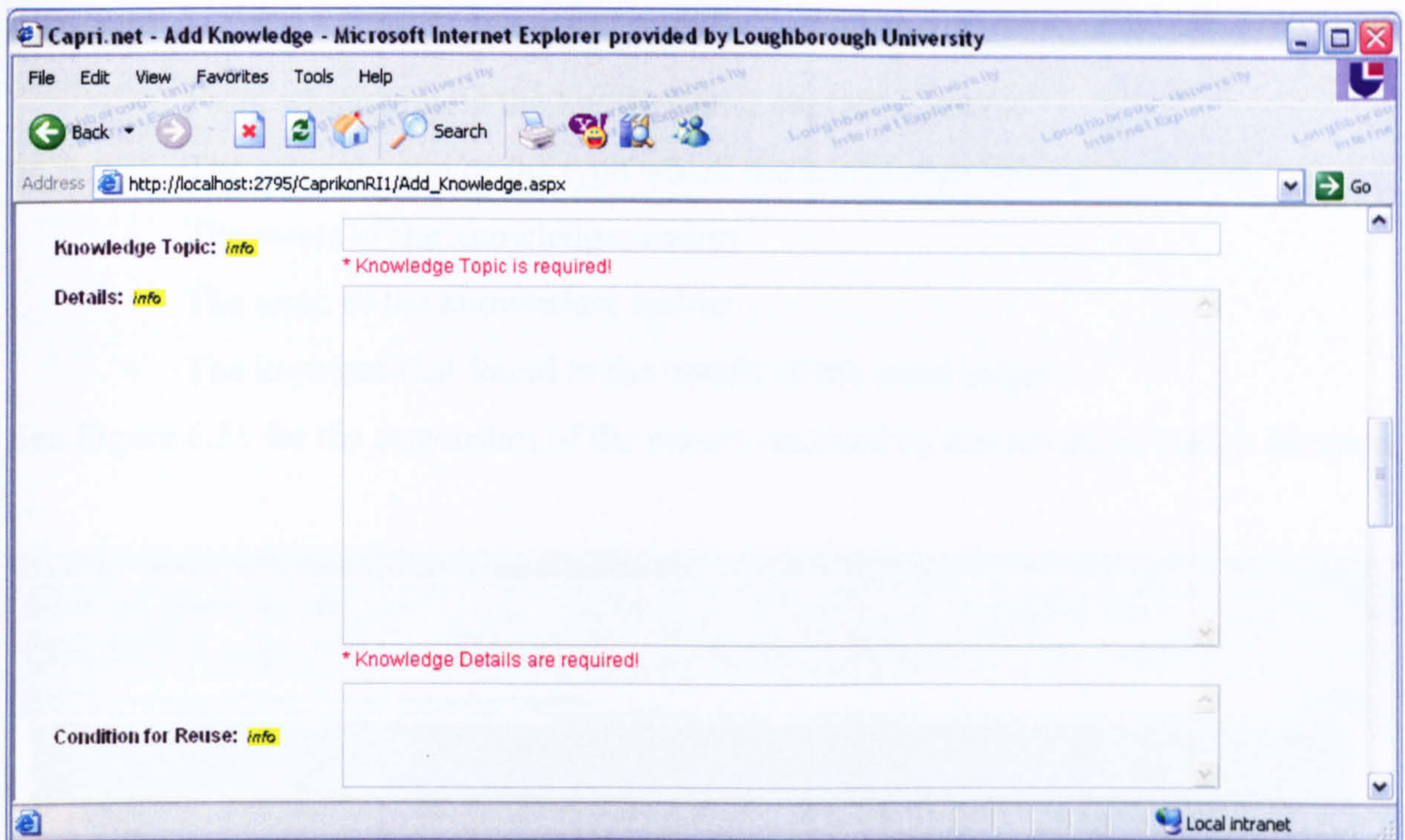


Figure 6.28: Screen shot of warning message if the required field information is not provided

6.6.9 Conducting a Search

A user can search the Project Knowledge File using the Google™-like search function available at the top and bottom of the 'Index Page' (see Figure 6.16 and Figure 6.29), or through the 'Advanced Search' function found on the 'Search Page' (see Figure 6.30). For the Google™-like search function, the system will return all the results that contains the searched keyword(s). See Figure 6.29 for the result page of the Google™-like search function when the keyword 'concrete' is searched. Please note that the 'delete' button in Figure 6.29 is only visible to the PKM only.

If the user would like to limit the search results to the most relevant items only, then the advanced search function should be used. If the user selects the search button without specifying any search criteria, the search results returned will contain all the knowledge items captured in the system. If the user selects a particular project from the dropdown list before clicking 'search', the system will return a list of knowledge that was captured from that project only. However, the advanced search function also allows the user to narrow the search result by specifying a combination of details about the knowledge searched. These

include:

- From which project the knowledge is captured; and/or
- The category and/or the type which the knowledge belongs to; and/or
- The status of the knowledge; and/or
- The topic of the knowledge; and/or
- The keyword that found in the details of the knowledge.

See Figure 6.31 for the screenshot of the results returned by the advanced search function.

ID	Knowledge Topic	Knowledge Category	Knowledge Type	Project Title	Date Entered	Captured From	Status	Author	Email
Delete 164	Concreting for improved speed and efficiency	Process Knowledge	Construction methods and techniques	Non Project Specific	14/03/2006	Individual	Validated	Admin	Click Here
Delete 165	Early striking and improved backpropping for efficient flat slab construction	Process Knowledge	Construction methods and techniques	Non Project Specific	14/03/2006	Individual	Validated	Admin	Click Here
Delete 167	Early age strength assessment of concrete on site	Process Knowledge	Construction methods and techniques	Non Project Specific	16/03/2006	Individual	Validated	Admin	Click Here
Delete 186	Early age strength assessment of concrete on site	Process Knowledge	Construction methods and techniques	GlaxoSmithKline	03/04/2006	Individual	Validated	SMajor	Click Here
Delete 159	Recommendations for the efficient and economic reinforcement of concrete flat slabs	Process Knowledge	Design Knowledge	Non Project Specific	14/03/2006	Individual	Validated	Admin	Click Here
Delete 160	The benefits of using flat slab construction to improve construction efficiency	Process Knowledge	Design Knowledge	Non Project Specific	14/03/2006	Individual	Validated	Admin	Click Here
Delete 168	Prefabricated punching shear reinforcement for reinforced concrete flat slabs	Process Knowledge	Design Knowledge	Non Project Specific	16/03/2006	Individual	Draft	Admin	Click Here
Delete 161	Improving rebar information and supply	Process Knowledge	Planning	Non Project Specific	14/03/2006	Individual	Draft	Admin	Click Here

