BIM-based Knowledge Management System for Building Maintenance

By:

Abdulkareem A. M. A. Almarshad

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(Construction Project Management)

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Abstract

The importance of utilising knowledge is well recognised hence the concept of knowledge management (KM) has been introduced to organisations in various industries to improve their performance. Companies in the construction and building sector, seek the benefits brought by KM, to cope with economic and competitive pressures and to deal with complex projects. In addition, this sector has employed Building Information Modelling (BIM) technology to support processes throughout the whole life-cycle of projects. Building Maintenance (BM) departments have the duty of maintaining buildings that vary in shape, type, size, complexity and purpose, providing services ranging from minor repair works to bespoke renovation and rehabilitation projects, making the process of maintenance a complex matter. Lack of knowledge sharing and loss of knowledge gained in dealing with problems can cause repetition of mistakes and reinventing the wheel, leading to additional expenses and time wastage.

This research aims to facilitate decisions through developing a BIM-based KM system to aid in capturing knowledge generated and facilitating its reuse to BM professionals.

The methodology used interviews and focus group meetings to achieve the research aim, in addition to prototyping a Software Development Methodology (SDM) for system development. A series of semi-structured interviews were conducted with public BM departments in Kuwait to map and analyse the process followed by BM departments, investigate KM techniques used, and assess awareness and implementation of BIM. Relevant contract documents were also obtained and reviewed to assist in developing a knowledge taxonomy for use in the prototype. Focus group meetings were carried out for both development and evaluation of the KM prototype. Finally, a case study application was conducted to demonstrate the prototype functions and to validate its usage.

The findings of this research were used to draw a process map of the main activities for the public BM sector in Kuwait, which was used to identify several deficiencies to departmental knowledge sharing including poor communication between teams, paper based solutions and lack of knowledge-based systems. The findings also indicated that several KM techniques are used by BM departments, including mixing between experienced and inexperienced employees, training, and daily face-to-face interactions. BIM awareness was found to be limited, with no implementation in BM sector yet.

The results were used as a foundation for development of a BIM-based online prototype system named Knowledge Management of Building Maintenance (KMoBM). The prototype consists of three modules: a BIM-based module, Case Based Reasoning (CBR) module, and database module. Focus group meetings were carried out with potential users to validate and weigh knowledge case attributes utilised by the prototype. The developed prototype was then evaluated in a focus group meeting. The evaluation results indicate that the prototype has achieved the research aim and provides a useful tool to be used in BM departments.

**Keywords:** Building Maintenance, Knowledge Management, BIM, Kuwait.
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<th>Description</th>
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<tr>
<td>AEC/FM</td>
<td>Architecture, Engineering, Construction, and Facilities Management</td>
</tr>
<tr>
<td>AHP</td>
<td>Analytic Hierarchy Process</td>
</tr>
<tr>
<td>ANP</td>
<td>Analytic Network Process</td>
</tr>
<tr>
<td>BIM</td>
<td>Building Information Modelling</td>
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<tr>
<td>BM</td>
<td>Building Maintenance</td>
</tr>
<tr>
<td>BMCoP</td>
<td>Building Maintenance Community of Practice</td>
</tr>
<tr>
<td>BMPB</td>
<td>Building Maintenance Price Book</td>
</tr>
<tr>
<td>BMPB</td>
<td>Building Maintenance Price Book</td>
</tr>
<tr>
<td>BSI</td>
<td>The British Standards Institution</td>
</tr>
<tr>
<td>C</td>
<td>Criteria</td>
</tr>
<tr>
<td>CAFM</td>
<td>Computer Aided Facility Management</td>
</tr>
<tr>
<td>CAWS</td>
<td>Common Arrangement of Work Sections for building works</td>
</tr>
<tr>
<td>CBR</td>
<td>Case-Based Reasoning</td>
</tr>
<tr>
<td>CESMM3</td>
<td>Civil Engineering Standard Method of Measurement, Third Edition</td>
</tr>
<tr>
<td>CI/SFB</td>
<td>Construction Index/SFB</td>
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<tr>
<td>CIB</td>
<td>International Council for Building</td>
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<tr>
<td>CIOB</td>
<td>The Chartered Institute of Building</td>
</tr>
<tr>
<td>CM</td>
<td>Construction Management</td>
</tr>
<tr>
<td>CMMS</td>
<td>Computerised Maintenance Management Systems</td>
</tr>
<tr>
<td>COBie</td>
<td>Construction Operations Building Information Exchange</td>
</tr>
<tr>
<td>CoP</td>
<td>Community of Practice</td>
</tr>
<tr>
<td>CRC</td>
<td>Cooperative Research Centre Construction Innovation</td>
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<td>CSI</td>
<td>Construction Specifiers Institute</td>
</tr>
<tr>
<td>CTC</td>
<td>Central Tendering Committee</td>
</tr>
<tr>
<td>e-COGNOS</td>
<td>COnsistent knowledGe management across prOjects and between enterpriSes in the construction domain</td>
</tr>
<tr>
<td>EPIC</td>
<td>Electronic Product Information Co-operation</td>
</tr>
<tr>
<td>FM</td>
<td>Facilities Management</td>
</tr>
<tr>
<td>FMM</td>
<td>Facility Maintenance and Management</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>IFC</td>
<td>Industry Foundation Class</td>
</tr>
<tr>
<td>IS</td>
<td>Information system</td>
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<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
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<td>Information Technology</td>
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<td>KDP</td>
<td>Kuwait Development Plan</td>
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<td>KMoBM</td>
<td>Knowledge Management of Building Maintenance</td>
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<td>KSE</td>
<td>Kuwait Society of Engineers</td>
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<td>MAUT</td>
<td>Multi-Attribute Utility Theory</td>
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<td>MCDM</td>
<td>Multi-Criteria Decision Making</td>
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<td>ME</td>
<td>BuildingSMART Middle East</td>
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<tr>
<td>MoPMIT</td>
<td>More Productive Minor Construction Projects through Information Technology</td>
</tr>
<tr>
<td>MPW</td>
<td>Ministry of Public Works</td>
</tr>
<tr>
<td>MTC</td>
<td>Measured Term Contract</td>
</tr>
<tr>
<td>NBIMS</td>
<td>National BIM Standard</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
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<tr>
<td>NIBS</td>
<td>The National Institute of Building Sciences</td>
</tr>
<tr>
<td>PHP</td>
<td>Hypertext Preprocessor</td>
</tr>
<tr>
<td>RIBA</td>
<td>Royal Institute of British Architects</td>
</tr>
<tr>
<td>RICS</td>
<td>Royal Institution for Chartered Surveyors</td>
</tr>
<tr>
<td>RM</td>
<td>Reactive Maintenance</td>
</tr>
<tr>
<td>SC</td>
<td>Sub-Criteria</td>
</tr>
<tr>
<td>SD</td>
<td>System Dynamics</td>
</tr>
<tr>
<td>SECI</td>
<td>Socialization, Externalization, Combination and Internalization</td>
</tr>
<tr>
<td>SOH</td>
<td>Sydney Opera House</td>
</tr>
<tr>
<td>SPA</td>
<td>Special Projects Administration</td>
</tr>
<tr>
<td>SQL</td>
<td>Structured Query Language</td>
</tr>
<tr>
<td>UML</td>
<td>Unified Modeling Language</td>
</tr>
<tr>
<td>Uniclass</td>
<td>Unified Classification for the Construction Industry</td>
</tr>
</tbody>
</table>
Publications


Chapter 1 - Introduction
1.1. Introduction

Maintenance is defined as “The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function” (BSI, 1984, p.26). The item mentioned in the definition is recognised in this research as a building structure. Therefore, a Building Maintenance (BM) project is concerned with maintaining, improving or refurbishing every part of a building and its associated surroundings and services including repairing and/or replacing any affected building component. The BM project can extend from fixing minor issues such as repairing plumbing leaks and door locks to large complex problems including fire related failures, structural problems and complete building overhaul. Therefore, the objectives of BM include (Alner & Fellows, 1990; Cited in Horner et al., 1997):

- Ensuring that a building and its related services are in a safe state.
- Ensuring that a building is suitable for usage.
- Ensuring that a building’s condition meets all legal requirements.
- Performing maintenance works needed to preserve the value of physical assets of the building stock.
- Performing maintenance works needed to preserve the quality of the building.

Generally, maintenance of buildings can be either planned or unplanned (Chanter & Swallow, 2007). Planned maintenance concerns about the routine maintenance plan whereas unplanned maintenance concerns the reactive maintenance in response to a cause of failure or breakdown. In current practice, the information required for implementing planned maintenance can be easily prepared ahead of actions, compared with the information required for unplanned maintenance. One of the key challenges in projects is always the need to have sufficient information on products readily available for any maintenance operation, such as specifications, previous maintenance work, list of specialist professionals to conduct work, etc. Moreover, knowledge and experience acquired during a products’ lifecycle should be included in the maintenance mechanism, for continuous improvement (Takata et al., 2004). However, while recognised as a strategic concern, managing knowledge is considered as a challenge to organisations (Pathirage et al., 2008).
Knowledge Management (KM) is defined as “practice of selectively applying knowledge from previous experiences of decision-making to current and future decision making activities with the express purpose of improving the organization's effectiveness” (Jennex, 2005). The concept of KM has been implemented by organisations to gain better market share and competitive advantage (Nonaka & Takeuchi, 1995). Knowledge can be classified into explicit and tacit. While it is acknowledged that individuals possess their own tacit knowledge, genuine potential benefits reside in transforming individual knowledge into institutional knowledge (Egbu, 2000). Moreover, tacit knowledge is perhaps the most important aspect in organisations and the least supported by Information Technology (IT) (Tiwana, 2000b). Approaches such as of that Nonaka and Takeuchi (1995) have been proposed to convert knowledge from tacit to explicit and vice versa, to assist organisations to benefit from this knowledge. This research explores how managing knowledge can improve the service delivery of public BM.

1.2. Justification of the Study

Kuwait is considered one of the wealthy countries, as it has one of the highest per capita incomes in the world. However, even though the country seems secure, with large oil revenues and reserves, it is perhaps one of the most vulnerable to the impact of future oil peak crises (Roaf et al., 2009). Therefore, measures need to be taken to increase efficiency of public organisations to be prepared when calls for tighter expenditures are made. Several issues were observed by the researcher during his professional work in two public BM departments in Kuwait, such as discarding of documents after project completion or expiry of a maintenance contract resulting in new experience or knowledge being simply forgotten with time. This usually leads to effort and time being mostly consumed in “reinventing the wheel” in dealing with repeated projects, mistakes or recurring issues.

Public BM departments in Kuwait have the duty of maintaining properties owned or rented by the state. Buildings used by particular ministry vary in shape, type, size, complexity and purpose. Furthermore, services provided by the departments extend from minor repair works to large bespoke renovation and restoration projects. This in turn involves many people in a typical BM project. Such a mixture of people and categories of buildings and services can make the process of maintenance complex.
This requires BM departments to seek means to improve their business performance to keep up in maintaining public buildings.

Egbu (1999) emphasis that relative importance of knowledge and management skills in refurbishment projects are higher than those in general construction management. KM principles have been adopted in BM to leverage employees’ knowledge assets (Fong & Lee, 2009). BM and construction departments implement the concept of KM to improve performance, lower costs, reduce mistakes and increase efficiency and quality (McAdam & Reid, 2000; Robinson et al., 2001; Syed-Ikhsan and Rowland, 2004). This is because knowledge is important to public and private organisations (Al-Athari & Zairi, 2001) and exists in the organisation’s processes, policies work flow and databases (Syed-Ikhsan & Rowland, 2004). However, lack of communication and knowledge sharing in BM can produce several major problems including selecting the right contractor for the right problem, double handling of data entry and transferring of information (Ali et al., 2002).

Due to the lack of formal knowledge networks, public employees usually acquire information and knowledge through informal channels (Yao et al., 2007). Moreover, even though the area of KM has been widely researched, much of the literature of KM has been focused on private sector while little has been concentrated on the public sector (Cong & Pandya, 2003; Syed-Ikhsan & Rowland, 2004; BSI, 2005). The reason for this is that the public sector implements KM mainly to improve services rather than to gain financial benefits (Syed-Ikhsan & Rowland, 2004).

Several KM applications for BM have been developed to improve the performance of BM process, such as those of Ali et al. (2004), Lepkova and Bigelis (2007) and Fong and Wong (2009). The main functions of these applications are capturing, sharing, and reusing knowledge by stakeholders. They can help facilitate communication between parties and in identifying problems, selecting the appropriate contractor and allowing feedback on completed work. Despite the useful functions provided by these applications, they lack the intelligent capabilities of linking maintenance operations affecting various building elements with the knowledge cases of the related maintained element. The new development in Building Information Modelling (BIM) technology can change the way these applications work. BIM can enable KM systems to be integrated to help maintenance teams to manage and share all details about knowledge cases over the building’s life time.
While CAD systems are used as drafting tools, BIM technology is utilised to tie building components alongside their information to create virtual projects. Therefore, BIM can provide the facilities for developed solutions and overcome problems in a comprehensive manner. BIM can enhance collaboration between team members and facilitate further the mutual channel for information, providing frameworks and IT tools that can support stakeholder collaboration over a project life-cycle. However, while BIM is thought to transform the way the built environment is working (Smith & Tardif, 2009), studies related to BIM have often focused only on storing and sharing technical information. The capabilities of BIM can be enhanced by knowledge-based techniques to enable both information and knowledge-sharing that will benefit stakeholders. By incorporating KM principles with the intelligence of BIM systems, the transformation from ‘Building Information Modelling’ to ‘Building Knowledge Modelling’ can be better recognised.

Therefore, this research attempts to develop an integrated BIM-based KM system that enables capturing/retrieving of knowledge on BM while considering the affected buildings’ components to assist in maintenance operations.

1.3. Research Aim and Objectives

The merit of this research is to facilitate professionals’ decisions in public BM departments through the use of an innovative KM system. Therefore, this research aims to develop a BIM-based system to aid in capturing generated knowledge and facilitating its reuse to professionals, when performing their BM duties.

The following objectives were set to achieve the research aim:

1) To map and examine main processes of services provided by BM departments.

2) To explore issues related to KM, including techniques, IT usage, and perceptions regarding introducing a KM system for BM.

3) To assess BIM implementation in the building maintenance sector.

4) To develop a prototype BIM-based system to manage knowledge in Kuwaiti public departments, to overcome challenges arising in their BM projects.
5) To validate the developed BIM-based system through the process of evaluation by potential users working in the public BM sector in Kuwait.

6) To demonstrate the usage of the developed BIM-based system.

1.4. Research Methodology and Design

The general philosophy of this research is phenomenological which uses qualitative approach to address the research aim and objectives (as will be discussed in section 2.2). The researcher’s understanding was that an approach with qualitative methods would best capture individuals’ experience and views to aid the investigation of this research. Therefore, a methodology with qualitative methods was employed for this the research (as will be illustrated in section 2.5).

As shown in Figure 1-1, six stages were set out to achieve the research aim and objectives. The first stage comprised a review of literature on the BM sector (Chapter 3), KM in the BM sector (Chapter 4), and BIM in the BM sector (Chapter 5). At the end of first stage, the research objectives were reviewed and formulated based on the identified research gap from literature. The research methodology with its methods was then designed to address research objectives. Chapter 2 will discuss in detail the adopted methodology to conduct this research.
Figure 1-1: Stages of the research.
The second stage was set to investigate the process of maintenance followed by BM departments; KM related issues; assessment of BIM implementation, and to review documents related to maintenance contracts. This was done by conducting interviews with appropriate professionals working in public BM departments (as will be discussed in Chapter 6). The analysis of data collected from the interviews was used to conduct the following stage of the research.

The third stage of the research involved developing the KM prototype. In this stage, a prototyping methodology was selected for software development (section 2.6.3). Building the prototype involved developing its modules, attribute validation and refining (Chapters 7, 8, 9 and 10). The results of attribute validation are based on input from experts participating in focus group meetings (Chapter 8). Moreover, testing of the prototype functions was carried out during the development period to ensure that all functions were working correctly (Chapter 11).

The fourth stage comprised of the evaluation of the KM prototype (Chapter 11). In this stage, the prototype was demonstrated to experts participating in a focus group meeting. The evaluation revealed that prototype functions scored between 4 and 5 out of 5. These results indicate that the prototype has achieved its aim of facilitating professionals working in BM to share and manage their knowledge. Moreover, the evaluation stage suggested several modifications to the prototype, most of which were dealt with, and the prototype modified, while others were considered for future development. The fifth stage comprises of demonstrating the prototype through a case study (Chapter 12). A sample project is provided by the researcher’s sponsor to be used for demonstration. Finally, the sixth stage involves presenting drawn conclusions from research results and recommendations for future development (Chapter 13).

1.5. Research Scope and Limitations

Research in the area of KM is fundamentally about aspects of capturing and retrieving knowledge. However, although this research was centred on these aspects, other interrelated aspects of KM needed to be addressed, including organisational BM processes, people and Information Technology (IT). The scope of this research has thus been extended to develop an organisational process map for BM, exploring people’s attitudes towards KM, current use of IT and KM techniques. Also the scope has been extended to assessment of BIM implementation. This research is not about
investigating other aspects of KM and BIM such as measuring maturity levels and developing implementation models. The scope of this research is primarily oriented to assist in developing a system to facilitate capturing and retrieving of organisational knowledge to ease its reuse and sharing. In addition, the results of this research are based on the views of participating professionals working in the public BM sector in Kuwait. Therefore, the area of specific focus in this research is the public BM sector in Kuwait.

1.6. Thesis Layout

The thesis contains 13 chapters. A brief description of each chapter is given in this section to demonstrate the progression of the thesis.

**Chapter 1** introduces the research background, research aim and objectives, and justification of the research. It then provides a brief overview of the research methodology, research scope and limitations and thesis layout.

**Chapters 2** presents the philosophical position of this research, detailed research methodology and adopted methods for data collection. The chapter also illustrates the research stages designed to fulfil study objectives.

**Chapters 3, 4, and 5** form the literature review in this thesis. Chapter 3 provides an in-depth review of the literature on BM. Definitions of BM and the types of contracts used in BM are examined. The chapter also investigates processes followed in BM and IT in BM. Chapter 4 reviews the literature on KM, first exploring definitions and dimensions of knowledge itself. The chapter then focuses on KM in terms of its importance in organisations, techniques, models and applications in the BM sector. Chapter 5 explores the definitions, benefits and evolution of BIM and examines methods for storage, sharing and exchange of data and information through BIM. In particular, applications of BIM in the BM sector are discussed.

**Chapter 6** presents and discusses the interview findings regarding the BM process, KM in BM and assessment of BIM implementation. The chapter also examines related documents and conducts an analysis to identify the knowledge taxonomy.

**Chapters 7, 8, 9 and 10** explain the development prototype and its modules that form the base of the prototype.
Chapter 11 illustrates and discusses process of prototype testing. In addition, the chapter demonstrates the evaluation results derived from experts views who participated in the focus group meeting.

Chapter 12: demonstrates case study prototype applications through using a sample project provided by the researcher’s sponsor.

Chapter 13 summarises the thesis and presents main findings of the research. The chapter also highlights benefits of the developed prototype, contributions to knowledge, limitations of the study, and recommends particular areas for future research.
Chapter 2 - Methodology
2.1. Introduction

The essence of this research is to assist decision making in Building Maintenance (BM) through the use of a Knowledge Management (KM) system. In doing so, it is important to investigate current BM practices and how the proposed research will improve these.

It is worthy of note that presenting this chapter prior to chapters of literature review does not demonstrate the chronological order of the actual research work as this study commenced with reviewing literature to provide the relevant background and to establish research territory. Positioning the chapter at this part of the thesis has been considered to enable the reader to gain full understanding of the overall research methodology at an early stage of reading the thesis.

This chapter provides a detailed description of the methodology employed throughout the research project to investigate BM, KM and BIM in Kuwait. It first states the philosophical position of this research is discussed and established. The chapter then identifies the appropriate methodology and resulting methods for gathering and analysing data. The methodology for developing the prototype is then discussed. The chapter also presents a summary of the proposed research stages: literature reviews, interviews, prototype building, prototype evaluation, and prototype application.

2.2. Research Philosophy

Ontology is the commencing position of all research, from which one’s epistemological and methodological stance logically follow (Grix, 2002). It is therefore, necessary to illustrate the ontology and epistemology to outline the philosophical stance of this research. Ontology is concerned with what is knowledge, while epistemology is about how we know it (Creswell, 2002). Burrell and Morgan’s (1979) conceive subjectivist and objectivist dimensions in viewing ontology and epistemology. They observe ontology as either realism or nominalism; and epistemology as positivism or anti-positivism. Burrell and Morgan (1979) ontological view of realism is that social and organisational reality exist separately from human consciousness and cognitions, while in nominalism, reality is simply a product of our minds, a projection of our consciousness and cognition with no independent status. Moreover, their epistemological view suggest that it is possible in positivism (objectivism) to view the empirical world in a neutral way through the accumulation of objective sense-data;
whereas in anti-positivism (subjectivism), knowledge has no neutral bases since all observations are influenced by value and theory. Therefore, the base of a research methodology can be established based on integration of ontological and epistemological assumptions of a researcher.

Quantitative and qualitative research methodologies have originated from these two opposing sides of ontology. The positivist view suggests that research can achieve findings from scientific studies on society, produce social facts and broad generalisations about human behaviour. The positivist researcher should be thus neutral, objective and separated from his or her own values, to achieve the scientific study of society (Dunsmuir & Williams, 1990). Therefore, research derived from the positivist position uses quantitative (statistical) and experimental methods to test the accuracy of a theory.

On the other hand, interpretivistm suggests that social world and natural world are different since people are unpredictable, and therefore, the search for generable laws and truths about human behaviour should be abandoned (Cooper & White, 2012). Researchers in interpretivistm approach are part of the world they are studying and cannot be objective. The interpretivistm approach proposes that research methods and methodologies employed in natural science are not effective in social science (Cooper & White, 2012). Instead, qualitative techniques are used to inductively and holistically understand human behaviour in context-specific settings (Amaratunga et al., 2002).

Within the general area of Construction Management (CM), three methodological paradigms are identified: positivist, interpretivist, and pragmatic or combined approach (Falqi, 2011). However, the subject of selecting a universally appropriate management research methodology in CM field is highly debated (Mukherjee et al., 2002). This is probably because research in CM can be classified at the cross-ways of natural science and social science (Love et al., 2002).

The ontological and epistemological positions of researchers influence their research methodology and selection of specific methods (Greener, 2008). In terms of ontology, this research tries to understand the phenomenon (i.e. the process of building maintenance) and how its knowledge comes from the experience of individuals. Moreover, the participating individuals in this research are part of the world being studied (i.e. the public building maintenance sector).
The first objective of this research seeks to understand and map the management process of Building Maintenance (BM). To achieve this objective, departments involved in BM have to be investigated through exploring the elements that contribute to the management process. This is to establish whether concepts of knowledge management can be introduced to the BM process. Also, this objective is set to identify any deficiencies found in the process related to the management of knowledge, to identify and justify the need for improvement.

The second objective of this research is to explore Knowledge Management (KM) techniques currently being used by the investigated departments and, in addition, to investigate perceptions about the introduction of the KM system.

The third objective is to assess BIM implementation in the BM sector. This involves exploring several issues, including awareness of BIM technology, levels of implementation, factors affecting levels of implementation, and attitudes towards the future of BIM in BM sector. The outcome of the first three objectives contributes to the achievement of the fourth, fifth and sixth objectives: the development of a prototype KM system, its subsequent evaluation to assess its applicability to potential users and its applications in BM projects.

In light of the above, the researcher is adopting a subjectivist stance regarding this phenomenon. Hence, an epistemologically subjectivist approach to understanding this phenomenon (the BM process), by gathering data through people, is considered appropriate. A phenomenological (interpretivist) study, as a methodological perspective, using a qualitative approach, is deemed best for understanding the working nature of BM. This is because a phenomenological study focuses on describing the meaning for several individuals of their experienced phenomenon (Creswell, 2007). This research therefore takes the nominalist position in ontology and subjectivist in epistemology.

### 2.3. Research Methodology

Blaxter et al. (2010) define research as a systematic investigation to find answers to a problem; Research is also an attempt to add to what is known through revealing original facts and relationships (Frankfort-Nachmias & Nachmias, 1992). In order to direct a research to achieve desired aim and objectives, a general plan or roadmap is applied and named a research methodology. Research methodology governs the principles and procedures of logical thought processes utilised for an investigation (Fellows & Liu,
There are several classifications of strategies for research methodology: one prime distinction is between quantitative and qualitative (Neuman, 2007; Creswell, 2008). Since no one universal method is appropriate for all research questions (Hakim, 2000), quantitative and qualitative approaches are at times mixed or triangulated to address research goal and objectives.

Quantitative research, which is also named scientific research, is objective in nature. It is usually related to deductive approach, where data is used to test a theory, but may also include inductive approach where data is implemented to develop theory (Saunders et al., 2012). In deductive approach, inquirer develops theories or hypotheses and then test out these theories and hypotheses through empirical observations (Lancaster, 2005). Robson (2002) listed five stages of the deductive approach: (1) deducting a hypothesis, (2) expressing hypothesis in operational terms, (3) testing the hypothesis, (4) examining outcome, and (5) modifying the theory based on findings. According to Gill and Johnson (2002), the deductive research approach is closely rooted in the positivist paradigm of philosophical assumptions. Data in quantitative research can be expressed numerically or categorised by particular numerical value (Ghosh & Chopra, 2010). This approach principally obtains and analyses small amount of data from large number of participants (Pankowska, 2002).

On the other hand, qualitative research which is also known as interpretivist or naturalist is subjective in nature and relies on obtaining and analysing large amount of data from a small number of subjects. Qualitative research is “an inquiry process based on distinct methodological traditions of inquiry that explore a social or human problem. The researcher builds a complex, holistic picture, analyzes words reports detailed views of informants, and conducts the study in natural setting” (Creswell, 2007, p.15). Qualitative approach is inductively based where researcher formulates explanation of theories and hypotheses based on empirical observations of the real worlds (Lancaster, 2005). The research in this approach commences without a clearly defined theoretical framework; instead relationships between collected data are identified, and then theory develops from the process of data collection and analysis (Saunders et al., 2009). Qualitative research pursues data that denote personal experience in specific situations (Stake, 2010), it is associated with phenomena, and difficult to quantify (Lancaster, 2005). Moreover, it expressed in the form of descriptive accounts of observations (Ghosh & Chopra, 2010). Table 2-1 depicts the main differences between quantitative and qualitative research.
Table 2-1: Differences between quantitative and qualitative research strategies (Bryman, 2003).

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Quantitative</th>
<th>Qualitative</th>
</tr>
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<tbody>
<tr>
<td>1 Principal orientation to the role of theory in relation to research</td>
<td>• Deductive, testing of theory</td>
<td>• Inductive, generation of theory</td>
</tr>
<tr>
<td>2 Epistemological orientation</td>
<td>• Natural science model, in particular positivism</td>
<td>• Interpretivism</td>
</tr>
<tr>
<td>3 Ontological orientation</td>
<td>• Objectivism</td>
<td>• Constructionism</td>
</tr>
<tr>
<td>4 Role</td>
<td>• Fact-finding based on evidence or records</td>
<td>• Attitude measurement based on opinions, views and perceptions measurement</td>
</tr>
<tr>
<td>5 Relationship between researcher and subject</td>
<td>• Distant</td>
<td>• Close</td>
</tr>
<tr>
<td>6 Researcher stance in relation to subject</td>
<td>• Outsider</td>
<td>• Insider</td>
</tr>
<tr>
<td>7 Scope of findings</td>
<td>• Nomothetic</td>
<td>• Idiographic</td>
</tr>
<tr>
<td>8 Nature of data</td>
<td>• Hard and reliable</td>
<td>• Rich and deep</td>
</tr>
<tr>
<td>9 Methods</td>
<td>• Structured interviewing</td>
<td>• Ethnography and participant observation</td>
</tr>
<tr>
<td></td>
<td>• Self-completing questionnaires</td>
<td>• Qualitative interviewing (in-depth, semi- or unstructured)</td>
</tr>
<tr>
<td></td>
<td>• Structured observations</td>
<td>• Focus group</td>
</tr>
<tr>
<td></td>
<td>• Sampling</td>
<td>• Discourse and conversation analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Documentary analysis</td>
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</table>

As indicated in section 2.2, a subjectivist attitude is adopted in this study. Therefore, the research methodology in this study is based on interpretivist approach. Inductive approach with qualitative methods is consequently used for data collection and analysis to address the research aim and objectives illustrated in section 1.3. Figure 2-1 depicts the research paradigm of this study.
As system development is a main part of this research, selecting an appropriate Software Development Methodology (SDM) to develop the proposed system is important. Therefore, the following section discusses available SDM in literature.

### 2.4. Software Development Methodologies

Whitten and Bentley (2007, p.6) define Information System (IS) as “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”. System developers employ frameworks during the IS development lifecycle named System Development Methodology (SDM). SDM refers to the formalised development process that outlines a collection of procedures, methods, best practices, deliverables, and automated tools that aid system developers and project managers to develop and continuously improve the information system and software (Behl, 2009). Pressman (2010) groups the methodologies used based on their activities and workflow. The groups are: the waterfall model, incremental process models, evolutionary process models, and concurrent models.

- **The waterfall methodology**

The waterfall methodology is based on linear framework and focuses on sequential phases. This means a phase begins only when the previous phase has been completed and signed off. The main phases are shown in Figure 2-2 below:

![Figure 2-1: Adopted research paradigm for this study](image)
The methodology of the waterfall lifecycle has several properties (CMS, 2005) which include the following:

1) It supports less experienced project teams or teams with fluctuating composition.

2) The orderly nature of the development stages and strict control of documentation and design ensure the quality, reliability, and maintainability of the developed software.

3) The methodology can provide a measurable progress of system development.

4) It conserves resources.

Vidgen et al. (2002) criticise this traditional methodology as rigid, time-consuming, and for its need for complete and fixed requirements before commencing the design phase. This means that the staged nature of waterfall SDM may negatively affect the progress of the research, in terms of restricting any modifications that may be recommended after the prototype has been developed. Also, errors may appear during the testing stage, which leads further time consumption.

• The incremental methodology

The second type is the incremental methodology, or iterative development. This SDM breaks a project into a series of incremental waterfall segments. Each segment involves a build-test-demonstrate model of repetitive development, in which frequent progress demonstrations, verifications and validations of work are highlighted (Fairley, 2009). In
other words, a basic operational product is delivered after each increment, for verification and validation. Figure 2-3 below illustrates a typical process of incremental methodology. Advantages of this methodology include obtaining early feedback, maintaining control over the lifecycle, early demonstrations to stakeholders, and monitoring the effect of changes, to isolate risks (CMS, 2005).

Figure 2-3: Incremental methodology (Pressman, 2010).

According to Futrell et al. (2002), the incremental methodology is not suitable for relatively small projects. Moreover, they pointed out that this model requires a definition for the complete and fully functional system at an early stage of development. Breaking a project into increments, is therefore, an expensive approach, where formal reviewing and auditing are implemented at each increment of the development lifecycle (Futrell et al., 2002). Since feedback is crucial, adopting this methodology will result in requesting volunteering professionals to repeatedly verify and validate the developing prototype, several times, after each project increment. This may lead to lack of commitment from participants and consequently result in deficiency of critical comments and suggestions.

- The evolutionary process methodologies
The third group of SDMs are the evolutionary process methodologies. Common methodology in this group include spiral and prototyping SDM (Pressman, 2010). The essence of the spiral methodology, shown in Figure 2-4, is based on managing the risk of a software development project (Boehm, 2000). This is done through dividing a project into smaller parts, while assessing the risk throughout the development lifecycle. The spiral SDM employs an expanding cycle that crosses four quadrants: (1) determine objective, (2) identify and resolve risks, (3) development and test, and (4) plan next iteration (Boehm, 2000). Its main strength is in enhancing risk avoidance, useful in selecting a methodology for a given software iteration, and it can incorporate other SDM as spatial cases in a framework (CMS, 2005).

The spiral SDM is a risk management driven methodology and therefore demands considerable expertise in risk assessment and project management (Pressman, 2010). This particular condition requires developers to have extensive practical experience in the field of risk management.

The other type of evolutionary SDM is prototyping methodology. This approach can be used to handle much larger development models (Fairley, 2009). The basic principle of this methodology is dividing the project into smaller segments and developing a small scale mock-up until the prototype has evolved to meet the user’s requests (CMS, 2005). In this methodology, successful prototypes can evolve into working systems.

As shown in Figure 2-5, the prototyping methodology starts with communicating with stakeholders to identify requirements and define the general software objectives. Then a
quick design is developed to represent system key parts for initial revision and evaluation. After that, a working prototype is built for evaluation and refinement. Next, iterations are carried out in this methodology leading to evolution of a prototype to satisfy the requirements of clients.

![Prototyping methodology](image)

**Figure 2-5: Prototyping methodology (Pressman, 2010).**

- **Concurrent methodology**

The fourth type identified by Pressman (2010) for software development is the concurrent methodology. This methodology allows for different software engineering activities to occur concurrently. For example, high-level programming can start as soon as high-level conceptual design is determined, even while detailed requirements are still being investigated (Poppendieck & Poppendieck, 2003). This methodology allows for different teams to collaborate despite of geographical constrains. The concurrent methodology can also be applied to all other models as a modeling activity within a phase of a larger SDM. Benefits of this approach include faster execution of programmes and collection of problems from several simultaneous tasks to allow for natural representation of solutions (Hughes & Hughes, 2003). The concurrent nature of this methodology is more appropriate for projects that have different contributing stakeholders. This is to allow several simultaneous software related activities to be performed at a one particular time. The following section discusses and presents the research methods selected for this study.
2.5. Selection of the Research Methods

Research methods are defined as “techniques and procedures used to obtain and analyse data” (Saunders et al., 2009, p.3). The research methodology can be quantitative or qualitative. The main research methods adopted in the area of CM are qualitative, quantitative, and mixed methods (Dainty, 2008). However, research purpose and objectives are the most significant factors affecting the selection of the research methods (Lancaster, 2005).