Figure 6.29: Screenshot of the result page of the Google™ - like search function

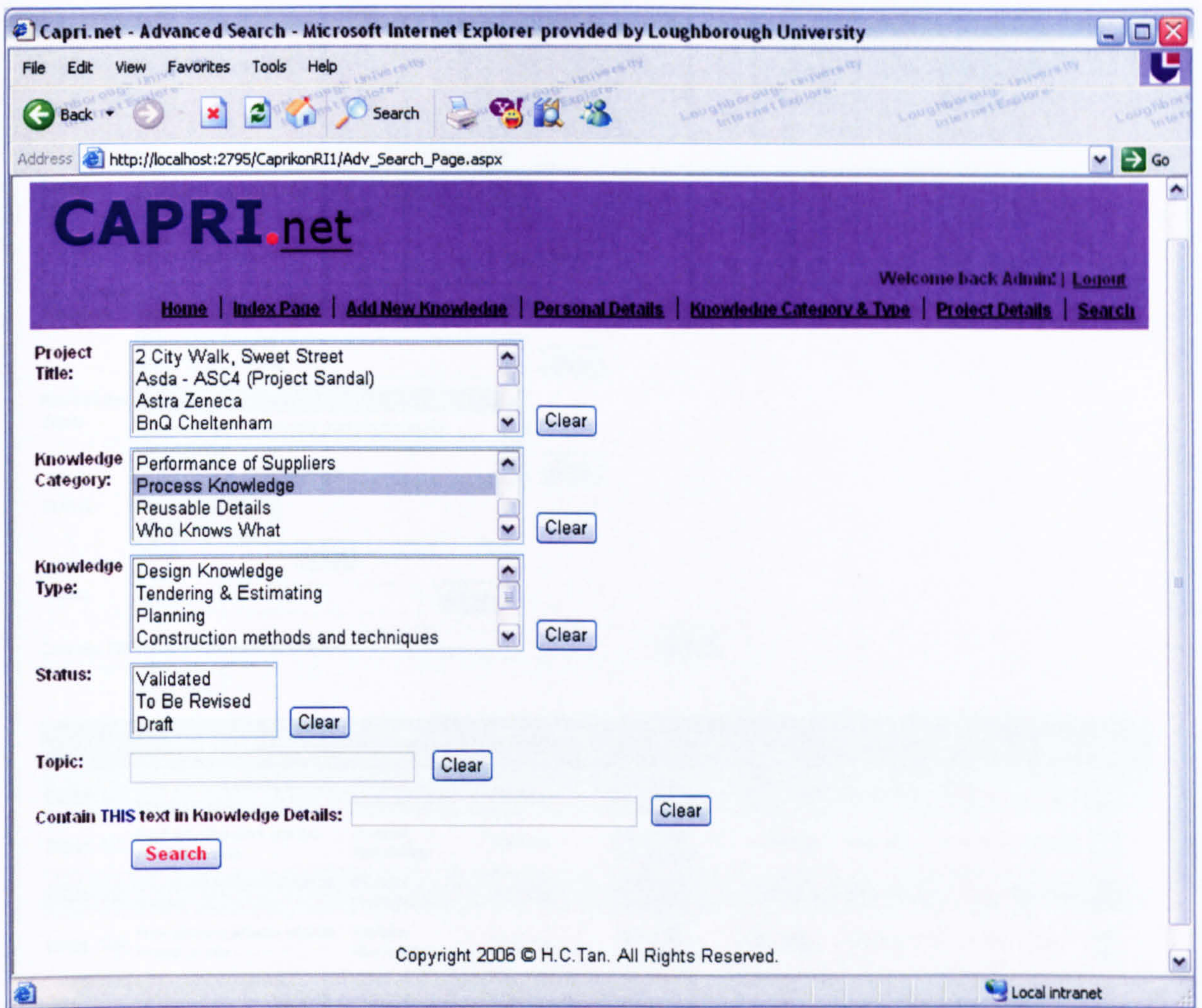


Figure 6.30: Advanced search function

Project Title: 2 City Walk, Sweet Street
 Asda - ASC4 (Project Sandal)
 Astra Zeneca
 BnQ Cheltenham

Knowledge Category: Performance of Suppliers
 Process Knowledge
 Reusable Details
 Who Knows What

Knowledge Type: Planning
 Construction methods and techniques
 Buildability
 Operation & maintenance

Status: Validated
 To Be Revised
 Draft

Topic: issues

Contain THIS text in Knowledge Details:

Search

ID	Knowledge Topic	Knowledge Category	Knowledge Type	Project Title	Date Entered	Captured From	Status	Author	Email
Delete 184	How planning affects access issues on site	Process Knowledge	Planning	2 City Walk, Sweet Street	03/04/2006	Individual	Validated	Admin	Click Here
Delete 115	Roof mounted plant and the acoustic issues	Process Knowledge	Planning	2 City Walk, Sweet Street	14/04/2005	Individual	Validated	APalmer	Click Here
Delete 112	Lift - Separate synchronisation issues	Process Knowledge	Planning	2 City Walk, Sweet Street	20/01/2005	Individual	Validated	APalmer	Click Here
Delete 104	How planning affects access issues on site	Process Knowledge	Planning	2 City Walk, Sweet Street	30/09/2004	Individual	Validated	Admin	Click Here

Figure 6.31: Screen shot of the results returned by the advanced search function

The details of the feedbacks and suggestions for improvements for the prototype application obtained from the evaluation are presented in Chapter 7.

Chapter 7 Testing and Evaluation of Methodology

This chapter describes the definitions, procedures and results of the methodology adopted for the testing and evaluation of the prototype application developed. Two types of test - Acceptance Test and Entity-Life Histories Test were first conducted on the prototype application. Evaluation of the prototype application was subsequently undertaken by a selection of industry practitioners who participated in the case study described in Chapter 5, which aided in the development of the 'live' methodology. Based on the findings of the evaluation, the prototype application was further refined.

7.1 Introduction

Software testing is the process of executing computer software in order to determine whether the results it produces are correct (Glass, 1979) and to uncover evidence of defects (McGregor and Sykes, 2001). It is the examination of the behaviour of a program on sample data sets (Adrion et al., 1982). According to Ould and Unwin (1986), two terms that frequently come across in the testing literature are *validation* and *verification*. Verification is the testing of an object against its specifications (Ould and Unwin, 1986), or "Are we building the product right?" (Sommerville, 2001). Validation is the process of confirming that a deliverable matches the user's expectations (Ould and Unwin, 1986), and is concerned with "Are we building the right product?" (Sommerville, 2001). An important classification of the tests available are the black-box and white-box dichotomy (Roper, 1994). Black-box techniques are also called 'functional' or 'specification-based' techniques (Roper, 1994). Black-box testing verifies the output is correct for a given input without verifying the process that produced the output (Hutcheson, 2003). White-box techniques may be referred to as 'structural' or 'code-based' technique (Roper, 1994). White-box testing examines and verifies the process by which programme functions are carried out (Hutcheson, 2003).

For software evaluation, it is the quality management process of software development conducted to determine the deviation from desired behaviour of specific software products and is used to monitor the outcome of procedural changes made to improve product quality

(McDaniel, 2002). Some overlap of the functions of software testing and software evaluation in the literature are observed. Although the definitions of software testing tend to refer to *program* (i.e. the software codes) testing only (Roper, 1994), it has also been broadly defined to cover the scope of software evaluation. For instance, Hetzel (1993) defines testing as any activity aimed at ‘evaluating’ an attribute or capability of a program or system. However, as various aspects of the software will be assessed in software evaluation (Vlahavas et al., 1999), the testing aspect of software may be covered as well. To avoid confusion, it is appropriate to distinguish between the testing and evaluation of software. Hence, for the purpose of this research, testing is regarded as an examination of the functionalities of the software to ensure that it is free from error. Evaluation is regarded as the subsequent process conducted to obtain external views from users or potential users on whether the software has addressed its design requirements and to identify further refinements to the software. Therefore, in the context of this research the term testing is closely related to the “verification”, whereas evaluation is more concerned with “validation” aspect respectively. The details of the testing and evaluation undertaken were as follows:

7.2 Prototype Testing

The selection of tests to be performed is dependent on the aspects of the software to be tested (such as integration test to examine the communication between modules), and is restricted by time and resource constraints. Due to time constraints, extensive tests such as life-cycle testing (Roper, 1994) and hierarchical approach testing (McGregor and Sykes, 2001) which involve a series of different tests at different development levels of a software, were considered inappropriate. Moreover, as the main objective for the test was to ensure that the prototype will work as intended for the purpose of the evaluation, a Statement Test and Entity-Life Histories Test (which examine the functions of the prototype against those stipulated in the design requirements) are more relevant. A Statement Test is conducted to ensure that all the sub-tasks attributed to a function work in the way they are supposed to do. Entity-Life Histories Tests are conducted to ensure that all of the potential combinations of functions performed to the entity (e.g. reusable project knowledge) can be executed and will give the required result. In other words, the Entity-

Life Histories Test is to ensure that the whole system will work as expected. This combination of tests inclined towards the black-box approach. The details of the test procedures are described in the following sections.

7.2.1 Statement Test

This is the acceptance tests on the requirements (i.e. statements) for the design of software. Each of the requirements comprises an input action to be performed on the software application and an expected output of the input. In order to pass the test, the real output must match with the expected output. The details of the requirements of the prototype application that were tested are depicted in Table 7.1.

The test results reveal that all the test inputs delivered the expected outputs. This means that the prototype application passed the Statement Test. Table 7.1 provides details of the test results. The prototype application was subsequently subjected to another test (i.e. the Entity-Life Histories Test) before its evaluation was conducted. The details are presented in Section 7.2.2.

Table 7.1: Test results of the Statement/Requirement Test

Input	Expected output	Result
Log into the system using individual user name and password	<ul style="list-style-type: none"> • Login succeeded 	Achieved
Log out from the system	<ul style="list-style-type: none"> • Log out succeeded 	Achieved
Add project details into the system (PKM only)	<ul style="list-style-type: none"> • Project details added into system • Duration of project calculated automatically based on the start and completion dates entered 	Achieved Achieved
Edit project details (PKM only)	<ul style="list-style-type: none"> • Project details edited • Duration of project updated automatically based on the start and completion dates entered 	Achieved Achieved
Add new user (PKM only)	<ul style="list-style-type: none"> • New user added 	Achieved
Add personal details into the system	<ul style="list-style-type: none"> • Personal details added into system 	Achieved
Edit personal details	<ul style="list-style-type: none"> • Personal details edited 	Achieved
Add a new knowledge category and its definition	<ul style="list-style-type: none"> • Knowledge category and its definition added into system 	Achieved
Add a new knowledge type and its definition	<ul style="list-style-type: none"> • Knowledge type and its definition added into system 	Achieved
Add a knowledge item, where the knowledge should be tagged as "draft"	<ul style="list-style-type: none"> • Knowledge details added into system 	Achieved Achieved