The main methods in qualitative inquiry are observation, interviews, group interviews, and reviewing of relevant records and documents (Maykut & Morehouse, 1994; Mertens, 2009). Data in qualitative research is collected from small number of individuals (Creswell, 2011a) and comprised of thorough descriptions of the incident rather than numerical codes (Marvasti, 2003). Qualitative research methods aim to achieve ‘depth’ rather than ‘breadth’ through focusing more on exploring in much detail smaller number of instances or examples which are perceived as being interesting and enlightening (Blaxter et al., 2010). Data analysis in qualitative research usually involves compiling, disassembling, reassembling to prepare them for interpreting (Yin, 2010a).

Main quantitative methods include sampling, structured interviewing, questionnaires, and structured observation (Bryman, 2012). Data in quantitative methods are typically in a numeric form (Blaxter et al., 2010) collected from large sample of individuals (Creswell, 2011a) and mostly analysed using statistical techniques (Lancaster, 2005).

The research objectives should guide researchers into selecting appropriate methods for data collection and analysis to maximise the achievement of the research aim and objective. Table 2-2 depicts the research aim and objectives with the selected research methods.
Table 2-2: Selected research methods.

**Research aim:**
To develop a BIM-based system that aids in capturing generated knowledge and facilitating its reuse to BM professionals when performing their duties.

<table>
<thead>
<tr>
<th>Research objectives</th>
<th>Research methodology</th>
<th>Selected research method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To map and examine main processes and stages of services provided by BM departments</td>
<td>Qualitative</td>
<td>Interviews</td>
</tr>
<tr>
<td>2. To explore issues related to KM including techniques, awareness, perceptions, and IT usage</td>
<td>Qualitative</td>
<td>Interviews</td>
</tr>
<tr>
<td>3. To assess BIM implementation in the building maintenance sector</td>
<td>Qualitative</td>
<td>Interviews</td>
</tr>
<tr>
<td>4. To develop a prototype BIM-based system to manage knowledge in Kuwaiti public departments to overcome challenges arising in their BM projects.</td>
<td>SDM</td>
<td>Prototyping</td>
</tr>
<tr>
<td></td>
<td>Qualitative</td>
<td>Document review</td>
</tr>
<tr>
<td></td>
<td>Qualitative</td>
<td>Focus group</td>
</tr>
<tr>
<td>5. To validate the developed BIM-based system through the process of evaluation by potential users working in the public BM sector in Kuwait.</td>
<td>Qualitative</td>
<td>Focus group</td>
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<tr>
<td>6. To demonstrate the usage of the developed BIM-based system.</td>
<td>Qualitative</td>
<td>Case study application</td>
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While quantitative methods can obtain data from large samples, a qualitative method is needed to understand and obtain more in-depth level of details being investigated in the research objectives. Therefore qualitative semi-structured interviews are conducted to meet the first three objectives of this research. The first objective is set to understand and attempt to map the process followed by BM departments. In addition, interviews are carried out to investigate issues related to KM and to assess BIM implementation in the sector (second and third research objectives). Findings from collected data are used in developing a prototype KM system (fourth research objective). Prototyping
methodology is used for system development. During building the KM prototype, validation of system attributes is required. Therefore, another qualitative method, in the shape of focus group meetings, is used to address this issue. The fifth research objective requires evaluating the developed prototype. Hence discussion-based feedback is required after performing usability testing; therefore focus group meetings are deemed most appropriate. The sixth research objective is set to demonstrate the usage of the developed prototype. This is done through a case study application in a realistic project to illustrate the functions of the prototype. The following section presents the research design, showing in detail the adopted research methods for each stage.

2.6. Research Design

The research process is designed to optimise the ability of the research to achieve its defined aim and objectives, as illustrated in section 1.3 Figure 2-6 illustrates the stages of the research process that are set to achieve the research aim. First stage of this research is illustrated in section 2.6.1 which consists of a comprehensive review of the literature to identify the area and scope of the research. Second stage of the research is discussed in section 2.6.2 including the type of data collection used to address first, second, and third research objectives. This stage also involves reviewing relevant documents obtained from participating departments. The third stage of this research is illustrated in section 2.6.3 which discusses KM prototype building. This stage includes selecting the methodology for system development, tools that are used for prototype development, attribute validation, attribute refining, and prototype testing. This is followed by the fourth stage which describes prototype evaluation process shown in section 2.6.4. The fifth stage demonstrates the applications of the developed prototype, as shown in section 2.6.5. Finally, the sixth stage sums up the research and presents conclusions and recommendations for future research, as shown in section 2.6.6.
Chapter 2: Methodology

Figure 2-6: Stages of the research.
2.6.1. Stage 1: Literature reviews

The initial stage of any empirical research involves preparatory work and ground-clearing in form of reviewing literature and current studies to provide fusion of different areas of knowledge on a precise question (Hakim, 2000). The initial stage of this research involves collecting secondary data through reviewing the literature to provide understanding of the concepts of KM, BM, and BIM.

The review first studies the concept of KM in general, its processes, and its importance to organisations then reviews work on KM based systems applied in BM. The review then continues to study BM in organisations, including BM processes and systems developed for BM. Finally, the BM sector in Kuwait and its significance in the Kuwaiti context are examined.

The literature review then proceeds to study the BIM concept, with a focus on BIM in BM sector, and BIM based systems and technologies developed for BM sector. The outcome of this stage aims at providing background on the field investigated and establishing a research opportunity through identifying the research gap in KM and BIM-based systems.

2.6.2. Stage 2: Interviewing participants and reviewing relevant documents for data collection

Interviewing in its simplest matter is a conversation with a purpose of gathering information (Berg, 2001). Schostak (2006) points out that through an interview one can extract insights into the experiences, beliefs, values, knowledge, interests, concerns, and it also provides means of viewing, reasoning and actions of the other. Addressing research objectives of this stage, i.e. gaining an understanding of departmental processes, and investigating KM related issues and perceptions, interviewing was considered the most appropriate method for data collection.

A series of semi-structured interviews are carried out to acquire the primary data of this research. The interviews are conducted with ten professionals working in BM departments within public ministries and organisations (further details are illustrated in section 6.2). The criteria for selecting the participants are based on managerial position and years of experience in BM. As a result, professionals holding management positions from three small, four medium and three large BM departments were interviewed.
The outcome of the interviews includes mapping a generic process for public BM, techniques and perceptions about KM and identifying existing deficiencies in knowledge sharing within public BM, current levels of BIM implementation and future expectations. BM contract documents being used by the participating department are also examined during this phase of the research. This is done to identify a taxonomy of knowledge familiar to and utilised by BM employees, which could then be employed in the developed system.

2.6.3. **Stage 3: Developing prototype KM system**

As the aim of this research is to develop a KM system for BM, this makes developing the KM system the longest stage of this research. Therefore, several sub-stages are set including selection of a software development methodology, developing the KM prototype, prototype attribute validation, prototype attribute refining and prototype testing.

**2.6.3.1. Selection of software development methodology**

Selecting a Software Development Methodology (SDM) is based on comparing the models illustrated in section 2.4 to find the most appropriate one to serve the research purpose. The first SDM reviewed was the waterfall methodology, which was seen impractical for this research due to its staged nature and rigidity, which may lead to extensive time consumption.

The incremental methodology was also considered unfeasible for this research. The reason behind this decision was the requirement of repetitive input, which might not be achieved, due to lack of commitment from participants.

The spiral methodology was also deemed inappropriate for the system development process, as it is a risk management driven methodology and consists of expanding repetitive tasks which would consume excessive time.

The concurrent methodology is particularly appropriate for software development projects that contain several teams, since it permits simultaneous input. As the contribution of this research is based on individual effort in carrying out concurrent activities which are difficult to perform and manage, this methodology was seen as inappropriate for this research.
Therefore, developing the KM prototype system in this research will be based on the prototyping methodology. The reason for that is because the development of software is usually tailored to client requests and funding. However, the application being developed in this study is mainly research driven not a client driven. In other words, initial stages for development of the software are based on gaps found in research to answer an existing problem. The input from potential users comes at later stages, to modify and refine the developed KM prototype. Therefore, an evaluation stage carried out by potential users is crucial to measure attitudes towards the developed prototype. This methodology allows the prototype to be demonstrated and evaluated for approval as well as allowing for feedback for further improvements.

2.6.3.2. Stage 3.1: developing the KM prototype

Based on the prototyping methodology, the process of system development commences by integrating findings obtained from interviews and opportunities for further research found in literature. A main gap identified from the literature review is the lack of research on BIM-based applications to be used as a KM system in the BM sector. Moreover, the results from interviews can reveal deficiencies and problems which can be addressed by the proposed system.

These results aid in developing a BIM-based KM prototype that aims at facilitating knowledge sharing between employees. During this stage, an investigation is conducted on how BIM technology can be used as part of KM system and also how Case-based Reasoning (CBR) principal as a KM technique can be employed in the proposed system.

As the development of the proposed KM system involves integration of technologies, certain structure and coding is required. This involves the use of a software environment including EasyPHP. This environment includes several software applications: Apache, MySQL, PhpMyAdmin, and Xdebug. Hypertext Preprocessor (PHP) language is used as a general language for coding in developing the KM prototype. Furthermore, Structured Query Language (SQL) is used to develop and structure the system knowledgebase through MySQL software. Other software applications used during the KM prototype developing stage include MS Expression, Notepad++, and MySQL Workbench. A Graphical User Interface environment is used to connect the parts of the proposed
prototype in a user-friendly presentation that allows users to use selection options such as buttons, text boxes and dropdown menus.

2.6.3.3. Stage 3.2: KM Prototype attribute validation

The development of KM systems requires validation and weight setting of knowledge case attributes. The attributes are developed to describe knowledge cases that will be retained in the system.

The validation of the attributes will be conducted by the involvement of BM professionals through focus group meetings. Focus group is “the label given to a special type of group interview that is structured to gather detailed opinions and knowledge about a particular topic from selected participants” (Bader & Rossi, 2002, p.2). Focus group is employed to reach an agreement about a subject that is comprehended differently (Krueger & Casey, 2009). A key benefit of focus groups is that participants can respond to and comment upon the replies and remarks of others, which can lead to the emergence of information or stimulating ideas that would otherwise not have occurred (Langford & McDonagh, 2003). Furthermore, data emerging from focus group reveals more information than surveys, and participants can contribute without much preparation (Bader & Rossi, 2002).

The focus group meeting used in this study will be organised by the researcher. Eight participating members comprised of BM professionals holding a cross-section of positions and years of experience and were selected as potential users (further details are provided in section 8.7). The Kuwait Society of Engineers (KSE) supported the researcher in terms of facilitating suitable workshop venues.

The validation procedure requires the focus group participants to validate and weight the knowledge case attributes. Several techniques can be used for such purpose. In this research, the “Analytic Hierarchy Process” (AHP) technique is employed to achieve the purpose of the focus group meeting. The results are analysed utilising software including Expert-Choice and an Excel template, prepared and provided by Goepel (2012), and used to refine the knowledge case attributes.
2.6.3.4. **Stage 3.3: KM Prototype attribute refining**

Based on the results obtained from previous stage the refining process is in the form of modifying the number of attributes and adjusting their weights. The resulted attributes are utilised in the process of case retrieval.

2.6.3.5. **Stage 3.4: KM Prototype testing**

The aim of system testing is to verify that all functions are working properly and ready for the evaluation stage. Therefore, prototype testing commences during the development of the prototype. This sub-stage includes testing system interface functions and contents. Since system testing can be a lengthy process, the researcher devised the system testing in a form of predefined tasks to identify and fix errors and defects. Examples of predefined tasks include: testing the function of login and out of the prototype, reading the contents of knowledge cases, extracting and indexing knowledge cases, testing the accuracy of knowledge retrieval, searching for cases using keywords, navigating for knowledge cases, the presentation of system results, and attaching files to the system. The final outcome of the testing stage should be a working prototype with functions performing as designed.

2.6.3.6. **The BIM environment**

Several types of BIM-based software can be used to generate digital models including: *ArchiCAD*, *Bentley*, and *Revit*. The BIM environment used during the whole development stage of the prototype is *Revit* software, since this is provided free by the university.

2.6.4. **Stage 4: KM Prototype evaluation**

The evaluation stage involves external experts participating in a focus group meeting to review and evaluate the prototype through usability testing (further details are illustrated in section 11.3). This is done with group members performing predefined tasks. These tasks aimed at evaluating the overall performance of the system and its expected level of improvement to knowledge sharing and reuse in BM departments. The feedback and outcomes of this stage are used to enhance the developed prototype and to guide future improvements.
2.6.5. **Stage 5: Prototype application**

This stage comprises of demonstrating the functions of the prototype using a sample project as a case study for system application.

2.6.6. **Stage 6: Conclusion and recommendations**

This stage involves drawing conclusions based on the research results and framing recommendations for future development. Also limitations of the research are identified in this stage.

2.7. **Summary**

This chapter has discussed the methodology adopted and methods used in this research. The research is based on the nominalist position in ontology and subjectivist in epistemology. Therefore, inductive approach with qualitative methods for data collection and analysis was considered appropriate in this research. The research adopts the prototyping methodology for software development. Several qualitative research methods were considered as suitable to achieve the research aim and objectives. These are literature reviews, interviews, and focus group meetings for prototype building, prototype validation, prototype refining and evaluation, and prototype application. As literature review is the first stage of this research, the following three chapters review published literature in the areas of BM, KM, and BIM.
Chapter 3 - Building Maintenance
3.1. Introduction

Maintenance services have a significant role in providing a comfortable environment to the occupants for working and living. A unique aspect of Building Maintenance (BM) is that its activities are extended throughout a building’s life span and unlike other construction stages, involve multiple stakeholders who are replaced over time.

This research is focused on implementing KM into BM. Therefore, this chapter provides background information on BM and begins with definitions of BM. This chapter then discusses types of maintenance and different types of BM. Next, the process of BM is examined, and technologies used in maintenance are briefly discussed. After that, issues related to BM are considered. Lastly, this chapter provides information on the Kuwaiti economy, its construction industry, and the significance of BM in that context.

3.2. Building Maintenance

The British Standard BS EN 15331:2011 defines BM as: “Combination of all technical, administrative and managerial actions during the lifecycle of a building (or a part of it), intended to retain it, or restore it to, a state in which it can perform the required function” (BSI, 2011, p.5). The British Standard BS 8210:2012 defines Facilities Maintenance as: “work needed to maintain the performance of the building structure, fabric, and components, and engineering installations” (BSI, 2012, p.2).

These definitions recognise several aspects related to BM including:

- The recognition of buildings as tangible assets and resources that have functions in organisations.
- Such assets need continuous maintenance, appreciation and protection.
- The maintenance activities are diverse: technical, administrative and managerial.
- Maintenance covers all aspects of building components which require collaboration of professionals from different fields.
- Maintenance can extend to the whole lifecycle of a building.
- A building may need restoring or improving at certain stage to provide a better service. For instance, technologies, materials and components employed at early
years of buildings will inevitably age and become obsolete with time. As a result, selecting appropriate products and technologies can have a significant impact on the level of service provided by the facility. Therefore, maintenance teams have to have knowledge on function of buildings and appropriate products.

- Since maintenance works commence from buildings’ initial use till their disposal, buildings are frequently occupied during projects. Therefore, further health and safety measures are needed during projects.

The Chartered Institute of Building (CIOB) (1990) also supports the significance of BM and recognises buildings as the “nation’s most valuable asset” for providing shelter and facilities for leisure and work. CIOB (1990) embraced the following definition:

*Building maintenance is work undertaken to keep, restore or improve every facility, i.e. every part of a building, its services and surrounds to an agreed standard, determined by the balance between need and available resources*.

The CIOB definition considers the financial aspect as a main factor affecting the level of maintenance for buildings. Both the BSI and CIOB definitions emphasise the importance of the BM activities for organisations in form of maintaining assets (buildings). However, the CIOB definition expands this more widely and recognises the value of balancing between need and available resources.

Availability of resources can be subjected to several factors including economic, political, and social. Within the area of the public sector, Barrett and Baldry (2003) pointed out that decisions, policies and processes of maintaining buildings are largely influenced by non-financial aspects related to standards of public service terms, public accountability and probity, in order to meet the needs, expectations and interests of various and authoritative stakeholders.

This may become clear when authorities attempt to balance between budgets for maintaining buildings and factors from the economy, politics and society. Balancing such factors usually places pressure on BM, since it is still viewed as an expenditure liability by many organisations (Jones & Sharp, 2007). This is perhaps due to BM and Facilities Management (FM) being seen as “non-core” functions that provide only “supportive” services in organisations (Waheed & Fernie, 2009) and spending on these is commonly regulated by renewed budgets (CIOB, 1990). Moreover, unlike other
industries, BM has no clearly distinguished sector, but is seen as an activity in the larger context of FM (Barrett & Baldry, 2003) and simultaneously is considered as part of the construction sector (Ali et al., 2006; Doran et al., 2009). Therefore, little consideration is offered to improvement in the delivery of the services of building maintenance (RICS, 2009). None the less, with pressure on businesses in private and public sectors, the practical relevance of FM/BM is increasingly being recognised by organisations (Pathirage et al., 2008). Therefore, finding an equilibrium between continuous improvement of services within available budgets is a constant pursuit of BM organisations.

3.3. Types of Building Maintenance

There are several classifications for maintenance. Sullivan et al. (2010) categorised maintenance into four classes: reactive maintenance, preventive maintenance, predictive maintenance, and reliability centred maintenance. However, BSI 3811 (1993) categorises maintenance into the following seven types: planned maintenance, preventive maintenance, unplanned maintenance, corrective maintenance, emergency maintenance, condition-based maintenance, and scheduled maintenance. The BSI 3811 (1993) defines these maintenance terminologies as follows:

- **Planned maintenance**: organised and carried out with forethought, control and the use of records, to a predetermined plan.

- **Preventive maintenance**: carried out at predetermined intervals, or corresponding to prescribed criteria, and intended to reduce the probability of failure, or the performance degradation of an item.

- **Unplanned maintenance**: carried out to no predetermined plan.

- **Corrective maintenance**: carried out after fault recognition and intended to put an item into a state in which it can perform a required function.

- **Emergency maintenance**: maintenance that is necessary to put in hand immediately to avoid serious consequences.

- **Condition-based maintenance**: carried out according to the need indicated by condition monitoring.

- **Scheduled maintenance**: preventive maintenance carried out in accordance with an established time schedule.
As shown in Figure 3-1, Booty (2006) and Chanter and Swallow (2007) categorised the types of maintenance into only two main classifications: planned and unplanned. Planned maintenance (also known as cyclical, proactive, and programmed) encompasses condition-based maintenance, preventive maintenance, corrective maintenance and scheduled maintenance (Booty, 2006; Chanter & Swallow, 2007). On the other hand, unplanned maintenance (also known as reactive) consists of corrective and emergency maintenance (Booty, 2006; Chanter & Swallow, 2007).

**Figure 3-1: Types of maintenance (Chanter & Swallow, 2007).**

**Figure 3-2: Decision-based type of maintenance (Chanter & Swallow, 2007).**
A different classification of maintenance is provided by Chanter and Swallow (2007). As shown in Figure 3-2, such classification is based on decisions as to how the action of maintenance is performed.

Maintenance can also be classified into Tactical and Strategic maintenance (Audit Commission for Local Authorities in England and Wales, 1988; Cited in Chanter & Swallow, 2007). Tactical maintenance refers to the day-to-day minor maintenance works in response to immediate needs such as a water leak. Tactical maintenance can also include work that is not essential to the structure’s integrity such as internal decoration (Audit Commission for Local Authorities in England and Wales, 1988). Strategic maintenance is the long term preservation of a property. This type of maintenance can be forecasted, with future budget allocation, for example, programmed maintenance, planned renovation, major structural repairs, and installation of engineering equipment.

The review in this section has provided the background of types of building maintenance. This has helped the researcher to be more familiar with BM methods, and to thus identify common problems and types of approaches during field data collection. Distinguishing between types of maintenance and adopting a particular one is not considered in this study since such an approach does not affect the research output.

3.4. Contracts in Building Maintenance

A contract is defined as: “A binding agreement between two or more persons which creates mutual rights and duties which are enforceable at law” (Chappell et al., 2001, p.97). Hence, a contract enforces contractual and legal responsibilities on parties that are impossible or difficult to change (Sweet, 1989; Cited in Thomas & Ellis, 2007). In general, a valid contract must have the following elements (Thomas & Ellis, 2007):

- **Competent parties**: parties involved in a contract should be in proper age and obtain adequate mental awareness.
- **Offer and acceptance**: that is a mutual agreement between contract parties.
- **Reasonable certain of terms**: contract terms should be reasonably clear.
- **Proper subject matter**: parties must agree to do something legal.
- **Considerations**: something of value must be exchanged.
In the construction industry, a typical contract comprises of at least two mutual responsibilities: the contractor has the responsibility of performing work specified in the contract, and the owner has the responsibility to pay the contractor for that work (Kelley, 2012). Moreover, a contract usually consists of several documents that regulate the main aspects of the legal relationship between the contractor and the owner including the scope of work, the project budget, the project schedule, the quality of work, and rights and remedies for parties when obligations are breached (Kelley, 2012). As a result, most contracts in the construction industry include the following documents (Rodriguez, 2013; Murdoch & Hughes, 2008):

- **Articles of agreement** (owner-contractor agreement): these record, in general terms, what the project parties have contracted to do.
- **General conditions**: these highlight and explain the basic obligations and rights the parties undertake to execute the project.
- **Special conditions**: project-specific conditions where clauses and facts are formulated for a particular project.
- **Bill of Quantities**: this defines the quantity and quality of obligated work. This document may not be required by the client.
- **Drawings**: the group of drawings that form the model of the project.
- **Specifications**: the technical information regarding the project’s components, materials, standard of workmanship, codes and standards, and accepted performance levels.
- **Schedules**: time plan or programme of work for project tasks.
- **Pricing schedules** (schedules of rates): price breakdown of project items.
- **Insurances**: these can include insurance protections, required bonding, and types of coverage.

As part of the construction industry, the BM sector usually employs such documentation for maintenance contracts. However, different contracting approaches are followed to carry out maintenance works. This is because construction contracts involve designing and/or constructing a new structure, while BM contracts involve exchanging of money for maintenance and repair services to an existing building or group of existing buildings.
The approaches to contracting in maintenance works differ in the methods and allocation of financial risk that result in diverse pricing arrangements, work evaluations, payments processes and documentation requirements (Chanter & Swallow, 2007). Additionally, Chanter and Swallow (2007) point out that each of the contractual approaches of procurement is designed to suit particular group of circumstances. Several approaches to maintenance work contracts can be employed in BM (Wordsworth, 2001; Murdoch & Hughes, 2008; Wiggins, 2010):

- **Lump sum contract**: a fixed price is paid by the client to the contractor in exchange for a defined requirement to be supplied or performed.

- **Measured Term Contract (MTC)**: work in this form of contract is measured and priced after completion on the basis of agreed pricing schedules.

- **Cost reimbursement contract**: in this form of contract, the client reimburses the contractor with the all costs of labour and materials plus an agreed fixed fee or percentage.

- **Term contract**: this form of contract is used for a planned programme of work or call-off goods, where prices and conditions are agreed.

- **Fixed price maintenance contract**: a fixed price is agreed to carry out all recurring work over a specific period of time.

- **Direct labour**: in-house teams carrying out maintenance activities.

Since the pursuit for increased efficiency motivated by best practice has stimulated the public sector to outsource maintenance activities (Chanter & Swallow, 2007), the BM departments investigated in this research employ contractual arrangements with external contractors to outsource some or all building maintenance works.

This section has provided the researcher with a background in terms of the types of approaches to contracting and documents included in BM contracts. This research will later review contracts used by departments investigated during the field work for data collection. This is done to assist in understanding the process of BM and to identify common features in BM contracts that can be utilised in later stages of this research.
3.5. Process of Building Maintenance

The diverse types and sizes of buildings influence maintenance activities and processes. Therefore, the responsibility of maintenance can range from an additional secondary duty assigned to an individual in a small firm (Ali et al., 2006) to a large distinguished BM department with designated contracts and teams. The arrangement of a BM department in an organisation relies on the strategic goals of that organisation and the significance it attaches to the condition of its buildings (Chanter & Swallow, 2007). Therefore, BM departments follow series of processes to deliver their services. A process is defined as “set of interrelated or interacting activities which transform inputs to outputs” (ISO 9000, 2008, p.3). Mapping a process and categorising its involved parties can assist in identifying deficiencies and issues related to the service delivery in BM.

Typically, four main parties are involved in the building maintenance work: the user, the client, the management team and the contractors (Ali et al., 2006). Users are the occupants or tenants who use the facility and are affected by the level of its condition. The client is the owner of the property and ultimately liable for the costs, the management team manages the contract between the client and contractors and can either be an in-house department or an outsourced agency, while the contractors are those who carry out the actual works (Ali et al., 2006). In addition, large organisations use both in-house staff and outsourced contractors to carry out maintenance work (Wordsworth, 2001). Therefore, other parties such as in-house teams, materials suppliers and auditing divisions can also be included as additional main parties involved in maintenance works.

In the building maintenance field, Ali et al. (2002) have developed a process model for reactive maintenance projects in the UK. The model includes a high level business process, Figure 3-3, showing interactions between four stakeholders: the client, the FM agent, the contractor and the suppliers.
Figure 3-3: Reactive maintenance project high-level business process (Ali et al., 2002).

Based on an examination of the process shown in Figure 3-3, Ali et al. (2002) identified several deficiencies that hinder the performance of the participating maintenance organisation. These deficiencies include inadequate knowledge support in the helpdesk IT system, double handling of data entry, and poor communication medium. Based on the identified deficiencies, a prototype KM system named “More Productive Minor Construction through IT” (MoPMIT) was developed, with the main aim of exploring the use of web-based technology to enhance the management of reactive maintenance (Ali et al., 2002, 2004).

Akasah and Amirudin (2006) developed a model that represents the existing maintenance management processes of school buildings. The model, shown in Figure 3-4, consists of six main activities (A1 to A6), with interrelations of input elements (on the left of the model), control elements with needed resources (top of the model), and roles of responsible personnel (bottom of the model). Akasah and Amirudin (2006) state that the application of such a model is expected to improve understanding of the maintenance process, leading to effective maintenance management (right of the model).
Within the area of Facilities Management (FM), McAndrew et al. (2005) examined the processes of managing and tracking work orders in several FM departments, to enhance their service delivery. Their study examined three selected FM departments in organisations from different sectors: academia, healthcare, and banking. Figure 3-5, Figure 3-6, and Figure 3-7 illustrate typical reporting and job allocation scenarios in FM departments in organisations in each of these sectors.

**Figure 3-4: Main function model for maintenance management processes (Akasah & Amirudin, 2006).**

**Figure 3-5: Typical reporting and job allocation scenario for a FM department in banking organisation (McAndrew et al., 2005).**
Figure 3-6: Typical reporting and job allocation scenario for a FM department in healthcare organisation (McAndrew et al., 2005).

Figure 3-7: Typical reporting and job allocation scenario for a FM department in a higher education organisation (McAndrew et al., 2005).

McAndrew et al. (2005) identified several key issues when the processes from the three departments were examined and compared. It was found that in overview, health and higher education organisations are similar, being in closed campuses. On the other hand, the banking organisational structure consisted of thousands of individual branches and
various considerably-sized offices. Key problems identified included insufficient input from design stage of new-build projects. Moreover, all the departments were found to employ inefficient methods for problem reporting and tracking of FM services. Also there was lack of real-time reporting and tracking facility for FM related aspects.

Based on such findings, McAndrew et al. (2005) concluded that a FM system can be useful to improve practice and utilise working time with respect to real-time job reporting and tracking. They therefore, proposed a conceptual technology outline within a wireless web-based service for recording and tracking requests in FM.

Coenen et al. (2011) investigated the process of provision of services within the field of FM and developed a model that visualises related activities. While their study is not directly related to BM, it investigates the processes from management point view of FM services. Figure 3-8 shows a conceptual insight into this technique using the health-care sector as an example. The figure depicts the process flow of a one-day hospital stay for surgery. The process flow illustrated in the FM model depicts four possible zones representing involved parties, which are: customer zone, employee zone, management zone, and finance zone. The customer zone represents all potential processes and related physical evidence from patient perspective, from checking in to the hospital to checking out. The employee zone illustrates all processes (core and supporting) of hospital employees that are in direct interaction with the patient from checking in to checking out. The management zone shows all processes (core and supporting) that are related to managing the processes of other zones. Finally, the finance zone shows the cost/benefit breakdown (i.e. sales revues, material cost, property cost, manpower cost, and profit per unit) for each step of the process. Coenen et al. (2011) suggest that effectiveness and efficiency can be managed through visualisation of FM services. The visualisation can optimise FM service through modifying steps of the process and financial transparency can aid finding answers to process-design challenges.
Figure 3-8: FM blueprint of a one-day hospital stay for surgery (Coenen et al., 2011).

The review of the above studies shows that although all FM/BM organisations aim at improving their service delivery, they follow different routes, based on several factors such as organisational structure, size, business functions, and type of beneficiaries.

This study will later investigate how public BM sector in Kuwait deliver its services. This will be done through mapping the business process of public BM departments. The output of such investigation establishes understanding of the adopted processes which will help identify deficiencies that hinder delivery of BM service.

The following section discusses how Information Technology (IT) is used to facilitate the delivery of BM services.

3.6. Information Technology in Building Maintenance

Implementation of IT in FM/BM sector will ultimately improve quality, cost-effectiveness and efficiency of the delivered services (Olalla, 2000; Barrett & Baldry, 2003) through better access to information. Hence, several academic studies have focused on proposing technological solutions to improve delivery of service in FM and
BM fields. Examples of research for implementing IT in FM and BM include: integration of open-source FM software (Nes, 2005), adopting BIM for FM in the Sydney Opera House (Akhurst & Gillespie, 2006; CRC, 2007), cost estimation for building restoration (Wang et al., 2008), Community of Practice for BM (Fong & Wong, 2009), and a knowledge portal for good practice in FM (Elmualim et al., 2010b). The purpose of such studies is to enhance information flow, leading to lower costs and better efficiency and improved service quality.

On the commercial side, Sun and Howard (2003) describe several commercially available off-the-shelf software applications such as: Archibus/FM, CAFM Explorer, QFM, FacilityOne and Planet FM. Their advertised functions include: assisting in helpdesk call centres, planning, managing, tracking and controlling of organisations’ projects, assets, spaces and budgets and costs. Computer Aided FM systems (CAFM) can be classified into Asset management systems, Graphical spatial planning systems, and Computer integrated facilities management systems (Sun & Howard, 2003). In Asset management systems, data about assets are entered and extracted from spreadsheet databases for maintenance scheduling and analysis. In Graphical spatial planning systems, further to the integration of asset management databases, such CAFM systems employ graphic displays of technologies such as CAD, 3D, BIM and GIS to enable FM managers to carry out their tasks. The chief function of computer integrated facilities management systems is the integration and distribution of FM activities through computing networks and the internet.

According to Davenport and Short (1990; Cited in Pintelon et al., 1999), IT systems have several capabilities in organisational processes:

1) Transactions: transform disorganised procedures into routine transactions.

2) Geographic: allow communications over long distances.

3) Automation: reduce human labour.

4) Analytic: employ complex analytical methods.

5) Information: handle large amount of information.

6) Simultaneous: allow working on concurrent multiple tasks.
7) Knowledge management: allow capturing and retrieving of knowledge and expertise to improve procedures.

8) Track: allow thorough follow-up on inputs, outputs, and task status.

9) Disintermediation: allow direct communication between parties without intermediate parties.

Since this research aims at managing knowledge of BM, Chapters (4) and (5) will provide a more in-depth review on technology implementation in organisations from the perspectives of Knowledge Management (KM) and Building Information Modelling (BIM).

3.7. The Building Maintenance Sector in Kuwait

This section attempts to examine the public BM sector in Kuwait. However, it has been difficult to make a separation between the sectors of BM, FM, and the construction industry in Kuwait. This is because the state budget, public spending, development plans, and policies recognise all such disciplines as one category under construction projects, maintenance projects and public acquisitions. Therefore, to be consistent with the available information reviewed on Kuwait and its economy, this section recognises building maintenance and facilities management as part of the construction industry in Kuwait.

3.7.1. The Kuwaiti economy

Kuwait is considered one of the wealthier countries with large oil reserves leading to have one of the highest per capita incomes in the world (The World Bank, 2012). However, According to the Minister of Finance, the economy of Kuwait is mono-resourced with income from oil revenues, and international investments are the main economical drivers (Alhajraf, 2011). In 2011, the oil sector alone represented more than 94% of total public income and more that 62% of the total GDP, 66% when including the oil refining sector (NBK, 2012; CBK, 2013).

Government spending largely dominates the economy in Kuwait. This is attributed to the limited manufacturing and production foundations in Kuwait forcing the private sector to be dependent on public demands and contracts awarded for goods and services
Chapter 3: Building Maintenance

(Al-Sultan et al., 2000). This, consequently, has resulted in a significant public sector portion in the Gross Domestic Product (GDP). According to NBK (2012), the public sector in 2010 accounted for 74% of the economy’s gross value added (= GDP + subsidies – sales taxes), and as much as 80% in 2011. Therefore, public spending, including the expenditure on the construction sector, is largely affected by oil prices, which have remained steadily high for several years. Consequently, fiscal state budgets have experienced continued surpluses for more than a decade. This in turn has led to high public expenditure (CIA, 2013).