or “validated” based on its source	<ul style="list-style-type: none"> • Knowledge captured from individuals and groups are tagged as “draft” knowledge and “validated” knowledge respectively • Date of entering knowledge inserted automatically • Details of the author captured automatically • Index page and summary page updated • Email notification sent 	Achieved Achieved Achieved Achieved
Delete a knowledge item (PKM only)	<ul style="list-style-type: none"> • Knowledge removed from system • Index page and summary page updated 	Achieved Achieved
Search for a knowledge entry using:		
Google™-like search function	<ul style="list-style-type: none"> • Details of relevant knowledge, and the associated author and project details returned 	Achieved
Advanced search function (i.e. through a combination of knowledge title, knowledge category, project name, and project type)	<ul style="list-style-type: none"> • Details of relevant knowledge, and the associated author and project details returned 	Achieved
Access to Knowledge		
Click to access the summary page (i.e. the default.aspx page)	<ul style="list-style-type: none"> • The summary and abstract of the latest five knowledge items added displayed • List of the knowledge items that are either tagged as ‘draft’ or ‘to be revised’ shown 	Achieved Achieved
Click to access a knowledge item	<ul style="list-style-type: none"> • Details of knowledge, and the associated author and project details returned 	Achieved
Click to access relevant documents through the hyperlinks	<ul style="list-style-type: none"> • Dialogue box for either opening or downloading the files displayed 	Achieved
Click on the relevant hyperlink to access the author’s details	<ul style="list-style-type: none"> • Author’s details displayed 	Achieved
Click on the relevant hyperlink to send email to the author	<ul style="list-style-type: none"> • Depending on the default email client of the computer used, the template for writing email displayed 	Achieved
Click on the photo/image shown on the page representing a knowledge item	<ul style="list-style-type: none"> • The photo/image displayed in its original (which is normally larger) size 	Achieved
Click on the ‘knowledge category’ menu to access the knowledge that falls under a special category	<ul style="list-style-type: none"> • The list of all of the knowledge that fall under that category displayed 	Achieved
Configure system on:		
Interval for sending routine email reminders (PKM only)	<ul style="list-style-type: none"> • Email reminders sent in accordance to the interval set 	Achieved
The option for receiving email notifications when a new knowledge item is added	<ul style="list-style-type: none"> • Email notification sent to the user if s/he has chosen to receive email notification • No email notification sent to the user if s/he has chosen not to receive email notification 	Achieved Achieved
Knowledge Validation		
Add comment about a knowledge item	<ul style="list-style-type: none"> • Comment added • Details of the user who submitted the comment captured 	Achieved Achieved
Add rating for a knowledge	<ul style="list-style-type: none"> • Rating added • Average rating updated 	Achieved Achieved
Access the knowledge validation function/control (PKM)	<ul style="list-style-type: none"> • The knowledge validation function/control is made visible to the PKM only 	Achieved
Change the status of the knowledge from “draft” to “validated” (PKM only)	<ul style="list-style-type: none"> • Knowledge status changed; email notification sent 	Achieved

	<ul style="list-style-type: none"> • Index page and summary page updated 	Achieved
Change the status of the knowledge from "draft" to "to be revised" (PKM only)	<ul style="list-style-type: none"> • Knowledge status changed • Index page and summary page updated; email notification sent 	Achieved Achieved

7.2.2 Entity-Life Histories Test

Entity-Life Histories (ELHs) describe the life cycle of a knowledge item, from its creation in the system through all the actions performed on it, to its removal from the system (Roper, 1994). The life history of a knowledge item starts when it is being captured into the system, where it may subsequently be validated and hence shared, or removed from the system if rejected. While the knowledge item is captured in the system, it may be searched for and referenced any number of times. When the knowledge has become obsolete or is rejected, the knowledge item may be removed from the system. The life history of a knowledge item is depicted in Figure 7.1. Attached to Figure 7.1 are numbers that represent functions executed at particular stages in the life history of a knowledge entity. See Table 7.2 for the descriptions of the functions.

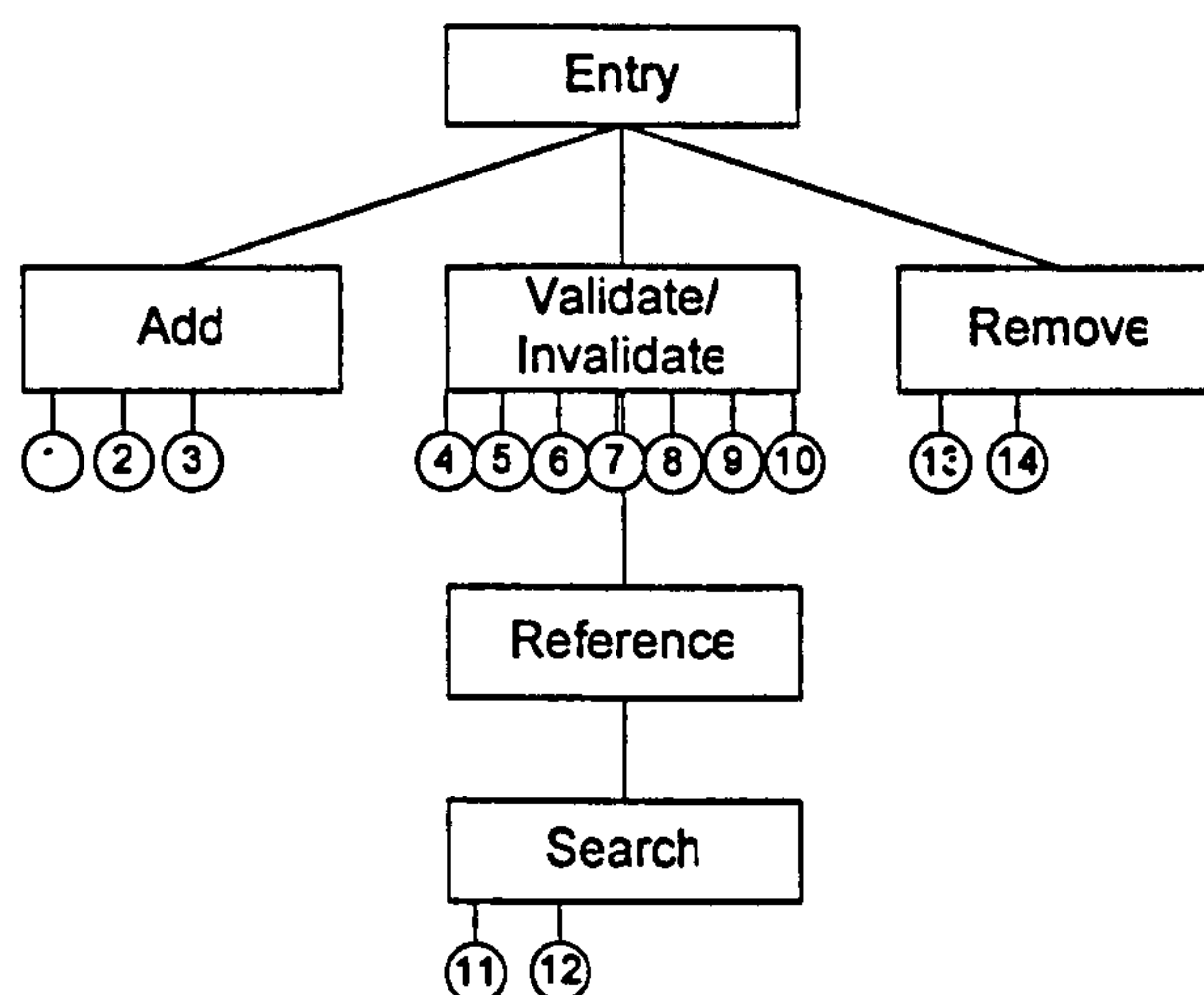


Figure 7.1: Entity-life history for entry

Table 7.2: Entity-Life Histories

Add	<ol style="list-style-type: none"> 1. Read and validate entry details 2. Add entry into system 3. Send email notification
Validate	<ol style="list-style-type: none"> 4. Read entry key 5. Display for validation 6. Read rating and comments given (i.e. either to approve or reject the knowledge) 7. Write rating and comments option into system

	8. Compute outcome of validation 9. Display outcome of validation (if approved, the status of knowledge is changed from draft to validated knowledge; otherwise, the knowledge is removed from the system) 10. Send email notification
Search	11. Read search details 12. Display corresponding entry details
Remove	13. Read entry key 14. Remove from system

The possible life histories experienced by a knowledge entity include:

- Possibility 1: Add, Search;
- Possibility 2: Add, Invalidate, Remove;
- Possibility 3: Add, Search, Invalidate, Remove;
- Possibility 4: Add, Validate, Search, Remove (when a knowledge item becomes obsolete); and
- Possibility 5: Add, Search, Validate, Search, Remove (when a knowledge item becomes obsolete).

These generate the test requirements shown in Table 7.3 where the double horizontal lines separate distinct sets of test data. The test results are also shown in Table 7.3. The test result revealed that the prototype application passed the test on all the four possibilities of a knowledge item's life-history. This shows that the prototype application can perform all the operations on a knowledge item as designed and that the prototype application is ready for the evaluation.