3.7.2. The construction and maintenance industry in Kuwait

With large budget surpluses, public expenditure on construction has increased over the years. Table 3-1 shows public expenditure on the construction sector.

Table 3-1: Public expenditure on the construction sector.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Expend. on construction*</td>
<td>1201</td>
<td>1285</td>
<td>1420</td>
<td>2121</td>
<td>2663</td>
<td>2421</td>
<td>3807</td>
<td>5446</td>
</tr>
<tr>
<td>% of total expend.</td>
<td>8.41</td>
<td>8.29</td>
<td>6.10</td>
<td>9.68</td>
<td>6.45</td>
<td>9.52</td>
<td>10.38</td>
<td>12.40</td>
</tr>
<tr>
<td>% of change</td>
<td>N/A</td>
<td>-0.13</td>
<td>-2.19</td>
<td>3.58</td>
<td>-3.22</td>
<td>3.07</td>
<td>0.86</td>
<td>2.02</td>
</tr>
</tbody>
</table>

* In million GBP

As can be seen in Table 3-1, the trend of public spending on construction has been steadily increasing except for the period 2009-2010. However, it can be noted that the percentage of change in expenditure on construction compared to the total public spending was negative in the periods of 2005, 2006, and 2008. This is due to other sectors occupying a larger share of the increased public spending compared to the construction sector. The largest share of this spending surge went particularly to salary increases for public sector employees (CIA, 2013). With continuing budget surpluses from strong oil revenues, it is expected that the spending on the construction sector will continue to grow. Moreover, this section expresses only half of the story of public spending on construction sector. The following section examines the other forms of public spending in the construction sector, where BM significantly emerges as an importance discipline.

In parallel to the annual public spending on construction sector, a large scale economic development plan, named “Kuwait Development Plan” (KDP), was approved in 2010 to
help transform the State of Kuwait into a Middle East financial and trade centre. The KDP has a five year time period with a budget of approximately £85bn and consists of approximately 1100 projects, including several mega projects. Table 3-2 illustrates the progress of several selected KDP projects:

Table 3-2: Sample of KDP projects (Ansari, 2013).

<table>
<thead>
<tr>
<th>Project</th>
<th>Cost</th>
<th>Status</th>
<th>Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Az-Zour Power and Seawater Treatment Plant</td>
<td>£1.63 bn</td>
<td>Phase 1 under construction</td>
<td>2017</td>
</tr>
<tr>
<td>(Phase 1&amp;2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bobyan Port (Phase 1)</td>
<td>£0.78 bn</td>
<td>Under construction</td>
<td>2014</td>
</tr>
<tr>
<td>Expansion of Kuwait International Airport Hospitals</td>
<td>£3.90 bn</td>
<td>Under construction</td>
<td>2016</td>
</tr>
<tr>
<td>Housing Projects</td>
<td>£3.25 bn</td>
<td>Under construction</td>
<td>2020</td>
</tr>
<tr>
<td>Kuwait Metro Rail system</td>
<td>£4.55 bn</td>
<td>Preparation of expression of interest for phase 1 (currently put on hold)</td>
<td>2020</td>
</tr>
<tr>
<td>Kuwait National Rail Road Network</td>
<td>£6.50 bn</td>
<td>Feasibility Study (currently put on hold)</td>
<td>N/A</td>
</tr>
<tr>
<td>Sabah Al-Salem University</td>
<td>£4.34 bn</td>
<td>Under construction</td>
<td>2018</td>
</tr>
<tr>
<td>Sheikh Jaber Bridge</td>
<td>£1.71 bn</td>
<td>Under construction</td>
<td>2018</td>
</tr>
</tbody>
</table>

3.8. Significance of Building Maintenance

The importance of BM can be easily recognised when knowing that operational stage of a facility comprises approximately 60% of the overall cost of a construction project (Liu & Issa, 2012). Indeed, while the design and construction stages can extend for a few years, maintenance can last for the whole operating stage of a facility. The significance of the maintenance sector in the economy can also be acknowledged by appreciating the size of its share in the construction industry. For example, the repair and maintenance sector accounted for approximately 39% of the total UK construction output in Q2 2013 (ONS, 2013).

In Kuwait, the surge of projects mentioned above will subsequently place enormous pressure on maintenance departments to maintain public facilities. Therefore, the
number, complexity and size of projects being developed in KDP, along with the facilities already owned or leased, require public BM departments to perform their duties in more efficient manner. This becomes apparent when social and political pressures compel BM to reconcile conflicting demands with limited allocated resources (Chanter & Swallow, 2007).

Although Kuwait is considered a wealthy country with one of the highest per capita incomes in the world and seems secure with large oil revenues and reserves, it is perhaps one of the most vulnerable to the impact of future oil peak crisis (Roaf et al., 2009). Therefore, measures need to be taken to increase efficiency of public organisations to be prepared when calls for tighter expenditures are made.

3.9. Summary

This chapter has considered several aspects of building maintenance: its definitions, types, contracts, process, technology, and, specifically, the status of building maintenance in Kuwait. The chapter has concluded that buildings are recognised as assets and resources which require continue maintenance during their whole lifecycle. Therefore, BM is not only essential to sustaining the built environment, but its worth in terms of employment and spending in the economy is also substantial (RICS, 2009). In terms of service delivery, building maintenance departments can follow different processes in delivering their services and employ different type of contracts to achieve their strategies. Since technology can improve performance, several commercial and research-based applications were proposed to manage the building maintenance process.

In Kuwait, with continuing large surpluses in public budget from oil revenues (NBK 2009), it is expected that public expenditure will maintain its firm support to construction and renovation projects. Such expectation has proven to be true: public expenditure doubled in 2012, compared to 2009. Moreover, the KDP was approved, in parallel to the annual public spending. With maintenance service continuing for the whole operational stage of a facility, such a surge of expenditure on construction projects will certainly place large pressures on public maintenance departments of how to maintain the facilities that have been constructed. This will drive BM departments to improve their performance to meet such additional pressure. Improving performance can be achieved through numerous approaches, one of which is the effective use of the knowledge of employees within organisations.
The literature review in this chapter provided the researcher with background on BM and established that there is a lack of studies that investigate the BM process in Kuwait. This provides a research opportunity to examine and develop a BM process map to help identify deficiencies to knowledge sharing, which can be addressed in this research. Also examining the current BM processes followed by BM departments will assist in identifying potential opportunities for knowledge management activities that can improve the delivery of services. The following chapter discusses the concept of knowledge management and how it can be used in building maintenance.
Chapter 4 - Knowledge Management in Building Maintenance
4.1. Introduction

Even though a building is unique and custom-built, many of its maintenance activities are repeated over time. Since the management of knowledge in a situation where works are often repeated is much more beneficial than management of knowledge for activities that are only carried out once or carried out occasionally (Falqi, 2011), many benefits can be gained in the field of BM when accumulated knowledge is properly managed.

This research attempts to implement the concept of Knowledge Management (KM) into the BM sector. Therefore this chapter provides an in depth literature review on the area of KM, illustrating different perspectives on the definition of knowledge. The chapter also discusses dimensions of knowledge, the concept of KM, different perspectives of KM, techniques used in KM, and the importance of KM to BM and its applications in this area. This is followed by examination of several taxonomies to organise information and knowledge in the AEC/FM industry.

4.2. Knowledge

Since understanding and defining knowledge is a wide and open-ended quest (Schwartz, 2010), numerous debates have been raised on the exact meaning of knowledge (Tiwana, 2000a). Therefore, different perspectives of definitions have been formulated to illustrate what knowledge represents. These definitions can be classified according to two main perspectives. The first approach, based on the knowledge pyramid proposed by Ackoff (1989), closely relates knowledge to data and information. The second approach defines knowledge without a direct relation to data and information.

The former perspective observes knowledge as either a higher hierarchical level to data and information (Tobin, 1996; Kanter, 1999; Rainer & Turban, 2009; Russ et al., 2010), or knowledge can be inversely observed as a foundation to data and information (Tuomi, 1999; Fahey & Prusak, 1998). An example of the former view defines knowledge as “data and/or information that have been organized and processed to convey understanding, experience, accumulated learning, and expertise as they apply to a current business problem” (Rainer & Turban, 2009, p.6). Supporting the same view, Russ et al. (2010, p.2) believe that “data and information are the building blocks for knowledge”. Data, in this view are considered as raw facts (Bhatt, 2001); while information is interpreted data in a given context (Patel et al., 2000).
In contrast, Tuomi (1999) argues that the hierarchical order of data, information and knowledge is reversed. The study by Tuomi (1999) asserts that data arises only after obtaining and articulating information, and that information arises only after obtaining and interpreting knowledge. In support of this approach, Fahey and Prusak (1998) believe that knowledge does not exist separately from the knower (the knowledge carrier). Therefore raw data does not exist in such an approach (Alavi & Leidner, 2001). Alavi and Leidner (2001) clarify this viewpoint, saying that information is transformed to knowledge once it is interpreted in the mind of individuals, and knowledge is converted to information when it is articulated and depicted in form of words, graphics or other representations.

The latter perspective defines knowledge without a direct link to data and information (Nonaka & Takeuchi, 1995; Sanchez et al., 1996; Davenport & Prusak, 2000). Knowledge is defined from this perspective 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” (Davenport & Prusak, 2000, p.3). Such a definition hence focuses on knowledge characteristics and avoids distinguishing between knowledge and information (Tan et al., 2010). The definition by Davenport and Prusak (2000) illustrates several characteristics of knowledge (i.e. experience, values, contextual information, and insight). Moreover, it views knowledge as a complex matter a “fluid mix” of these characteristics which is hard to locate. This definition by Davenport and Prusak has therefore been favoured in this research. While this section discussed different perspectives in defining knowledge, the following section examines different perspectives for identifying the dimensions of knowledge.

4.3. Dimensions of Knowledge

Polanyi (1966) theorised two dimensions of knowledge, explicit and tacit. Explicit knowledge is knowledge that can be easily codified, communicated, or articulated and can therefore reside in fixed formats such as documents, textbooks, manuals, and formulae (Ahmed et al., 2002). In contrast, tacit knowledge is embedded in the individual’s mind and cannot be readily expressed or articulated (Bollinger & Smith, 2001). Tacit knowledge encompasses skills and hence might be transferred by demonstration rather than description (Ahmed et al., 2002). Moreover, tacit knowledge cannot be easily stored and shared unless it is converted into explicit knowledge (Falqi,
Chapter 4: Knowledge Management in Building Maintenance

2011). This can be done through utilising KM tools to capture, sort, and mobilise some of the tacit knowledge to be transformed into explicit knowledge.

Davenport and Prusak (2000) state that knowledge in organisations spans from complex accumulated and indescribable tacit knowledge to the organised and explicit content. Table 4-1 illustrates some codification approaches that differentiate between tacit and explicit knowledge.

Table 4-1: Dimensions of knowledge (Winter, 1987; Cited in Davenport & Prusak, 2000).

<table>
<thead>
<tr>
<th>Tacit knowledge</th>
<th>Explicit knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not teachable</td>
<td>Teachable</td>
</tr>
<tr>
<td>Not articulated</td>
<td>Articulable</td>
</tr>
<tr>
<td>Not observable in use</td>
<td>Observable in use</td>
</tr>
<tr>
<td>Rich</td>
<td>Schematic</td>
</tr>
<tr>
<td>Complex</td>
<td>Simple</td>
</tr>
<tr>
<td>Undocumented</td>
<td>Documented</td>
</tr>
</tbody>
</table>

Musgrave (1993) distinguishes three types of knowledge: 1) knowledge of propositions or statements (knowing-that), 2) knowledge of how to do things (knowing-how), and 3) knowledge of things and objects (knowing-of). Collins (1993) proposes four types of knowledge: 1) symbol-type knowledge that can be transferred through media without loss, 2) embodied knowledge that is held in individual’s body and is hard to transfer, 3) embraigned knowledge that is held between the peoples’ ears, and 4) encultured knowledge that is knowledge of society, culture and social groups. Based on Collins approach, Blackler (1995) introduces five images of knowledge that can be found in organisational design and management: 1) embraigned knowledge, 2) embodied knowledge, 3) encultured knowledge, 4) embedded knowledge, and 5) encoded knowledge. According to Blackler (1995), embraigned knowledge is conceptual and dependent on individual skills and reasoning abilities possessed via certain kind of formal learning, embodied knowledge is action oriented that is related to specific activities and roles in organisations, encultured knowledge is about the process of accomplishing shared beliefs and understandings of an organisation’s culture, embedded knowledge refers to abilities to undertake systematic routine tasks without
thinking, and lastly encoded knowledge is the knowledge transcribed, organised and expressed by media such as books and manuals.

Lundvall and Johnson (1994) proposes four types of knowledge: 1) *know-what*, 2) *know-why*, 3) *know-how* and 4) *know-who*. Know-what is knowledge about facts and can be easily codified, know-why refers to knowledge of principals and laws, know-how that includes skills and capacity to successfully perform the given tasks, and know-who that involves the social capability of knowing who knows what and who knows to do what.

Fleck (1997) developed a knowledge categorisation approach based on knowledge source, storage, capture, and how components can be associated to each other. Such knowledge categorisation includes: 1) *formal* knowledge that is embodied in theories and formulae which can be transcribed or presented in diagrammatical forms, 2) *instrumentalities* refers to knowledge of how to effectively use instruments and tools, 3) *informal* knowledge that is usually embodied in oral interactions and rules of thumb, 4) *contingent* knowledge that is specific to particular context, 5) *tacit* knowledge that is embedded in individuals and can be learnt through practice, and 6) *meta*-knowledge that is embodied in organisations.

Blumentritt and Johnston (1999) presented a knowledge classification that distinguishes between *codified* knowledge and other *real* forms of knowledge. This classification of knowledge consists of four categories: 1) *codified* knowledge, 2) *common* knowledge, 3) *social* knowledge, and 4) *embodied* knowledge. Codified knowledge denotes explicit knowledge that has been expressed in a transferable form. Common knowledge is accepted without being explicitly expressed, such as in routines and practices. Social knowledge is knowledge about cultural issues and interpersonal relationships. Embodied knowledge such as accumulated skills and experience in rooted inside individuals.

Finally, Tiwana (2002) identifies three types of knowledge 1) *externalised* knowledge: which refers to knowledge that can be expressed and embodied in procedures and processes, 2) *multilocational* knowledge: which means knowledge that can resides inside and outside organisations, and 3) *migratory* knowledge: that is knowledge independent of its owner and creator.
This research focuses on capturing and retrieving both the explicit knowledge and the tacit knowledge that can be codified, mobilised and explicitly utilised by a familiar knowledge taxonomy. In the context of this study, capturing and retrieving of knowledge is related to work-based knowledge, such as solving maintenance problems, processes of handling projects, and dealing with legal aspects in projects. Hence, explicit knowledge to be captured and retrieved can be in the form of documented solutions and decisions buried in meeting minutes and letters between project parties. Tacit knowledge can be in the form of the individuals’ rationale for solutions to BM problems and reasoning for product selection. This section discussed dimensions of knowledge; the following section expands to discussing managing knowledge in organisations.

4.4. Knowledge Management

Knowledge Management (KM) attracted attention in early 1990s when large consulting organisations began investing significantly in implementing the KM technologies and practices (Al-Athari & Zairi, 2001). As KM is related to several fields and is an evolving discipline (Falqi, 2011), it is somewhat difficult to obtain an agreed definition. Consequently, numerous definitions of KM derived from different perspectives have been presented in the literature, where it is viewed in different forms (Falqi, 2011).

Example of definitions in which highlight the processes of KM are presented in Davenport (1994) and Scarbrough et al. (1999). Davenport (1994; Cited in Firestone, 2003, p.171) defines KM as “the process of capturing, distributing and effectively utilising knowledge”. With further illustration of the stages of KM, Scarbrough et al. (1999, p.1) define KM as “any process or practice of creating, acquiring, capturing, sharing and using knowledge to enhance organisational learning and performance”.

Another perspective of providing definitions has focused on delivering accurate knowledge to the right individuals at the correct time. Robbins (2003, p.575) observes KM as “process of organizing and distributing an organization’s collective wisdom so the right information gets to the right people at the right time”. Petrash (1996; Cited in Chaudhary, 2005, p.46) understands KM as “getting the right knowledge to the right people at the right time so that they can make the best decision”.
With more focus on the effect of properly reusing knowledge on organisational performance, Jennex (2005) defines KM as “practice of selectively applying knowledge from previous experiences of decision-making to current and future decision making activities with the express purpose of improving the organization's effectiveness”.

The KM definition by Jennex (2005) has been preferred in this study since it promotes the improvement of organisational performance when knowledge is appropriately and selectively captured, stored, retrieved, and reused. Therefore, the output of this study should facilitate the capturing, storing, retrieving, and reusing of knowledge to improve effectiveness in organisations.

Collison and Parcell (2004) propose that three fields are involved in managing knowledge in organisations: people, process and technology, where the latter is employed by employees to follow the organisational process. Figure 4-1 illustrates how Collison and Parcell (2004) view the relationship between KM and the organisational fields involved.