Table 7.3: System test based on a test of the ELH (with and without built-in validation mechanism)

System test		
Input	Expected output	Result
<u>Possibility 1:</u>		
Add a knowledge	Knowledge added into system; email notification sent; index page updated	Achieved
Remove the knowledge	Knowledge removed from system; index page updated	
<u>Possibility 2:</u>		
Add a knowledge	Knowledge added into system; email notification sent; index page updated	Achieved
Search for the knowledge	Knowledge details returned	
Remove the knowledge	Knowledge removed from the system; index page updated	
<u>Possibility 3:</u>		
Add a knowledge	Knowledge added into system; email notification sent; index page updated	Achieved
Validate the knowledge	Status of knowledge updated; index page updated; email notification sent	

Search for the knowledge	Knowledge details returned	
Remove the knowledge	Knowledge removed from the system; index page updated	
Possibility 4:		
Add a knowledge	Knowledge added into system; email notification sent; index page updated	
Search for the knowledge	Knowledge details returned	
Validate the knowledge	Status of knowledge updated; index page updated; email notification sent	Achieved
Search for the knowledge	Knowledge details returned	
Remove the knowledge	Knowledge removed from the system; index page updated	

7.3 Prototype Evaluation

This section describes the evaluation and associated results of the prototype application developed. The most useful features of the prototype application identified and the participants' suggestions for improvements are also presented.

7.3.1 Evaluation Procedure

It is crucial to ensure consistency in the end-users' requirements identified from the case studies for the development of the methodology for 'live' capture of project knowledge and the prototype application which was developed accordingly for the purpose of the evaluation. To achieve this, the evaluation involved ten participants from four companies which were involved in the previous case study (i.e. Companies A, B, D and E). Out of the ten participants, nine had participated in the case studies conducted which led to the development of the methodology. However, the tenth participant was also well informed of the development progress of the methodology through his colleague. The participants from the other two case study companies (i.e. Companies C and F) were unable to participate due to unforeseen circumstances.

Most of the evaluations were conducted on one-to-one basis with the exception of Company A. The evaluation started with a brief introduction of the concept of 'live' capture and reuse of project knowledge in construction. This was followed by the demonstration of the various features and operations of the prototype application. Subsequently, the participants were allowed to experiment with the prototype application by themselves. Guidance was given to the participants whenever necessary. An evaluation questionnaire was then given to the participants to complete. The details of the

questionnaire are presented in the next section.

7.3.2 Questionnaire Design

A questionnaire (see Appendix G) was designed to evaluate the prototype application against the end-users' requirements for developing the methodology for 'live' capture and reuse of project knowledge. The questionnaire comprised three main sections. Section A covered the background information about the participant while Section B consisted of twelve questions about the prototype application. The questions were further grouped into three sub-sections: Section 1 - Capture of knowledge, Section 2 - Representation of knowledge, Section 3 - Sharing/Reuse of knowledge, and Section 4 - Ease of use. The participants were requested to provide their answers to the questions using a rating scale from 1 (very poor) to 5 (excellent). Section C provided an opportunity for the participants to identify the most useful features of the prototype application and to put forward their suggestions for improvements to the prototype application.

7.3.3 Evaluation Results

The prototype application scored an average 3.9 out of 5.0 in the evaluation. The results based on the analysis of the completed questionnaires are depicted in Table 7.4. The average ratings of the various sections are presented in subsequent sections.

Table 7.4: Ratings of key features of the prototype application

Sections	Average Rating (Out of 5)
<i>Section 1: Capture of Knowledge</i>	
1.1 How well does the system enable project knowledge to be captured 'live' (i.e. as soon as possible after a knowledge is created or identified)?	4.3
1.2 How complete is the system in capturing the details of a knowledge?	4.1
1.3 How well does the validation mechanism ensure the accuracy and correctness of knowledge captured?	3.7
1.4 How well does the system cope with avoiding the creation of additional workload?	3.4
<i>Section 2: Representation of Knowledge</i>	
2.1 How well does the index page provide users an overall view of all the knowledge captured in the system?	4.1
2.2 How well is knowledge organised in the system?	4.1
2.3 How well does the template represent the knowledge captured?	3.9
<i>Section 3: Sharing/Reuse of Knowledge</i>	

3.1	How well does the system facilitate the sharing of the project knowledge captured (i.e. through the provision of access to the knowledge captured through Web, links to additional information in the template for representing knowledge, the search function provided, etc.)?	4.1
3.2	How well does system achieve the concept of the 'live' sharing of project knowledge captured from a project (i.e. through allowing users to access of the knowledge via Web and sending email to users once new knowledge is added into the system)?	3.9
3.3	How reusable is the knowledge captured (i.e. during a subsequent project stage or on another project)?	3.6
<i>Section 4: Ease of Use</i>		
4.1	How good is the search function in locating the knowledge required?	4.1
4.2	How easy is the system to use overall?	4.3

7.3.3.1 Capture of Knowledge

The participants found the prototype application very capable of enabling the 'live' capture of project knowledge. A high average rating of 4.3 was given to this question. The participants were also highly satisfied with the prototype application's capability in terms of capturing the details of reusable project knowledge. This was evident by the average rating of 4.1 given by the participants. The third question (i.e. Question 1.3 in Table 7.4) on the validation mechanism of the prototype application received an average rating of 3.7. This reveals that the participants were confident that the adopted mechanism can help to ensure the accuracy and correctness of the reusable project knowledge captured. A satisfactory average rating of 3.4 was received on how well the overall methodology copes with avoiding the creation of additional workload. The comparatively lower average rating received was due to a rating of 2.0 given by two participants. They saw the need to adapt their companies' existing procedures to fully implement the methodology as an additional workload. However, four of the ten participants acknowledged that it was impossible to totally avoid the creation of additional workload, but that created by the methodology was acceptable to them. This group of participants gave a rating of 3.0 for this question. Furthermore, there were also four participants who felt that the additional workload created was negligible. They gave a rating of 5.0, 4.5, 4.0 and 4.0 respectively.

7.3.3.2 Representation of knowledge

The prototype application was recognised as very effective in representing the reusable project knowledge captured, where an average rating of 3.9 was given by the participants.

Related to this, the participants also gave an average rating of 4.1 for both the way the index page provides users an overall view of all the knowledge captured in the system and the way knowledge is organised in the system.

7.3.3.3 *Sharing/Reuse of knowledge*

The methodology developed excelled in facilitating and realising the concept of 'live' sharing of the reusable project knowledge captured. It received an average rating of 4.1 and 3.9 for these areas respectively. The methodology was also found useful in facilitating the reuse of the project knowledge captured. This was evident by the average rating of 3.6 given by the participants to this question.

7.3.3.4 *Ease of use*

The search functions (i.e. the Google™-like and the advanced search functions) received a high average rating of 4.1. This showed that the search functions of the prototype application are very efficient in helping the users to locate the required knowledge in the system. The prototype application was also perceived by the participants as very easy to use with a very high average rating of 4.3.

7.3.4 **Suggestions for Improvement**

Participants described the prototype application as: '*overall excellent method of capturing knowledge*', '*like the simplicity and general index page that offers quick links to knowledge*', '*good interface design*', '*good search function*', '*format is clear*', '*easy to use*', '*not difficult to pick up and appears easy to work with*' and '*easy to navigate*'. They further pointed out that it is very easy to add relevant information and documents into the system, and that the 'time to add the knowledge is modest and will encourage use'. This proved that the methodology had successfully addressed the critical end-user requirements that significant additional workload is not desired. However, some suggestions for improvement were also received. These include:

- a) Create a mechanism for recording the quantity of hits on each knowledge item;
- b) Integrate built-in viewers for certain document types into the prototype application (e.g. Voloview for viewing AutoCAD files);

- c) Provide an audit trail for revisions made to the knowledge captured; and
- d) Needs a disclaimer to indemnify the author of a knowledge item against the legal consequences of misuse or others relying on the accuracy and correctness of the knowledge.

A suggestion to automatically send out email notification when the status of a knowledge item is updated had been incorporated into the prototype application. The topic and textual details of the knowledge item can also be attached to the email notification sent. Suggestions (a), (b) and (c) entail extensive development in order to deliver the desired features and were hence not incorporated into this version of prototype. The preparation of a disclaimer might be essential for knowledge capture activities involving different organisations, but this is better drafted by legal professionals.

Some suggestions related to the future development of the prototype application. A participant suggested integrating the prototype application with other existing knowledge based systems in an organisation. The prototype application will then become the core of the integrated system which allows a search across different systems to be conducted through it. Others saw the potential to commercialise the prototype application and proposed that a business case for this purpose be developed. These suggestions have been carefully considered and would be further explored in the future as appropriate.

The following chapter presents the conclusions drawn from the research and the recommendations for further research.

Chapter 8 Conclusions and Recommendations

This chapter concludes the research that investigated the development of a methodology for 'live' capture and reuse of project knowledge. It summarises the research undertaken, highlights the key conclusions and makes the recommendations for further research. The limitations of the research are also outlined.

8.1 Summary

The aim of the research was to develop a methodology for 'live' capture and reuse of project knowledge in construction that will reflect both the organisational and human dimensions of knowledge capture and reuse, as well as exploit the benefits of technology. The rationale for conducting the research was to address the knowledge loss problem due to the time lapse in capturing important knowledge from a project. The aim was achieved following the successful development and the positive evaluation result received for the aforementioned methodology. The methodology developed comprises a Web-based knowledge base, and Integrated Workflow Systems and a Project Knowledge Manager. Various methodologies were used to achieve the objectives of the research, namely extensive literature review, case study, workshop, and the evaluation of the methodology developed. The results achieved through the methodologies are summarised below.

Extensive literature review on knowledge management was first carried out to gain the essential understanding on the subject in sufficient detail. Knowledge management processes which comprise knowledge capture, knowledge sharing, knowledge reuse and knowledge maintenance were proposed. Literature review also revealed the heavy reliance on post project reviews, the reassignment of people across projects, and the contractual and organisational arrangements for the transfer of knowledge in the construction industry. The various shortcomings of the existing practice in managing project knowledge effectively were uncovered. Capturing knowledge through post project reviews were found less successful mainly due to the time constraints for conducting it upon the completion of a project and the knowledge loss due to time lapse in capturing the knowledge gained. Reassignment of people from one project to another was undermined by the high staff

turnover in the industry and the weakness of human memory in memorising facts which it depends on for knowledge transfer. The attempt to facilitate the sharing of knowledge through contractual and organisational arrangements also suffered from the fact that organisations collaborate on one project might be in competition in another project which have made them reluctant to share critical knowledge. This was further aggravated by the corporate restrictions imposed on posting of knowledge and information.

Further review of existing literature suggested the need for a methodology that facilitates the capture and reuse of important knowledge from ongoing projects once it is created or identified (i.e. 'live') across geographical boundary. It was established that the methodology could address the aforementioned knowledge loss problem which is due to time lapse in capturing knowledge from projects and staff turnover. Furthermore, it would enable the knowledge captured from initial stages of a project to be reused at the later stages of a project, help to seize every knowledge reuse opportunity which would in turn help to maximise the value of reusing the knowledge captured.

The novelty of the aforementioned methodology was confirmed in subsequent literature review. A number of research projects conducted to address the various issues of managing knowledge in construction were identified from existing literature. However, these research projects were focused at either strategic and business perspectives, specific types of knowledge, specific project phases, or specific type of construction organisation. The need for an approach which is capable of capturing project knowledge, irrespective of the type of project, the type of construction organisation and project phases, and particularly capturing the knowledge 'live', has not been adequately addressed. Research at Stanford (Reiner and Fruchter, 2000) was considered as being closest to the goal of 'live' capture and reuse of project knowledge. Nonetheless, the research did not cover the entire project but focused only on the design evolution stage. Hence, a case for developing the methodology was made.

Various concepts were explored, in particular learning histories (Kleiner and Roth, 1996) and Collaborative Learning (Digenti, 1999), in terms of the capability to facilitate the 'live'

capture and reuse of project knowledge. The study of Collaborative Learning had indirectly led to the design of the methodology to capture knowledge through project meetings or reviews. This was because Collaborative Learning showed that the interactions among the members of a team can help to reveal and share their tacit knowledge. An insight was also gained from “learning histories” on how a standard format for representing the knowledge, as required by the case study companies, can possibly be designed.

The nature and characteristics of reusable project knowledge, the current practice for capturing reusable project knowledge in construction and the end-user requirements for the design of the methodology were identified through the six case studies conducted. A wide spectrum of reusable project knowledge were identified from the case study. The knowledge identified were aligned and grouped into the following categories: Process Knowledge, Knowledge of Clients, Costing Knowledge, Knowledge of Legal and Statutory Requirements, Knowledge of Reusable Details Knowledge of Best Practices and Lessons Learned, Knowledge of Performance of Suppliers, Knowledge of Who Knows What, and Other Types of Knowledge. Reusable project knowledge was found to exist as a mix of tacit and explicit knowledge, rather than as distinctive tacit or explicit knowledge alone. As a result, the methodology was designed to explicate tacit knowledge into explicit knowledge as far as possible and to help to connect people to the very tacit knowledge which is extremely difficult to explicate.

The end-user requirements for the development of the methodology for ‘live’ capture and reuse of project knowledge in construction identified were as follows:

- The methodology must facilitate the capture and access of project knowledge ‘live’ (i.e. as soon as possible once knowledge is created or identified) and across geographically dispersed offices;
- The methodology should not create significant additional cost and workload to the companies;
- An appropriate legal framework is required to overcome the client’s potential restriction or copyright problem on the sharing of knowledge;

- A validation mechanism is required to ensure the accuracy and correctness of knowledge before it is shared; and
- A standard format for representing the knowledge which contains the background information on the project, abstract, details, conditions for reuse and reference is required.

Various knowledge management (KM) techniques and technologies used by the case study companies for the capture of reusable project knowledge were investigated. The KM techniques used were post project reviews, communities of practice, reassignment of people, research collaboration, partnership-like arrangements, preparation of reusable details, research and development, team meetings, road shows, presentations, workshops, succession management and mentoring. The KM technologies used were Groupware, custom-designed software, expert directory and project extranet. The KM techniques and technologies used have their strengths and shortcomings, and in fact complement each other. Hence, a combination of KM techniques and technologies was selected as the most viable option for meeting the requirements for the development of a 'live' knowledge capture and reuse methodology.

A Web-based knowledge base was found to be the closest to meeting the end-user requirements identified. The reasons are as follows:

- A Web-based knowledge base allows knowledge to be entered and accessed 'live';
- No significant additional cost is required due to the pervasive use of intranets and the capability of the Web-based knowledge base to run on the existing intranet/internet systems;
- The Web-based knowledge base can be designed to be as user-friendly as possible and to capture some information automatically in order to avoid the creation of significant additional workload;
- A mechanism can be built into the knowledge base for monitoring the validation of knowledge submitted as a means of ensuring its accuracy;
- Standard templates can be created to ensure that project knowledge is entered in accordance with the format specified;

- It can provide the necessary platform for accessing and sharing knowledge which is captured in the form of video clips and other multimedia formats. It may be used in conjunction with other Web-based applications (e.g. Groupware and video conferencing tools) to enhance the sharing of knowledge, particularly the tacit knowledge.

Project meetings and reviews were chosen to capture knowledge in a group setting to ensure that a more holistic and more complete set of knowledge is captured. For security reasons and the fact that the prototype application would be accessed by users from different organisations, the prototype application was designed to run in the extranet environment.

The methodology developed, which comprises a Web-based knowledge base, an Integrated Workflow System (IWS) and a Project Knowledge Manager (PKM) as the administrator, allows project knowledge to be captured 'live' from ongoing projects. The methodology was encapsulated into a prototype application using ASP.NET Visual Basic 2.0 and Microsoft™ SQL Server 2005 Express Edition combination. The development of the prototype application was influenced by the Web IS Development Methodology (WISDM), which is specifically devised for the development of Web-based Information Systems including Web-based knowledge base. A mini workshop was conducted to refine the Integrated Workflow System and the design of the user interface prior to the commencement of the programming tasks. This helped avoid the potential introduction of changes to the design of the prototype application at later stages which might lead to significant reworks and delays. The prototype application was demonstrated to the ten participants from four organisations in the evaluation to assess the extent to which it had met the end-user requirements identified from the case study. A high overall average rating of 3.9 out of 5.0 together with positive comments from the participants were received in the evaluation. The practicality of the prototype application was also indirectly confirmed by the suggestions to commercialise the prototype application given by the participants. This signified the achievement of the research's aim.

8.2 Conclusions

Based on the findings of the research, the following conclusions are drawn:

1. The importance of knowledge management (KM) has been recognised by the construction industry with various KM techniques and technologies adopted for the capture and reuse of knowledge learned from projects. However, the industry still faces serious knowledge loss mainly due to:
 - The time lapse in capturing important knowledge from projects;
 - High staff turnover in the industry; and
 - The lack of an organised and systematic approach to the capture and sharing of reusable knowledge from projects.
2. Information and Communication Technology (ICT), particularly Web-based technology, is crucial in realising the concept of 'live' capture and reuse of project knowledge. The capture of reusable project knowledge is often confronted by the lack of a methodology to allow individuals to upload their knowledge at anytime which is convenient to them, and to access the knowledge captured at any place when they need it. The Web-based prototype application addressed these limitations and enables reusable project knowledge to be captured 'live' from an on-going project at anytime and any place, and to be shared in real-time across geographical offices.
3. The methodology for 'live' capture and reuse of project knowledge in construction developed in this study can help to minimise the knowledge loss problem by capturing project knowledge in the most timely way before the details are forgotten or the project team disbanded. By making project knowledge available for reuse once it is captured in the system, it helps to seize every knowledge reuse opportunity. Hence, it also helps to maximise the value of reusing the knowledge captured through 'live' reuse.
4. Reusable project knowledge in construction often exists as a mix of tacit and explicit knowledge, rather than as distinctive tacit or explicit knowledge alone. Any methodology developed for managing reusable project knowledge must therefore be capable of facilitating the capture and reuse of both tacit and explicit dimensions of the

knowledge. Generally, KM technologies are better for managing explicit knowledge, whereas KM techniques are crucial for the sharing of tacit knowledge. However, it was noticed from this research that KM technologies and techniques are in fact complementary. For instance, a KM technology such as 'skills directory' can help to connect the people with tacit knowledge with those who need the knowledge. On the other hand, a KM technique such as 'communities of practice' can help to direct the project team members to the right knowledge base (i.e. a KM technology) where the explicit knowledge is stored. Hence, the synergy of both KM technology and technique is required in order to better manage either tacit or explicit knowledge. Therefore, the methodology developed attempts to capture the collective view of the knowledge learned and facilitate the sharing of tacit dimension of the knowledge from a project through project meetings and reviews (i.e. a KM technique), and utilises a Web-based knowledge base (i.e. a KM technology) to facilitate the 'live' capture and reuse of the knowledge.