Figure 4-1: Fields involved in KM in organisations (Collison & Parcell, 2004).

In general, KM is positively promoted by academics and practitioners in different fields as a tool used to facilitate continues improvement. Therefore, the objectives of this research are centred on these fields, since appropriate consideration needs to be given to all areas involved in KM in organisations. This research will investigate the current
process followed by BM departments in Kuwait, the KM principals employed, and the supporting technology.

4.5. Importance of Knowledge Management

The benefits of KM implementation have been mentioned in several studies. Syed-Ikhsan and Rowland (2004) and McAdam and Reid (2000) reported that KM can significantly assist in reducing operating costs and in improving efficiency and quality. Such benefits can be recognised as the main drivers for implementing KM in organisations and therefore, KM is being employed in organisations to explore or transform knowledge as an asset for organisational use to facilitate continuous improvement (Robinson et al., 2005). Ahmad et al. (2008) believe that KM offers competitive edge by providing the ability to improve the performance of organisations in construction. This includes enhancing organisational learning through knowledge generation and sharing among employees (Li & Gao, 2003).

Cong and Pandya (2003) classify the benefits of KM gained by the public sector into two categories: individual and organisational. At an individual level, employees can develop their careers through enhancing personal skills, experiences and performances. Such goal can be achieved by knowledge sharing and learning opportunities provided by managing the organisations’ knowledge. At an organisational level, the overall performance can be improved by increased productivity, quality, efficiency and innovation. Further benefits of KM in public organisations are reduction in cost of operations and improvement in customer service.

Egbu (1999) emphasises that the relative importance of skills and knowledge in refurbishment management are higher than those in general construction management. Therefore, KM principles have been adopted in BM to leverage employees’ knowledge assets (Fong & Lee, 2009) to increase efficiency and performance.

The importance of KM emerges when it is recognised as a performance improvement concept in public organisations since they are funded by governments. For instance, attempting to explore old records of a governmental agency justifies the essential need of improved knowledge management to government at any level (Zimmermann, 1999). Also, Cong and Pandya (2003) argue that an increasingly knowledgeable general public necessitates governments to understand and cope with newly created knowledge since it
is constantly generated by wide range of stakeholders. In addition, Syed-Ikhsan and Rowland (2004) reported that for organisations structured for social benefits rather than financial profit, it is crucial for their employees to be more knowledgeable and be able to deal with the needs of the public.

As mentioned in Chapter (3), in Kuwait the whole financial system is largely dependent on oil revenues. Furthermore, the economy in Kuwait relies considerably on government spending. Therefore, the dependence on an exhaustible sole source of income that is subjected to market uncertainties places a constant pressure on public spending. This in turns creates the need to improve efficiency in terms of public service and expenditure.

Within the BM sector in Kuwait, the public departments receive budgets from the state to provide services to maintain public owned buildings used by the state employees and the general public. Olomolaiye et al. (2004) believe that KM can be implemented to accomplish an integrated and strategic approach to improve the overall performance of FM/BM organisations. Therefore, proper management of knowledge can improve the performance of public BM departments in Kuwait. The following section reviews several models to manage knowledge in organisations.

4.6. Knowledge Management Models

Numerous studies have investigated the area of KM. This has led to different perspectives which created various models to manage knowledge in organisations. Nonaka and Takeuchi (1995) introduced a KM approach in which knowledge is produced and converted from tacit to explicit and vice versa through social interactions between individuals. Nonaka and Takeuchi (1995) argue that tacit and explicit knowledge are not “totally separate”. Based on such argument, the model comprises four knowledge modes: Socialization, Externalization, Combination and Internalization (SECI), as shown in Figure 4-2, The SECI model depicts the interchange between the four modes of knowledge conversion. The spiral move represents a continuous expanding interchange between different SECI modes leading to organisational knowledge creation. The increase of the spiral radius stands for the spread of knowledge through various organisational levels.
Socialization: from tacit knowledge to tacit knowledge. This can be performed through practice, impersonation, observation, and interactions between expert and inexperienced professionals.

Externalization: from tacit knowledge to explicit knowledge. This can take place in the form of tacit knowledge being translated into standard solutions, formal reports, models, specifications, analogies, and hypothesis.

Combination: from explicit knowledge to explicit knowledge. This mode can take place by exchanging and combining related and similar knowledge through media such as documents, reports, and organisational networks. Also this mode can be done through classifying, adding and unifying explicit knowledge.

Internalization: from explicit knowledge to tacit knowledge. This can be done through learning, practising, and reapplying the explicit knowledge to produce new tacit knowledge.

Figure 4-3 depicts how knowledge is created in organisations based on its spiral progression. The continuous spiral move in the SECI model alternates between the four modes of knowledge leading to creation of organisational knowledge. The epistemological dimension (vertical axes) demonstrates the type of knowledge at each mode during the conversion procedure between modes. The ontological dimension
(horizontal axes) illustrates the spectrum of how knowledge is progressed and transformed from individual level to inter-organisational level.

![Figure 4-3: Spiral of Organisational Knowledge Creation (Nonaka & Takeuchi, 1995).](image)

Wiig et al. (1997) developed a conceptual KM model that utilises four processes in a knowledge management cycle. This KM cycle, shown in Figure 4-4, consists of four major activities. The activities in the KM cycle start with (1) Reviewing, which involves assessing current state and past achievements, then (2) Conceptualising, which means obtaining a view of knowledge in organisational contexts and evaluating its strong and weak aspects, followed by (3) Reflecting, which is aimed towards improvements such as selecting most suitable plans for resolving KM barriers and analysing implementation risks, and finally (4) Acting, which refers to actual implementation of selected plans from previous activities. According to Wiig et al. (1997), activities within the Acting phase in the KM cycle will be either one or a combination of the operations: knowledge developing, distributing, combining and consolidating.
Wiig (1999) then proposed a model for knowledge evolution cycles that include KM practices for two levels, personal and institutional. The principle of the personal knowledge evolution cycle shown in Figure 4-5 depicts five stages in which knowledge is gradually improved and transformed from tacit ideas to useful explicit knowledge.
According to Wiig (1999), the five stages of the personal knowledge evolution cycle are as follows:

1) Tacit subliminal knowledge: generally non-conscious and is not well understood. Usually it is the initial insight to a new concept. Also can be described as “intuition”.

2) Idealistic vision and paradigm knowledge: part of such knowledge is explicit (accessible consciously), while most of it is tacit (accessible non-consciously).

3) Systematic schema and reference methodology knowledge: most of the knowledge related to problem solving approaches and general principals is explicit and well known.

4) Pragmatic decision-making and factual knowledge: such knowledge is practical and generally explicit, supports daily work, well known and is employed consciously.

5) Automatic routine working knowledge: well-known knowledge that became automated. Mostly turned into tacit knowledge that is employed automatically without conscious reasoning.

On an institutional level, Wiig (1999) presented a KM cycle for knowledge evolution. Figure 4-6 shows the five stages of the enterprise knowledge evolution cycle.

Figure 4-6: Enterprise Knowledge Evolution Cycle (Wiig, 1999).
According to Wiig (1999), the five stages in the enterprise knowledge evolution cycle are as follows:

1) Knowledge development: knowledge is created through learning, innovation, researching and external importation.

2) Knowledge acquisition: knowledge is captured and stored to be leveraged by other means.

3) Knowledge refinement: knowledge is arranged, converted into included in media such as documents and knowledge bases to be widely available.

4) Knowledge distribution and development: knowledge is distributed to points-of-action through embedded procedures, training programmes, expert network, and other means of actions.

5) Knowledge leveraging: knowledge in this stage is applied and becomes a base for further learning and innovation.

Figure 4-7 shows a KM life cycle model proposed by McElroy (2000). This model comprises three fundamental processes: knowledge production, knowledge validation, and knowledge integration. Activities in the knowledge production stage include interaction, data/information acquisition, new knowledge formulation, and initial codification. The knowledge validation stage includes peer reviewing, validating criteria, weighing the value of new knowledge, and formal codification. The knowledge integration stage comprises knowledge sharing and transferring, teaching and training, operationalising new knowledge, and production of knowledge articles. The processes are then involved in an experiential feedback loop for improvement.

Figure 4-7: Knowledge Management Life Cycle (McElroy, 2000).
This research explores whether a KM model can be applied into the investigated BM process. This will be done through a conceptual implementation of a selected KM model into the investigated BM process. The reason for this conceptual implementation is to aid identifying knowledge opportunities in the BM process that can be utilised in KM activities. Each of the reviewed models in this section provides rich roadmap of how to manage knowledge in organisations. The SECI model by Nonaka and Takeuchi has been chosen in this study for the conceptual implementation of the identified process of BM on the grounds that it provides a clear model that converges between two dimensions of knowledge “tacit” and “explicit”. Moreover, the SECI model considers both social “socialisation + internalisation” and scientific “externalisation + combination” aspects in managing knowledge. The following section reviews techniques used to managing knowledge in organisations.

4.7. Knowledge Management Techniques

Availability and usage levels of KM techniques and tools significantly affect the overall KM principle in organisations. KM tools can be either IT-based or non-IT based (Tan et al., 2010). There are wide range of techniques and tools being developed and employed to assist in managing knowledge in organisations. Al-Ghassani et al. (2008) and Tan et al. (2010) present the following collection of IT and non-IT based tools and techniques that can be used in capturing and reusing knowledge in projects:

- **Post project reviews**: debriefing meetings organised to focus on lessons learned during the course of a project (Tan et al., 2010).
- **Communities of practice**: groups of individuals that share similar concerns or passion about something they do, and can deepen their knowledge when they interact regularly (Wenger, 1998).
- **Training**: “A process that facilitates the proper use of knowledge as a solution to all forthcoming events based on extrapolation of a careful analysis of all pertinent characteristics of the evolving scenario” (Wickramasinghe & Lubitz, 2007, p.368). Training is considered an important aspect in KM. Since knowledge is useless if it cannot be applied meaningfully and constructively (Wickramasinghe & Lubitz, 2007).
Recruitment: a process of obtaining new people to join an organisation; it is a typical an effective method of transferring new knowledge into an organisation (Tan et al., 2010).

Face-to-face interactions: direct contact between individuals; face-to-face interactions are argued to be a significant means for efficient diffusion of knowledge (Storper & Venables, 2004).

Mentoring: a deliberate coupling of a more skilled or experienced person with the less skill or experience with a mutually agreed aim of enabling the less skilled person to develop and increase specific competencies (Murray, 2001). Classification of mentoring includes one-to-one mentoring, circle mentoring, and needs-based mentoring (Klasen & Clutterbuck, 2002).

Succession planning and management: a proactive process to ensure the continuity of leadership by nurturing talents from within the organisation through strategic development activities; succession planning and management progresses beyond the simple form of replacement planning of employees (Rothwell, 2010).

Reassignment of people: relocation of experts and staff to other projects to facilitate the transfer of tacit knowledge between individuals (Tan et al., 2010).

Knowledge base: a highly organised repository and long term memory that can permanently store knowledge during its whole lifecycle (Tasso, 1998). An organisation's knowledge base can contain its organisational capabilities, the knowledge within individuals and teams, assisted by its collection of data and information (BSI, 2003). Knowledge in knowledge bases is usually depicted in a standard format (Wiig, 2004). Organisations create specified and tailored knowledge bases that store and organise their main processes, knowledge subjects, and practices.

Intranets: is “a private network (TCP/IP) that usually supports the same protocols and services as the public Internet including emails, news, chat rooms and web pages” (Muller, 2003, p.243). Intranet networks can be considered as a miniature local version of the internet that has been specifically designed for the use of an organisation and its employees (Falqi, 2011). Therefore, access to intranet networks is restricted to organisational staff.
• **Groupware**: is a software platform that assists teams to undertake a collaborative tasks (Plant & Murrell, 2007). Through groupware, team members located at different locations or time zones can still collaborate, communicate and share their own knowledge in joint projects.

• **Project extranets**: an extranet is an expanded intranet to allow organisations to communicate with external parties (Chan & Davis, 2000). However, Watson (1999b) points out that as access to extranet is limited to approved individuals that are associated to the organisation and/or a project, there is, in principle, little difference between intranet and extranet, apart from who possesses admission to information (Callaghan, 2002).

• **Case-Based Reasoning (CBR)**: a problem solving approach (Richter, 1998) that adapts previous solutions and experiences to understand and solve new problems (Kolodner, 1992). Lenz *et al.* (1998b) state that the fundamental essence of CBR is articulated by the general life notion that “similar problems have similar solutions”. According to Watson (1999a), the conceptual CBR-cycle encompasses the following four activities (the four-RE-s):

  - *Retrieve* the most similar case to the problem description;
  - *Reuse* the solution suggested by a similar case to solve the problem;
  - *Revise* or adapt the proposed solution to better fit the new problem;
  - *Retain* the new solution once validated for future problem solving.

• **Text mining**: refers to knowledge discovery (Zhang & Zhang, 2010) which encompasses the process of extracting patterns, behaviours, and general knowledge from large collections of textual information, which can be obtained from knowledge repositories as part of KM systems (Cox, 2000; Cited in Liebowitz, 2001).

As can be seen, a broad range of techniques has been developed to enable and manage knowledge in organisations. This study will particularly explore what KM techniques are currently employed in the investigated BM departments in Kuwait.
4.8. Knowledge Management Applications in Building Maintenance

BM activities are extended to a building’s life span and involve multiple stakeholders who are replaced over time. Moreover, Egbu (2000) argues that “people issues” represent 90 per cent of KM while technology represents mere 10 per cent. As a result, the concept of KM is particularly suited to improve performance of property management and BM organisations (Fong & Lee, 2009; Olomolaiye et al., 2004). Knowledge and experience gained from one maintenance project can be used to benefit another project.

Ali et al. (2004) developed a web-based knowledge management system named “More Productive Minor Construction Project through Information Technology” (MoPMIT). The main aim of the MoPMIT system is to improve the performance of parties involved in Reactive Maintenance (RM) projects, by having a common interface as a mean of communication for sharing information and knowledge. MoPMIT was designed to assist non-expert users in identifying problems and in describing the work required, leading to reduction in time wastage, since the appropriate contractors are then allocated the correct tools. The participants in the system development, testing and evaluation comprised a group of building owners, facilities management teams, contractors and suppliers. The architecture of the MoPMIT bespoke design is based on a process model developed by Ali et al. (2002). The main function of MoPMIT application is to mimic the process of a call centre, including accelerating the communication between parties, identifying problems, selecting the appropriate contractor and allowing feedback on completed work.

Lepkova and Bigelis (2007) proposed a web-based Consulting Knowledge System (CKS) to be used for management of facilities. CKS provides three methods of consulting: 1) searching the website using the domain ontology, 2) webmail and 3) using a decision support system. Lepkova and Bigelis (2007) claim that the search results will be accurate and short since information is mainly entered as snippets.

Another KM application has been developed by Fong and Wong (2009). They investigated whether forming a Community of Practice (CoP) among building maintenance organisations could increase the efficiency of knowledge and experience sharing and reuse. They examined the feasibility of a web-based experience management system in sharing, capturing and reusing knowledge and experience. Based
on their study results, an online Building Maintenance Community of Practice (BMCoP) prototype application was developed to be used by stakeholders. However, both CoP and BMCoP are advertised to be used by several parties with no particular organisation in charge of the system. Lack of ownership can be a major issue for continuity, in terms of issues such as ownership of knowledge saved in the system’s base, accountability of running costs and management and system improvements.

Elmualim et al. (2010b) developed a knowledge portal to share good practice between FM professionals, based on issues identified in Elmualim et al. (2009, 2010a). These issues include lack of practical guidance tools in information related to sustainability in FM. The portal proposed in Elmualim et al. (2010b) was designed to hold practical case studies, articles and links that provide information within the context of sustainability, climate change and sustainable FM. The case studies in the portal are grouped based on nine major parameters: practice description, practice drivers, business case, people involved, how was it done, benefits, barriers, further opportunities, and lessons learnt.

Within the Kuwaiti context, a small number of publications have explored KM. A study by Al-Athari and Zairi (2001) examined the current situation of the availability of KM systems in the Kuwaiti private and public sectors. Their study revealed that KM was perceived as very important to organisations in both sectors, and that employees and organisations’ existing knowledge are the most important sources of ideas. Also, it was found that internal journals are the common method for knowledge sharing between employees. In another study by Alazmi (2003), the actual implementation of IT-based KM systems was investigated. It also compared the use of KM systems in both UK and Kuwait public sectors with the specific aim of building a best practice model for KM implementation in conjunction with IT. However, the BM sector in Kuwait was not the target in either of these studies.

Two research studies focusing on the public construction sector in Kuwait aimed to investigate the application of web-based information technology in Special Projects Administration (SPA) in the Ministry of Public Works (MPW). The first study, by Al-Reshaid and Kartam (2000), investigated the communication between parties involved in the SPA projects. The study concluded that the existing type of communications failed to provide a reliable rapid mean of information delivery and exchange. It was therefore suggested to implement web technology as a supporting tool to enhance and increase the efficiency of information exchange and delivery. The later study, by Al-
Reshaid and Kartam (2003), described the implementation of a web page to be used by stakeholders involved in SPA projects. They proposed a web page that allows stakeholders to directly communicate with each other. Moreover, the website was proposed to be used as an electronic record of all discussions, decisions, and project notes. However, this revolutionary attempt was custom designed for the SPA department and its projects and stakeholders. The SPA was involved only in new large projects being built for the state.

The reviewed applications presented innovative approaches to managing knowledge in BM sector. However, with recent developments in construction IT and particularly in the concept of Building Information Modelling (BIM), there is a great opportunity to investigate how BIM can assist in managing knowledge in BM sector. Furthermore, the research by Al-Reshaid and Kartam (2000) and (2003) was focused only on improving communications in construction projects in Kuwait and no research was found that focused specifically on managing knowledge in the BM sector in Kuwait.

4.9. Summary

This chapter has examined the perspectives from which knowledge is defined, the dimensions of knowledge, knowledge management, importance of KM, and also KM models, techniques, and applications. From the literature three fields involved in managing knowledge in organisations were identified: people, process, and technology, in the way that technology is utilised by people to follow organisational process. In addition, the review discussed a range of IT and non-IT based techniques to capture and reuse knowledge. These perspectives will be applied to the research inquiry into the current KM techniques employed by public BM departments in Kuwait.

The chapter has illustrated the potential benefits of implementing KM in BM. Several innovative KM applications were reviewed in this chapter. However, with the recent developments in IT in construction industry and particularly in the BIM concept, this creates an opportunity to develop a KM application with the following characteristics: to be used by public employees working in BM, to be designed with simple search and retrieval methods, to allow employees and teams located in different locations to communicate and share knowledge when needed, and to utilise the BIM concept. Therefore, the next chapter will look into BIM applications in BM sector.
Chapter 5 - Building Information Modelling in Building Maintenance
5.1. Introduction

This chapter seeks to provide an in-depth review of Building Information Modelling (BIM) technology from a BM perspective. The chapter starts with how BIM is defined from different viewpoints. The benefits of BIM to BM are then discussed. The chapter then traces evolution of BIM in AEC and its implementation in building maintenance projects, and considers methods of storing, sharing and exchanging of data and information using BIM. The chapter concludes with a review of previous studies of BIM in BM and commercial BIM compatible solutions focused on BM.

5.2. Definitions of Building Information Modelling

Several definitions attempt to describe the expanding domain and meaning of BIM (Succar, 2010). In terms of viewing BIM as a model, the National Institute of Building Sciences (NIBS) (2007, p.21) defines BIM as “representation of physical and functional characteristics of a facility”. In other words, BIM is a project being planned and virtually built to simulate an actual project. The BIM is designed to serve “as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its lifecycle from inception onward” (NIBS, 2007, p.21). Moreover, in viewing BIM in means of modelling, BIM is defined as “a process improvement methodology that leverages data to analyze and predict outcomes throughout different phases of the building life cycle” (Reddy, 2012, p.1).

The public sector in the UK has a comprehensive understanding of BIM and views it as “a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets. BIM embeds key product and asset data and a 3 dimensional computer model that can be used for effective management of information throughout a project lifecycle – from earliest concept through to operation” (HM Government, 2012, p.3).

It can be observed from the above definitions that BIM has broader scope than any single interpretation. BIM can be regarded as a growing collection of principles and tools attributed with the transformative capabilities within the sectors of construction and facilities management (Succar, 2010). The NIBS (2007) developed three categorisations for the scope of BIM, which are as follows:

- **BIM as a product**: an intelligent digital representation of data about a facility.
• **BIM as a collaborative process**: covering business drivers, computerised process competence, and sustaining reliable open information standards.

• **BIM as a facility lifecycle management**: a tool for information exchanges, workflows, and procedures used throughout the building lifecycle.

BIM, consequently, can be utilised during the whole lifecycle of a building; in the preconstruction phase, construction phase, and operation phase. According to Kymell (2008), processes related to BIM are performed to enable the following aims: (1) owners can develop and accurately understand the nature and requirements of the purpose for a project, (2) designers can design, develop and analyse a project, (3) enable the management of the construction of a project, and (4) aid the management of the operations of a project during its actual use.

However, this research focuses on utilising the BIM technology during the operational stage of a building. Hence, this chapter will focus on research related to BIM in the operational stage of a facility.

### 5.3. Benefits of BIM to BM

Baladhandayutham and Venkatesh (2012) point out that corporations around the world are continuously pursuing new and sustainable approaches to attain competitive advantage in ever challenging economies and increasingly competitive markets. The construction sector also has to deal with the constant need to improve current work performance and to become more client-centred (Baladhandayutham & Venkatesh, 2012). Utilising BIM is one tool that organisations can adopt to improve their performance and competitiveness. Moreover, the benefits of BIM to the whole life cycle of a building are well acknowledged. However, only the post construction benefits of BIM are illustrated in this section, since the research focuses on the operational stage of a facility. Eastman *et al.* (2011) listes several advantages of using BIM during the post construction phase of a building, which are as follows:

1) Enhanced commissioning and handing over a facility information;

2) Improved management and operation of a facility; and

3) Integration with facility management and operation systems.
1) Enhanced commissioning and handing over facility information.

During the whole lifecycle of a building, different stakeholders independently handle each stage. As a result, only limited information is exchanged between teams at each stage which is generally limited to spreadsheets, word documents and 2D drawings (Vanlande et al., 2008). Therefore, accumulated history, decisions made, and insights realised may be fully or partially lost when moving from one stage to another. BIM can be utilised to link the information processed during the construction stage to building elements in the BIM-based model. Such information can then be handed over to be used in managing the facility.

2) Improved management and operation of a facility.

BIM can provide a 3-dimensional visualisation of a facility using the embedded geometry of a model. Moreover, a principal aim of BIM is the management of stakeholder input throughout the entire lifecycle of a project (Dzambazova et al., 2009). Thus, BIM abilities can be utilised as an efficient means of reducing and mitigating difficulties when managing activities during the operational stage. Furthermore, as the operational stages of buildings can last for decades, the activities of BM have to evolve with time to maintain the delivery of satisfactory service when products and technologies become obsolete. Therefore, having sufficient, accessible information is a key challenge before commencing maintenance works. The BIM can be used as a source of information for owners and facilities managers. BIM-based software has the capacity to extend its use to facilities and maintenance management through facilitating the information to be easily accessed, analysed, exchanged, and updated. Also, movable building elements, materials and equipment can be monitored and tracked for better maintainability.

3) Integration of BIM with facility management and operation systems.

Gallaher et al. (2004), inadequate interoperability between software systems resulted in an annual loss of $15.8B to the U.S. capital facilities industry. The same study suggests that two thirds of this cost was incurred by owners and operators as a result of their activities with maintenance operations and facilities management programmes. A
portion of the cost related to interoperability can be mitigated through integration of BIM with the facility management and operation system. Autodesk for instance enabled their BIM software suites to be linked with FM applications (i.e. FM:Interacts developed by FM:Systems) to enable managing and reporting of facility-related information. Also, BIM can be a reliable source to provide accurate as-built information to be used in maintaining a facility given that BIM-based software is being updated with all the changes during the construction stage (Eastman et al., 2011). The following section will discuss the evolution and implementation of BIM in the AEC sector.

5.4. Evolution and Implementation of BIM

The early CAD applications were employed as 2D drafting electronic boards. With the introduction of 3D CAD applications in the last few decades, project design has shifted from drafting in 2D planes to modelling in 3D space (Kymell, 2008). However, the 3D modelling at that stage was essentially for visualisation purposes. CAD development corporations acknowledged later that diverse industry segments require diverse solutions, which has led to development of specialised CAD software (Graphisoft, 2006). BIM-based software was then developed and transformed the design from drawings to object-based models.

Figure 5-1 depicts timeline of BIM’s evolution in the AEC/FM sector over more than half century. The figure shows evolution milestones including hand drafting, 2D CAD, 3D CAD, BIM, and 4-5D BIM.

Figure 5-1: AEC CAD timeline (Graphisoft, 2006).
In terms of BIM implementation in the operational phase, several efforts have attempted to implement BIM to existing buildings. An example is the FM Exemplar Project of The Sydney Opera House (Akhurst & Gillespie, 2006; CRC, 2007), where BIM was adopted as a main source for data and information then linked with existing FM applications. In addition, Kasprzak and Dubler (2012) developed an information exchange framework between BIM and FM applications to be used internally at the Pennsylvania State University. Their approach was focused on aligning BIM deliverables with FM processes to increase the BIM implementation to FM.

According to AMEinfo (2010), BuildingSMART Middle East (ME) conducted a study aimed at surveying BIM practices in the ME region. The survey included face-to-face interviews with key construction professionals including FM providers working in seven countries (Kuwait, Oman, Saudi Arabia, UAE, Qatar, Bahrain, and Jordan). The study found that there is a high recognition of BIM and its added value to organisations (AMEinfo, 2010) and concluded that the ME market is optimistic and aware of BIM, yet still inexperienced.

Barakat (2011) investigated the BIM implementation level in Kuwait through a survey of public and private organisations working in construction industry and found a limited use of BIM. Nonetheless, the study revealed that the majority of participating organisations showed an interest and desire for the application of BIM in the Kuwaiti construction sector. Additionally, the participants felt that the concept would be implemented successfully in the sector. Barakat (2011) also found that several benefits of BIM implementation in Kuwait were recognised, which include better consideration of client requirements, efficient coordination between project stakeholders, and reduction in design mistakes.

In light of the above findings, it can be argued that, even though BIM use is limited in the Kuwaiti construction industry, its implementation will logically evolve into lifecycle of projects, including the BM stage. This is principally true when BIM is considered as not a substitute for but a progression to CAD technologies (Patrick et al., 2012) to deal with the increasing complexity of modern buildings. The following section discusses types of data and information handling in BIM.
5.5. Storage, Share and Exchange of Data and Information through BIM

BIM is represented by an object model which is a logical structure of the data that outlines all entities, attributes and relationships (Isikdag et al., 2007). In BIM, data can be stored, shared, and exchanged (Motamedi & Hammad, 2009). Isikdag et al. (2007) present five mechanisms for storage and exchange of BIM files. The mechanisms include:

1) *Data exchange through physical files*: file transfer can be performed by means of physical media such as CD/DVD or using internet and intranet computer networks.

2) *Data sharing with application programming interfaces*: “Application Programming Interface” (API) can be used to share BIM files. XML appropriate interfaces can be employed to share “Extensible Markup Language” (XML) files.

3) *Data sharing using a central project database*: in this mechanism, a shared central project database is utilised to store BIM data. This is done to allow multiple applications to access the shared database for querying or creating new business objects.

4) *Data sharing using a federal project database*: BIM is viewed in this method as a combined information model where several distributed but synchronised databases are accessed and viewed through unified layer of software.

5) *Data sharing through web services*: the interface of a web-based system or software in this mechanism can provide access to (A) a central project database where the BIM is stored, or to (B) an API which in turn allows access to a physical BIM file or to the domain specific views of the model.

In a BIM-based project, partiers from different disciplines are brought together to collaborate. With such parties employing different types of BIM software, a standard for sharing and exchanging of BIM related data and information was needed. The “Industry Foundation Class” (IFC) standard was developed as a compatible common language to be employed between applications for sharing and exchanging of BIM data. IFC is one of the most well-known standards in the construction industry (Abanda et al., 2013).
The IFC is an open, neutral, and independent standard developed by BuildingSMART to facilitate interoperability between different applications (BuildingSMART, Online). The IFC schema main feature is allowing individuals to share project models while permitting each profession to define its own view of the component contained within the model (Isikdag et al., 2007). On top of that, the IFC not only handles component’s data and its geometry, but also can support exchanging lifecycle project information from the design stage to the facility operations and management stage (Liebich, 2001; Cited in Cheng et al., 2002).

In 2007, the United States Army Corps of Engineers introduced and adopted the “Construction Operations Building Information Exchange” (COBie) schema as an attempt to standardise the FM information exchange in BIM projects (East, 2007). According to East (Online), COBie was approved in 2011 as part of the “National BIM Standard” (NBIMS). The use of COBie standard is now mandated in public construction projects in the UK (NBS, 2012; East, Online). The following two sections review BIM focused research and developed applications in the operational stage of a building lifecycle.

5.6. BIM Research Related to FM and BM

Until recently, the construction industry has generally revolved around 2D systems as digital drafting tools with limited use of 3D models for visualisation and design development (Singh et al., 2011). Integrated systems were developed to manage building maintenance information, such as the work of Underwood and Alshawi (2000). Indeed, the use of intelligent building systems is becoming a necessity to cope with the rising complexity in constructing and maintaining buildings, especially after the development of BIM technology. Furthermore, as operational stages of buildings can last for decades, BM activities evolve with time to maintain the delivery of satisfactory service when products and technologies become obsolete. Therefore, having accessible and sufficient information is a key challenge before commencing maintenance operations. In this respect, studies aimed at utilising the features of BIM technology can considerably improve BM operations. Therefore, BIM is becoming largely acknowledged as an enabler for FM (Ahamed et al., 2010).

Several BIM applications have been developed focused on various aspects such as: sustainability (Arayici et al., 2011; Barnes & Castro-Lacouture, 2009), BIM in energy
analysis (Motawa & Carter, 2013; Stumpf et al., 2009; Cho et al., 2010), maintainability checking (Leite et al., 2009; Dehlin & Olofsson, 2008), visualization (Sacks et al., 2010; Babić et al., 2010), cost estimation (Kiziltas & Akinci, 2010), and BIM-enabled design (Khanzode et al., 2008). There are several BIM-focused studies aimed at improving FM and BM practices; application areas include locating components, facilitating access of real time data, checking maintainability, automatic creation of digital assets, quality control and assurance, energy management, and space management (Becerik-Gerber et al., 2012).

Table 5-1 compares several BIM-focused studies for FM and BM in terms of data and information entered in the BIM-based applications, their method of retention, representation of outputs, taxonomy of data and information, web capability, and ability to share information between facilities. Details of the studies shown in Table 5-1 are discussed subsequently in the same sequence.

Table 5-1: BIM-focused research for FM and BM.

<table>
<thead>
<tr>
<th>Research</th>
<th>Input details</th>
<th>Method of retention</th>
<th>Representation of output</th>
<th>Organisation of data</th>
<th>Web based</th>
<th>Data shared with other buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akcamete et al. (2010)</td>
<td>Activity time, type, and location.</td>
<td>Manual and CMMS&lt;sup&gt;1&lt;/sup&gt;</td>
<td>3D Visual object model with Coloured symbols</td>
<td>Element based</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Akhurst and Gillespie (2006); CRC (2007)</td>
<td>Asset Maintenance information and Building Condition Index (BCI).</td>
<td>Manual</td>
<td>3D Digital facility model</td>
<td>Zones and functional spaces</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Asen et al. (2012)</td>
<td>Cause-effect relationships over time.</td>
<td>Manual and CMMS</td>
<td>3D Visual object model with spatio-temporal relationships</td>
<td>Element based</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Bank et al. (2010)</td>
<td>LEED&lt;sup&gt;2&lt;/sup&gt; certification parameters.</td>
<td>Automated</td>
<td>Within BIM software</td>
<td>Element based</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Chen and Wang (2009); Chen et al. (2013)</td>
<td>Basic and monitoring information, examination and maintenance records and documents.</td>
<td>Manual and sensors</td>
<td>FMM&lt;sup&gt;3&lt;/sup&gt; different information modes in 3D visual object model</td>
<td>Element based</td>
<td>Yes</td>
<td>N/A</td>
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<td>Research</td>
<td>Input details</td>
<td>Method of retention</td>
<td>Representation of output</td>
<td>Organisation of data</td>
<td>Web based</td>
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<tr>
<td>Clayton et al. (2009)</td>
<td>Scheduling information: Area, comments, department, level, name, number.</td>
<td>Manual</td>
<td>Colour coded spaces drawings</td>
<td>Space based</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Dibley et al. (2011); Dibley et al. (2012)</td>
<td>Sensing data: Motion, temperature, humidity, proximity.</td>
<td>Wired and wireless sensors</td>
<td>High level knowledge that describes a space</td>
<td>Space based</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Hao et al. (2010); Shen et al. (2012)</td>
<td>Condition-based information, real-time asset tracking.</td>
<td>Software systems, Servers, RFID, and wireless sensor networks</td>
<td>Asset tracking maps, and decision support services: basic, composite, and system level services</td>
<td>Element based</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Isikdag and Underwood (2010)</td>
<td>Model based modifications</td>
<td>N/A</td>
<td>Collaborative Subset Views</td>
<td>Element based</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Lee and Akin (2011)</td>
<td>Maintenance information, operations information, and geometric representations</td>
<td>Manual, sensors, and geometric representation</td>
<td>Superimposed 3D augmented reality</td>
<td>Element based</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Liu and Issa (2012)</td>
<td>Maintenance scheduling information.</td>
<td>Manual and CMMS</td>
<td>Parameters in BIM and templates in CMMS</td>
<td>Element based</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Motamedi and Hammad (2009)</td>
<td>Lifecycle information: specifications, status, process data, history data, and environmental data.</td>
<td>RFID</td>
<td>4D model of 3D visualisation with stored lifecycle information</td>
<td>Element based</td>
<td>Comp</td>
<td>uter network</td>
</tr>
<tr>
<td>Sampaio et al. (2012)</td>
<td>Anomalies specifications, repairs solutions, and repair methodologies</td>
<td>Manual</td>
<td>3D virtual environment</td>
<td>Element based</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>Research</td>
<td>Input details</td>
<td>Method of retention</td>
<td>Representation of output</td>
<td>Organisation of data</td>
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<tr>
<td>Su et al. (2011)</td>
<td>Problem description, facilities maintenance information, document attachment</td>
<td>Manual</td>
<td>Condition status 3D model, web-enabled model browsing, and facility information reports</td>
<td>Element based and traditional searching methods</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Vanlande and Nicolle (2007)</td>
<td>Data and information</td>
<td>Manual and automated</td>
<td>User and profession defined 3D model</td>
<td>Element based</td>
<td>Yes</td>
<td>N/A</td>
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<td>Vanlande et al. (2008)</td>
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<td>Nicolle and Cruz (2010)</td>
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</table>