5. Cost and workload are the main concerns of construction organisations for the implementation of a knowledge management system. As it is notoriously difficult to justify the return on investment (ROI) for the implementation of a knowledge management system, most organisations favour a cautious approach and require that no significant additional cost and workload are created for the purpose.
6. It was observed that the implementation of knowledge management in the construction industry is very often executed without a detailed strategy nor a clear understanding of what exactly needs to be done in order to achieve the aims. Consequently, most of the approaches were adopted in a piece-meal manner without an overall strategy for how the various approaches can be synergised. This leads to the unnecessary waste of resources and less satisfactory results. It is crucial to have an overall strategy supported by the top management and a detailed action plan in order to address this problem.

8.3 Limitations of the Research

There are some limitations of this research. These include:

1. The prototype application which was developed using Microsoft's ASP.NET 2.0 can only run on Microsoft's Windows platform. Although some third party developers have developed some programmes to enable the applications developed using ASP.NET 2.0 to run on non-Windows platforms (e.g. Mono developed by Novell), these solutions are not mature yet;
2. It is recognised that wider validation of the result of the evaluation undertaken is needed as it only involved the same sources of data collection (i.e. the case study companies). In addition, there was also a lack of full representation from contractors' organisations as the views of contractor were mainly obtained from the construction division of a case study company and other interviewees based on their previous working experience in contractor organisation; and
3. It is also recognised that more time is required to fully evaluate the prototype application. This will allow more projects to be used in the evaluation to help improve the richness of the contents captured. Furthermore, this will also enable the users to provide more constructive suggestions for improvements through personal experience of using it over a reasonably long period of time. However, this was not possible in this project due to the time constraint imposed for completing a PhD study.

8.4 Further Work

For the prototype application to be effectively used in commercial environment, a number of additional features would need to be incorporated into the system whilst some existing features would need to be improved. These include:

- Improvement of the existing search functions in the prototype application. Although this received a very high rating in the evaluation conducted, the search function can be further improved to support Boolean queries (e.g. user can search for "hospital" AND "PFI" NOT "London"). The search function may even be extended to incorporate technology such as text-mining. This will help increase the precision of the search function;
- Improvement of the membership control to restrict the viewing of knowledge captured

to those projects in which the companies are involved. This is an advanced feature not available in the prototype application;

- Development of the function for the capture of the rationale for making changes to documents as outlined in the Integrated Workflow System of the methodology. This will entail the full integration of the prototype application with an electronic document management system (or a project extranet);
- Development of the other knowledge validation options (e.g. comment-based option and majority opinion-based option). These options should be made available to the PKM when configuring the system for the capture of knowledge;
- Development of a mechanism for recording the number of hits on each knowledge item;
- Integration of built-in viewers for certain document types into the prototype application (e.g. Voloview for viewing AutoCAD files); and
- Development of a mechanism to provide an audit trail for revisions made to the knowledge captured.

The research project has also revealed a number of areas for further research, which include the following:

- Explore the integration of the prototype application with other existing information systems of an organisation (e.g. customer relationship database, internal human resource database which contains staff's details, and other technical information databases). This may involve the development of a middleware application to streamline and automatically link the relevant information in other information systems with that in the prototype application. This can help to synergise the benefits brought about by the different information systems and to further enhance the richness of the prototype application's contents;
- Investigation to fully automate the methodology for 'live' capture of project knowledge. This may involve the use of software agents, which are capable of learning from the patterns of usage (e.g. through analysing the most searched key-words in the prototype application) and understanding the relationships between terminologies, to automatically locate and disseminate relevant project knowledge from the Internet and

intranet in real-time. The software application developed can be complemented by a robust way of representing the results returned to help people to understand the contents;

- Investigation of integrating the personal knowledge management systems of project team members with the organisational knowledge management systems. This may cover the development of a software application which allows individuals to capture their personal knowledge in a specified format, and share some of the knowledge (as desired) with others. This will allow others to tap into the knowledge of their colleagues in a way that is not possible through existing approaches. The software application developed may also have a built-in mechanism to assess the level of an individual's involvement and contribution to the organisational knowledge base, which can be linked to the staff appraisal system as appropriate;
- Development of a system for helping a project team to identify the relevant knowledge captured and to learn from the knowledge captured prior to the start of a new project. Currently, the explicated project knowledge is often captured in the printed form (e.g. best practice guide), and also in the form of electronic files (e.g. video and sound clips). There is a need to develop an effective methodology to represent the knowledge captured in various forms to improve the learning of project team members; and
- In CoPs, best practice and lessons learned are shared, and new knowledge can be created through the discussions amongst the members. However, although the knowledge captured or shared within a community of practice may also be important to the members of other CoPs, the existence of the knowledge is very often only aware by its members. As a result, the opportunities for reusing the knowledge are not fully seized and the potential resultant benefits of reusing the knowledge are not fully exploited. Therefore, it is critical for construction organisation to know what its CoPs know, and also to create a mechanism to facilitate the sharing of relevant knowledge from all CoPs prior to commencing new projects. This will allow the collective knowledge of relevant lessons learned and best practices from all the CoPs to be shared to avoid the repetition of similar mistakes, and to better manage new projects right from the beginning.

Further exploration of the commercial potential of the prototype application is also recommended.

8.5 Concluding Remarks

The importance of knowledge management in construction, in particular the 'live' capture and reuse of project knowledge, was evident through this research. The nature and characteristics of reusable project knowledge, the shortcomings of current practice in managing project knowledge, and end-user requirements as to the development for a methodology for 'live' capture and reuse of project knowledge in construction, were identified from the case studies conducted. The findings led to the development of the aforementioned methodology for 'live' capture and reuse of project knowledge, which was subsequently encapsulated in a Web-based prototype application. The application of the methodology developed can help to minimise the knowledge loss problem whilst enabling the knowledge captured to be reused widely to maximise the benefits to construction project teams.

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Appendix A

List of Publications Arising from the Research

Appendix A: List of Publications Arising from the Research

1. Published (or Submitted)

Udeaja, C.E., Kamara, J.M., Anumba, C.J., Carrillo, P.M., Bouchlaghem, N.M., and Tan, H.C. (2004), Developing a Methodology for Live Capture and Reuse of Construction Project Knowledge, *Proceedings of the 1st International SCRI Symposium*, University of Salford, Manchester, UK, 30 March – 1 April, Aouad, G., Amaratunga, D., Kagioglou, M., Ruddock, L. and Sexton, M., eds., pp. 153-159.

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Tan, H.C., Carrillo, P.M., Anumba, C.J., Kamara, J.M., Bouchlaghem, N.M. and Udeaja, C.E. (2006), Live Capture and Reuse of Project Knowledge in Construction – A Prototype Development, *Proceedings of Joint International on Computing and Decision Making in*

Civil and Building Engineering, (paper accepted).

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2. Forthcoming Publications

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Appendix B

Table Comparing the Various Knowledge Management Process Models

Appendix B: Table comparing the various knowledge management process models

Author(s)	Knowledge Management Processes
Robinson et al (2001)	<ul style="list-style-type: none"> ▪ Discovering, locating & capturing ▪ Organisation & storage ▪ Sharing & transferring ▪ Modifying & applying ▪ Archiving & retirement
Kululanga & McCaffer (2001)	<ul style="list-style-type: none"> ▪ Acquiring ▪ Creating ▪ Sharing ▪ Storing ▪ Utilising
Rollett (2003)	<ul style="list-style-type: none"> ▪ Planning ▪ Creating ▪ Integrating ▪ Organising ▪ Transferring ▪ Maintaining ▪ Assessing
Tiwana (2000)	<ul style="list-style-type: none"> ▪ Acquisition ▪ Sharing ▪ Utilisation
Bhatt (2001)	<ul style="list-style-type: none"> ▪ Creation ▪ Validation ▪ Presentation ▪ Distribution ▪ Application
Mertins et al (2001)	<ul style="list-style-type: none"> ▪ Create ▪ Store ▪ Distribute ▪ Apply
Soliman & Spooner (2000)	<ul style="list-style-type: none"> ▪ Create ▪ Capture ▪ Organise ▪ Access

	<ul style="list-style-type: none">▪ Use
Davenport & Prusak (1998)	<ul style="list-style-type: none">▪ Knowledge Generation: acquisition, dedicate resources, fusion, adaptation and knowledge networking▪ Knowledge Codification & Coordination▪ Knowledge Transfer

Appendix C

Reusable Project Knowledge Identified by the Case Study Companies

Appendix C: Reusable project knowledge identified by the case study companies

	Company A	Company B	Company C	Company D	Company E	Company F
Types of Reusable Project Knowledge	▪ Design	▪ Design			▪ Work processes	▪ Design
		▪ Tender	▪ Bidding			▪ Procurement
	▪ Planning	▪ Planning				
	▪ Construction process	▪ Construction method & techniques				▪ Construction
		▪ Off-site construction				
	▪ Buildability					
		▪ Facility management				▪ Commissioning & maintenance
	▪ Specific requirements			▪ Client's requirements		
	▪ Operational constraints	▪ About client		▪ Clients' organisational procedures		▪ Internal procedures
	▪ Building					
		▪ Financial Knowledge	▪ Project cost & performance of similar projects	▪ Cost information		▪ Project services (Cost management)
		▪ Whole Life Cost				
	▪ Regulatory requirements		▪ Regulation		▪ Design standards	▪ Regulation
	▪ Health & Safety		▪ Health & Safety			▪ Health & Safety
			▪ Who knows what	▪ Who knows what		▪ Who knows what
	▪ Technical details & specifications	▪ Design details			▪ Method statements	▪ Construction standard documents, etc.
	▪ Performance of other companies	▪ Performance of suppliers		▪ Performance of service providers		
	▪ Competitors			▪ Competitors		
		▪ Risk management				
		▪ Team working				
			▪ PPR report's findings	▪ Failures and success		
			▪ Non-compulsory standards			
			▪ Industry guidance			
			▪ Best Practice			
		▪ Innovation				
			▪ KPIs			
			▪ Training			

Appendix C: Reusable project knowledge identified by the companies (continued)

	Company A	Company B	Company C	Company D	Company E	Company F
Types of Reusable Project Knowledge				▪ Company's products & service		
						▪ Project management
						▪ Contract
						▪ Flooding
						▪ Geo-Engineering & Geo-Techniques
						▪ Technical Information Service (TIS)
						▪ Water Network & Modelling
						• Water resources

Appendix D

Details of the Types of Reusable Project Knowledge Identified

Appendix D: Details of the types of reusable project knowledge identified

Reusable Project Knowledge	Details of the Knowledge	Current Practice To Capture The Reusable Project Knowledge
<ul style="list-style-type: none"> ▪ Process Knowledge 	<ul style="list-style-type: none"> • Design Design knowledge can be subdivided into two categories: generic design knowledge and specialist design knowledge. Generic design knowledge is focused on the use of standard approach in design to ensure that designers have designed the entity by taking into consideration the issues like health and safety, and designer's risk assessment as required by regulations. For the latter category, i.e. specialist design knowledge, it is the expert knowledge required in the design a particular type of facility such as pharmaceutical facility. This knowledge covers what the necessary systems and facilities are and how they work. The possession of this knowledge enables a company to take this into account in the design although some of the necessary facilities are not mentioned or are omitted in the client's brief. In addition, this may even extend to a company proposing alternative design options to the client. • Tendering and Estimating This knowledge covers the assignment of proposals/operations manager for the task, the making of decision to submit tender, preparation of estimate, establishing overall strategy and framework for bid, risk and opportunity analysis, tender adjudication (deciding the mark-up for the tender) and further negotiation if the contract is being awarded. • Planning This knowledge is concerned with the sequence and duration of construction activities, as well as the estimated total time required to construct a particular design. This knowledge is also important in providing advice to the client on the impact of his/her decision to the duration of the project. The planning of a project can be based on the successful program of other similar type of projects. This can help to reduce the time required for planning if compared to start from scratching. 	<ol style="list-style-type: none"> 1. Generic design knowledge It is captured in designer's standard procedures to ensure that they have taken into consideration all criteria and issues while preparing the design. 2. Specialist design knowledge This knowledge remains tacit in the head of people and is reused through the reassignment of expert to other projects. In addition, this knowledge is also transferable through demonstrating to others how to do it. <ol style="list-style-type: none"> 1. This knowledge is shared through the estimators CoPs and informal discourse. 2. It is also captured in database system containing the prices of each of the elements <ol style="list-style-type: none"> 1. This knowledge is captured through personal experience and feedback from contractors and subcontractors 2. This knowledge is also partly captured in the planning application software used.

<ul style="list-style-type: none"> • Construction methods and techniques This comprises the knowledge on: <ul style="list-style-type: none"> a) Various construction methods or techniques available and the suitability of these methods to a project. This also covers the cost, speed, requirements in terms of human resources and technology, as well as the constraints imposed by the project's individual characteristics on the method of construction; b) Previous mistakes made on the selection of construction methods which are to be avoided; c) Influence of material selection to the construction of the facility. The decision made by designers on the selection of materials, such as the type of roof, affects the methods, process and speed of construction; and d) Other factors that have impacts on construction. • Buildability This is the knowledge on the 'optimum integration of construction knowledge and experience in planning, design, procurement and field operation to achieve overall project objective'. It is important to capture this knowledge as there is evidence that construction quality and productivity on site are affected by the buildability of design. • Operation and maintenance The growing importance of Private Finance Initiative (PFI) projects has significantly contributed to the need to capture the knowledge on managing the operation and maintenance of the facility built. This knowledge also covers the customers' feedbacks regarding the delivery of the building and their experience on occupying the building, the 'learning on which part of the design works and otherwise', as well as the influence of the design on the maintenance and operation of the facility. 	<p>1. This knowledge is captured through hands on experience and often remain tacit. It is normally reused by reassigning people to other projects.</p> <p>2. It is also captured through careful selection of staff to ensure that only those who have good understanding on construction process are recruited.</p>
	<p>This knowledge is captured in the head of people.</p>
	<p>This knowledge is captured in the post project review.</p>

<ul style="list-style-type: none"> ▪ Knowledge about Client 	<p>a) Clients' requirements There are two types of clients' requirements: general and specific. Clients from similar sector are very likely to have similar set of general requirements. For instance, the clients from education sector normally require that a rather similar set of class room facilities to be provided. However, due to difference in the nature of business, individual client also tends to have specific requirements or preference which are to be followed and incorporated into the design. This knowledge helps improve designer's capability to understand client's brief which in turn enables the designer to develop a design that better addresses the client's needs.</p> <p>b) Client organisations' internal procedure Public and private sectors clients may have their individual working procedures which can be so rigid until in some circumstances they are regarded as organisational red-tapes that affect the progress of the project. Therefore, it is important to identify the red-tapes and the potential impacts in advance if interruption to the progress of project is to be avoided.</p> <p>c) Clients' business This knowledge covers who are the people working for the client, the availability of new projects from the client and the background knowledge about his/her business activities.</p>	<ol style="list-style-type: none"> 1. Knowledge about client's standard procedures and operational constraints can be captured in procedural manual of the company. 2. Knowledge about clients specific requirements normally remain tacit and captured in people's head. This knowledge can be shared through formal meeting and discourse with the project team who has work with the client before. 3. Other specific types of knowledge under this category can be captured in PPR.
<ul style="list-style-type: none"> ▪ Costing Knowledge 	<p>a) Cost of alternative forms of construction This is the knowledge on the cost of alternative forms of design and construction methods with respect to the project location and the way that the project is being financed.</p> <p>b) Whole Life Cost (WLC) Whole Life Cost is the total cost of procuring, operating and maintaining an asset throughout its lifespan. There is evidence that many public and private sectors clients now procure on WLC rather than capital cost. The ability of a company to prepare a design with a low WLC is dependent on the wealth, currency and accuracy of this knowledge.</p>	<ol style="list-style-type: none"> 1. Costing knowledge can be captured in the estimating software and is also available through the subscription to the relevant website, e.g. Building Cost Information Service (www.bcis.co.uk). 2. Knowledge on Whole Life Cost is accessible by subscribing to the relevant web-based services such as the Whole Life Cost Forum (www.wlcf.org.uk) or captured through internal cost information.

<p>▪ Knowledge of Legal and Statutory Requirements</p>	<p>a) Regulatory requirements This knowledge covers the requirements and responsibilities imposed by British Standards, Code of Practice, etc. on the clients, designers and contractors. The regulatory requirements change regularly over time. Thus, all the parties have to be aware of the changes and the impacts to their practice in order to abide by the new requirements.</p> <p>b) Health and safety This is the knowledge on how to design and construct the building in a way that the designers' and contractor's responsibilities on health and safety, especially under the Construction (Design and Development) Regulations 1994, are fully discharged.</p> <p>c) Contract The terms and conditions of contracts must be continuously evaluated to suit changes.</p>	<p>1. This knowledge is available through subscription to the relevant web service and in the form of CD.</p> <p>2. It is also captured by sending representative to attend external course to understand the impacts of latest changes of regulations to current practice and then disseminate the learning within the company.</p>
<p>▪ Knowledge of Reusable Details</p>	<p>Reusable details consist of:</p> <p>a) Standard design details; b) Specifications; and c) Method statements.</p> <p>Standard design details are such as the design drawings of specific areas and associated fittings of a facility. The reuse of the design details, specifications and method statements helps to avoid the reinvention of the wheel and also leads to time and cost savings. Adaptations might be necessary for the reuse of the details. Time saved can be used for making improvements to the details.</p> <p>The chances to reuse the details are dependent on the proportion of similar type of projects, and the degree of repeating business from the same client.</p>	<p>1. The standard reusable design details and specifications are captured in the drawings and specifications of a project respectively. The reuse of such details may require the person to contact the originator of the documents for further explanation on the rationale of design and the context for reuse.</p> <p>2. Some companies use a more formalised approach where sessions are held for the project team working under the same client to identify the areas where standard details on design and specification can be created. The standard details created are then made available to others in electronic form for reuse</p>
<p>▪ Knowledge of Best Practices and Lessons Learned</p>	<p>Best practices and lessons learned are the proven ways of working that contribute to the success of projects and the mistakes made that must be avoided in future projects respectively. These are also referred to as the factors of 'success and failure' of project by one of the companies. Best practices and lessons learned are among the most common types of knowledge captured by construction organisations.</p>	<p>This knowledge is normally captured in the post project review and other reviews and meetings conducted at the end of the various project stages. The findings are then compiled as the company's best practice guide and code of practice</p>
<p>▪ Knowledge of Performance of Suppliers and KPIs</p>	<p>a) Performance of suppliers The suppliers referred to are other consultants, contractors, subcontractors, material suppliers, etc. i.e. anyone who has contributed services or goods to the project. The capture of this knowledge facilitates better selection of suppliers for future projects.</p> <p>b) Key Performance Indicators (KPIs) KPIs are used to evaluate the performance of a project. The results of the evaluation can be used as a bench mark for continuous improvement in other projects.</p>	<p>This knowledge is captured by carrying out a qualitative assessment based on a predetermined set of criteria at the end of project. The result can be fed into a custom designed database and made accessible for reuse through intranet.</p> <p>This is captured through internal reviews, post project reviews and collaboration with other companies.</p>

<ul style="list-style-type: none"> ▪ Knowledge of Who Knows What 	<p>This is the knowledge on the skills, experience and expertise of each of the members of staff. This knowledge is crucial as it impinges the successful reuse of other knowledge. It serves as a guide to lead people to the right source or right people with the knowledge. It assists in connecting people to people for the sharing of knowledge, particularly the tacit knowledge which is difficult to codify.</p>	<p>This knowledge is captured in the members of staff's personal file, curriculum vitae, or personal web page in company's intranet</p>
<ul style="list-style-type: none"> ▪ Other Types of Knowledge 	<ul style="list-style-type: none"> • Risk management This is about the associated risk of working with a particular client and suppliers in a particular area with particular contractual arrangement and time constraint. • Team working This is the knowledge on how to manage a team and to prevent the relationship breakdown. This knowledge is more concerned with the project management rather than the specific issues or areas of the construction project. • Project Management This is concerned with how to improve the performance of projects. 	<p>This knowledge is captured in the risk assessment report and the application software used to conduct risk assessment.</p> <p>Part of this knowledge is captured in the case study or history of the projects. People to people interactions play important role in the sharing of this knowledge.</p> <p>This knowledge is captured in people's head.</p>

Appendix E

Additional Learning Situations Related to Change Management, Problem-Solving and Innovation

Appendix E: Additional learning situations related to change management, problem-solving and innovation

	Learning Situations / Triggers of Knowledge Production	Type
PEER (2002)	<p>The most common reasons for change order, which result in changes, are:</p> <ul style="list-style-type: none"> • Change in scope: for instance, client has requested a design change; • Unforeseen condition: for instance, the site conditions differ from expected; and • Professional errors and omissions: for instance, the professional has incorrectly drawn the construction design plans and specifications. 	Change management
Lazarus and Clifton (2001)	<p>Sources of Change:</p> <ul style="list-style-type: none"> • Legislative change, for instance reduction in the acceptable discharge rates into external drainage; • Design change, for instance change to the cladding system which leads to further amendments in design; • Client change, for instance provision required by the client for further expansion of facility; • Contractor change, for instance contractor proposes different methods of construction for a section of work; and • Site conditions change, for instance existing foundation design has to be revised due to unexpected ground conditions. <p>There are two other factors which may lead to change:</p> <ul style="list-style-type: none"> • Inflation or relative price rise; and • Difficulties with contractors. 	Change management
Park (2002)	Changes in work state; processes and methods that deviate from original construction plan or specifications.	Change management
Trauner (1993)	<p>Trauner (1993) identifies a number of problem situations. However, only those directly relevant to learning situations are addressed here. The problem situations are:</p> <ul style="list-style-type: none"> • Termination and default; • Projects behind schedule; • Claims and disputes; and • Budgets related issues such as over budget. 	Problem-solving
McLoughlin et al (2000)	<p>McLoughlin et al (2000) identify a range of economic drivers which organisations have to respond to when there is any change. These drivers can be grouped into change management and problem-solving related triggers of knowledge production.</p> <ol style="list-style-type: none"> 1. Change management related triggers: <ul style="list-style-type: none"> • Changing market requirements, such as demands for time compression and requirements for whole life project management; • Regulation/De-regulation and environmental issues, that is the impacts of changes in regulatory requirements to the project; 2. Problem-solving related triggers: <ul style="list-style-type: none"> • New sources of competition, particularly when move into a market requiring new capabilities; and • Human resources issues, for instance the changes in the supply and cost of labour force from the local labour market. 3. Innovation related trigger: <ul style="list-style-type: none"> • Fundamental and invasive technology improvements which have an effect on the economics of the project during the course of its lifetime; 	Change management, Problem-solving & Innovation
Egbu (2002)	<p>Egbu (2002) identifies that those listed below are important types of innovations in project-based organisations:</p> <ul style="list-style-type: none"> • New technology that has internal benefits to the company; 	Innovation

	<ul style="list-style-type: none">• New process that has benefits to the company;• New approach to providing services to customers/clients;• New procedures for obtaining goods/services;• New product that provides competitive advantage for the company;• New external relations e.g. partnering, joint ventures• New administrative policy e.g. incentive schemes, bonuses	
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Appendix F

Companies' Practice and Requirements on Knowledge Representation

Appendix F: Companies' practice and requirements on knowledge representation

Company	How project knowledge is represented
A	<p>a) General headings are provided on the type of project knowledge</p> <p>b) Case studies or detailed explanation of the knowledge to help others to understand and hence reuse the knowledge</p> <p>c) The conditions for reusing the knowledge must be made clear to the users</p> <p>d) Checklists to show:</p> <ul style="list-style-type: none"> • The issues relevant to the particular project • The characteristics of the project that are related to the context for the reuse of the knowledge
B	<p>Sharing the bullet-point learning in a Web environment, each with a short description prepared to give the audience basic background information. This is supplemented by video clips to capture the detailed explanation from the originator of the learning.</p>
C	<p>Establishing convenient means, such as people's personal profile and knowledge network aided by custom-designed IT-systems, for people to communicate with each other and share their knowledge. Some knowledge of technical and contractual issues are represented in the form of 'feedback notes' in accordance with the format specified. The 'feedback notes' are made available to the members of staff over the company's intranet.</p>
D	<p>A standardised approach is required. The knowledge captured must be organised and represented in a logical and simple to understand way, and readily accessible to others within the organisation. Knowledge on know-how to perform a specific task (such as how to approach difficult situations) can be captured in the organisation's standard procedures.</p>
E	<p>The methodology developed for capturing or representing the knowledge should avoid the introduction of excessive additional workload to people. The additional workload created should be integrated into daily job functions and be carried out within normal working hours.</p>
F	<p>Knowledge represented comprises two sections:</p> <ul style="list-style-type: none"> • Context of the knowledge such as the type of project and project stage, where the knowledge is concerned, and an explanation of how to reuse the knowledge; and • The financial impact, such as the cost saving if the suggestion is implemented. <p>Some process knowledge can be represented in the form of interactive process maps.</p>

Appendix G

Evaluation Questionnaire

Appendix G: Evaluation Questionnaire

This evaluation questionnaire should be completed following a demonstration of the CAPRI.NET system.

Information about the participant

Your position (e.g. project manager, design consultant, engineer) _____

Area of experience (e.g. civil engineering, building, etc.) _____

Experience in the construction industry (years) _____

Evaluation of the CAPRI.NET System: *(Please put a tick in the box that best represents your assessment of a question)*

Capture of Knowledge	Ranking 1 is very poor, 3 is neutral & 5 is excellent				
	1	2	3	4	5
1. How well does the system enable project knowledge to be captured 'live' (i.e. as soon as possible after a knowledge is created or identified)?					
2. How complete is the system in capturing the details of a knowledge?					
3. How well does the validation mechanism ensure the accuracy and correctness of knowledge captured?					
4. How well does the system cope with avoiding the creation of additional workload?					

Representation of Knowledge

5. How well does the index page provide users an overall view of all the knowledge captured in the system?					
6. How well is knowledge organised in the system?					
7. How well does the template represent the knowledge captured?					

Sharing/Reuse of Knowledge

8. How well does the system facilitate the sharing of the project knowledge captured (i.e. through the provision of access to the knowledge captured through Web, links to additional information in the template for representing knowledge, the search function provided, etc.)?					
9. How well does system achieve the concept of the 'live' sharing of project knowledge captured from a project (i.e. through allowing users to access of the knowledge via Web and sending email to users once new knowledge is added into the system)?					
10. How reusable is the knowledge captured (i.e. during a subsequent project stage or on another project)?					

Ease of use

11. How good is the search function in locating the knowledge required?					
12. How easy is the system to use overall?					

What do you particularly like about the system (both content and User interface)?

In what way can the CAPRI.NET be improved?