1. CMMS = Computerised Maintenance Management System
2. LEED = Leadership in Energy and Environmental Design
3. FMM = Facility Maintenance Management
4. RFID = Radio-Frequency Identification

Akcamete et al. (2010) developed an approach to support maintenance planning through leveraging the spatial relationships represented in a BIM. This approach is based on visualisation and analysis of facility data during operations through employing colours and symbols to represent maintenance works. The repair works are recorded to enable visualisation of activities and spatial analyses of facility behaviour, to support prioritising maintenance decisions. Their framework starts with manually tagging maintenance activities to elements of the building. Then colour codes are selected to illustrate each category of work to that component in the building. Next, symbols are assigned to the maintenance activities performed. The method involves assigning different colours (type of maintenance work) to different symbols (building elements). The results generated can be observed in the BIM software with combinations of different coloured symbols located in different parts of the BIM model. According to Akcamete et al. (2010), this approach enables the visualisation and analyses of works being made to any particular space in a facility. Figure 5-2 depicts a building with resulted symbols and related colours assigned to maintenance works over a period of time.
Chapter 5: Building Information Modelling in Building Maintenance

Figure 5-2: Visualised history of maintenance and repair works (Akcamete et al., 2010).

The approach presented by Akcamete et al. (2010) is aimed at assisting decisions through analysing a trend of maintenance works being performed over time to a particular building. The visualised trends of this innovative approach are therefore limited to benefiting a particular building being maintained by a particular maintenance team. Moreover, this approach is restricted to colours and symbols, with no options to include texts such as documents, insights, recommendations, and solutions.

Akhurst and Gillespie (2006) proposed the FM Exemplar project for the “Sydney Opera House” (SOH). It was advocated in the same study that the FM Exemplar project should support the development of an interoperability standard to be used in BIM-based SOH. “Cooperative Research Centre Construction Innovation” (CRC) (2007) then presented the BIM-based prototype, the FM Exemplar, to support FM activities for the SOH. According to CRC (2007), the aim of the FM Exemplar was to enable storage and retrieval of integrated building, maintenance data and management of data for the SOH. The FM Exemplar project was also designed to act as main source of data and information for the existing FM software applications (CRC, 2007). Storing and retrieving of data in the SOH model is based on zones, and functional spaces. This categorisation can be linked with IFC model for data transfer between the BIM-based software and the existing FM applications.

The third research study in Table 5-1 was a BIM-based visual analytics approach for FM presented by Asen et al. (2012). Their proposed approach integrates data from “Computerised Maintenance Management Systems” (CMMS) with the BIM database. The data from CMMS and BIM can then be visualised and analysed based on queries.
about cause-effect relationships between building components. In this method, relationships of cause-effect are identified based on the relationships between building elements and spaces. The “Construction Operation Building Information Exchange” (COBie) along with manually assigned attribute definitions, was adopted by Asen et al. (2012) to define relationships of cause-effect deterioration conditions between building components.

Bank et al. (2010) integrated a decision-making framework with a BIM tool for sustainable building design and operation. A prototype direct link was established in Bank et al. (2010) between BIM software (Revit) and a decision-making tool (AnyLogic). This link populates the tool with BIM variables; and updates the BIM model with the output of the tool to aid in making modifications to the BIM model. The element parameter settings for information exchange are based on “Leadership in Energy and Environmental Design” (LEED) certification.

Chen and Wang (2009) and Chen et al. (2013) proposed a prototype of an expert system for the maintenance and management of existing buildings. Their prototype utilises visualisation technology to pursue and display maintenance data. This is done through employing a database to integrate and connect various “Facility Maintenance and Management” (FMM) data for the use of facility personnel. The prototype developed by Chen and Wang (2009) and Chen et al. (2013) considers the modelling components of a facility as a core to associate the stored data and information. Sources for data and information in the prototype are: manual input by users, scanned facility drawings, real-time monitoring sensors, and post processed data. The facility managers can search for data and information using a visual 3D model interface. Upon selecting a particular component, the digitised information can then be presented in different visual modes. This includes basic information and maintenance records in table presentations, engineering 2D drawings, text documents, real-time monitoring 3D visual data, graphics and charts, and post-processed theatrical diagrams.

Based on the results of focus groups, interviews, and case studies, Clayton et al. (2009) presented a web-based BIM utilisation framework for FM. Their prototype is developed to aid in scheduling of room space in a university. Their developed framework employs a BIM tool to generate information and populate a “Computer Aided Facility Management” (CAFM) system. The information generated is in the form of images and web-enabled 2D drawings being accessible to web-based CAFM for scheduling of
rooms for classes and events in a university campus. They conclude that BIM can provide much information for use in the in-house CAFM system.

A software system and its ontology was developed by Dibley et al. (2011) and Dibley et al. (2012) to generate beneficial operational knowledge for FM. According to Dibley et al. (2012), the solution (OntoFM) supports real-time building monitoring for data query. The data is generated through utilising wired and wireless network of sensors, associated storage for historical data, and an IFC model for the geometry of a facility. The high level information generated describes space usage to support decision making in FM such as optimising trade-offs between energy consumption and environmental comfort demands (Dibley et al., 2011). The information generated is in the form of high level functional illustration of zones, zone-based environmental condition summaries, space utilisation reports, and automated recognition of redundant energy usage in terms of heating and lighting (Dibley et al., 2011).

Hao et al. (2010) proposed a web-based decision support system prototype for facilities maintenance management named (FMM-DSS). FMM-DSS is based on integrating processes for Asset Management, Corrective Maintenance, Preventive Maintenance, and Condition-based Maintenance, to support decisions at both strategic and operational levels for optimised maintenance strategies. The FMM-DSS prototype also aims at facilitating integration with condition monitoring systems through BIM. This is done by utilising integration technologies such as Web services and agents for “loosely coupling” FMM-DSS, BIM, and “Condition Monitoring” (CM) systems together. Further to this research, Shen et al. (2012) illustrate in more detail the integration of BIM and CM with the FMM-DSS prototype. The FMM-DSS integration process starts with developing a common base for element referencing. This is done by initially utilising an IFC-based model developed from the BIM-based software. Then the FMM-DSS system receives and stores properties of elements, equipment, and assets issued from the BIM server. Locations of movable assets are then updated manually by FM personnel. Lastly, the FMM-DSS application receives 2D and 3D views of the maintained facility. According to Shen et al. (2012), the web-based user viewer within the FMM-DSS prototype can track and represent locations of movable assets through either 2D location maps or in 3D environment rendered by the BIM server. The innovative FMM-DSS presented in Hao et al. (2010) and Shen et al. (2012) is a data and geometry oriented prototype. Therefore, indexing of information stored in the FMM-DSS prototype is assumed to be associated with a particular element and facility. This
will result in information and data stored in the *FMM-DSS* prototype being accessed only by selecting single facility. Hence information from different facilities cannot be search and context compared.

Table 5-1 shows a prototype developed by Lee and Akin (2011) named “Augmented Reality-Based Operation and Maintenance Fieldwork Facilitator” (*AROMA-FF*). This is aimed at utilising data including BIM databases to obtain information and geometric representation of facilities and equipment. According to Lee and Akin (2011), the information model of the *AROMA-FF* includes maintenance information (specifications, responsible personnel, and maintenance history), operations information (sensor-based performance data), and geometric representation (exact location). The data sources in *AROMA-FF* include manual input, sensors, and geometric representations from BIM. The output was in a form of superimposed real-time 3D generated models of actual status onto the equipment and facility in the model using video streaming. Figure 5-3 depicts the superimposed augmented reality on the building section.

![Superimposed augmented reality of AROMA-FF (Lee & Akin, 2011).](image)

Isikdag and Underwood (2010) devised a BIM-based model for facilitating synchronous collaborations through the whole lifecycle of a building. The proposed model consisted of three components: the Domain Model, the View, and the Controller. The main principal of the model is broadcasting interactions and modifications made by stakeholders in a discipline in their View to all other registered Views. According to Isikdag and Underwood (2010), this approach will enable every different discipline to work with its own view of the project and will reduce the volume of information to be exchanged in the collaborative environment, since every stakeholder will work with a subset of the BIM.
Liu and Issa (2012) presented an approach based on bidirectional database communications between CMMS applications and BIM-based models, facilitating the transfer of historical information on maintenance and repair works between both BIM and CMMS. The process starts with assigning several parameters to facility elements, based on the information needed by the CMMS applications. After filling the parameters with the required maintenance information, a schedule template is manually created and exported to the targeted CMMS using a format that the FM application can accept. The schedule template creation made by the BIM software (Revit) can represent single or multiple categories. This is done once and can then be used repetitively. Once the schedule template is imported to the targeted FM application, it can then update the data in the software. A reverse process is then carried and an updated template is exported back to the BIM-based model. Any modification made to the template can therefore lead to a corresponding change in the BIM-based model. Liu and Issa (2012) claim that this approach can compensate for deficiencies in FM applications such as the 2D and 3D visualisation of work orders. Benefits of the prototype include prompt tracing of assets and their related information.

Motamedi and Hammad (2009) proposed a structure and implementation approach for attaching building components with “Radio-Frequency Identification” (RFID) tags. Their proposed approach populates attached tags with information obtained from a BIM database. The information is then updated through computers equipped with RFID readers. The information related to the maintenance and operational stage includes the inspection status and maintenance cycles. This prototype system generates 4D models consisting of 3D visualisation of the facilities’ elements with their maintenance status.

Figure 5-4: 3D visualisation for status of HVAC in building maintenance phase (Motamedi & Hammad, 2009).
Sampaio et al. (2012) developed a virtual 3D model as a tool to support decision making in preventative maintenance. Their model specialises in maintenance of walls where knowledge related to materials used in walls, inspection scheduling, techniques for renovation, and anomalies monitoring are retained in a database to support the activities of preventative maintenance in buildings. The database is then linked with a visualised 3D model in a virtual environment. The principal notion of the model is based on directly associating each building element with the integrated database for entering data and displaying results. Upon selecting a building component, the associated characteristics, problems, solutions, and attached documents are shown in a user friendly display. This virtual model was considered for review in this section even though it is not a BIM-based approach. The reason for that was the innovative approach in terms of incorporating a 3D virtual model with a knowledge base aimed at preventative maintenance of buildings. However, the indexing of the knowledge base of such approach is element-centred. Therefore, searching for, retaining, and retrieving of information stored in the database is dependent on identifying and selecting specific components in the building.

A “BIM-based Facility Management” (BIMFM) system for facility personnel was proposed by Su et al. (2011). The BIMFM system interprets BIM as an information model to capture and store problem descriptions, facilities maintenance information and document attachments. This is done through 3D visualisation and mapping of building assets to aid in schedule management of maintenance works. The BIMFM utilises colouring codes representing condition type of an element and mode of results for preformed maintenance works. The BIMFM also employs web-based technology to enhance facility information tracking and sharing efficiency. Therefore, the information can also be linked to external related files. Su et al. (2011) also pointed out that searching in the BIMFM is by a combination of functions, through the model, the software, or by exported reports. Indexing type and search criteria however are not mentioned in their study. According to Su et al. (2011), the proposed system encountered difficulties. For example, information and files related to FM could not be completely retained in the model of a facility.

The final research study presented in Table 5-1 is a semantic web approach to support facilities managers in managing information, developed by Vanlande and Nicolle (2007). This web-based collaborative platform, named “Active3D Facilities Management Server”, was developed to support the building lifecycle. Their proposed
approach facilitates maintenance data migration and aims at reducing the volume of data during the building lifecycle. The framework proposed by Vanlande and Nicolle (2007) handles model evolution, data mapping, chronological data, and adoption of data, according to its use and the targeted user. Extending the same project, Vanlande et al. (2008) proposed an IFC-based system that allows managing information during the whole lifecycle of a facility. Also, a web-based platform named “Active3D” was developed to support the building information system. Features of this platform include unifying activities carried out on a building during its lifecycle, extracting trade views of a building through combining information from heterogeneous sources, and handling such views through a 3D interface. Based on the Active3D platform, Nicolle and Cruz (2010) later proposed a web-based platform named “Active3D Facility Server” focusing on the operational stage of a facility. This platform allows professionals to exchange project documents in a consolidated 3D virtual environment using a web browser. As shown in Figure 5-5: Defined views for specific users of the same building (Nicolle & Cruz, 2010), the platform of Active3D allows facility managers to define the type of data to be viewed, based on a specified context. The context representation of data in the platform can be linked to a specific stage of a building’s lifecycle, or to a particular type of user. Consequently, when a particular type of user connects to the platform, e.g. an architect, a specific graph and view of the building is built and displayed.

![Defined architectural view of a building](image1.png)
![Defined structural view of a building](image2.png)

*Figure 5-5: Defined views for specific users of the same building (Nicolle & Cruz, 2010)*
5.6.1. Summary

Whereas BIM related systems discussed in this section mainly focus on utilising technical information and allowing the access to multiple databases, they generally do not target the knowledge gained during the stage of maintenance and operation of buildings that can also be captured and be transferable through a BIM model. Therefore, incorporating KM principles can help in achieving new levels of efficiency in BM performance. This will provide opportunities to further development of the BIM systems from the current focus on technical and geometric data to incorporate non-technical and non-geometric transferrable knowledge associated with building practices.

5.7. BIM Applications in FM and BM

FM and BM departments can utilise various types of available commercial software to handle increasing complex duties associated with facilities maintenance and management. According to the International Facility Management Association-IFMA (2013), Common software systems used in facility management include “Computerised Maintenance Management Systems” (CMMS), “Building Automation Systems” (BAS), “Document Management Systems” (DMS), and “Computer Aided Facility Management” systems (CAFM). BIM can assist with the use of FM software, such with CAFM (Ahamed et al., 2010), to bring additional benefits to FM activities. For example, BIM can facilitate the migration of the accumulated information of pre-FM stages to aid in the activities in the operational stage. Furthermore, providing a well maintained and updated model, BIM can offer cost savings to FM (Arayici et al., 2012). This section sheds light on commercial FM applications that have BIM compatibility.

Currently, several commercial CAFM applications have now incorporated BIM with their software. Table 5-2 below illustrates examples of commercially FM software with BIM compatibility, updated from (Ahamed et al., 2010).
Table 5-2: Commercial FM software with BIM compatibility, updated from (Ahamed et al., 2010).

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Description</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>ActiveFacility</strong></td>
<td>BIM-based server that stores, updates and provides access to FM information</td>
<td><a href="http://www.activefacility.com">www.activefacility.com</a></td>
</tr>
<tr>
<td>2</td>
<td><strong>ARCHIBUS</strong></td>
<td>Provides several specialised solutions and platforms for FM and operations</td>
<td><a href="http://www.archibus.com">www.archibus.com</a></td>
</tr>
<tr>
<td>3</td>
<td><strong>AssetWorks</strong></td>
<td>Provides an integrated workplace management. Suits include maintenance management, capital management, space and asset management.</td>
<td><a href="http://www.assetworks.com">http://www.assetworks.com</a></td>
</tr>
<tr>
<td>4</td>
<td><strong>Bentley Facilities</strong></td>
<td>BIM-based solutions for FM. Services provided include space management, move management, and maintenance management.</td>
<td><a href="http://www.bentley.com">http://www.bentley.com</a></td>
</tr>
<tr>
<td>5</td>
<td><strong>Ecodomus</strong></td>
<td>Formerly known as <strong>Tokmo</strong>. Provides a 3D view of facilities that are connected with real-time sensors.</td>
<td><a href="http://www.ecodomus.com">http://www.ecodomus.com</a></td>
</tr>
<tr>
<td>6</td>
<td><strong>FM:Systems</strong></td>
<td>Creates a direct link with BIM models through <strong>Autodesk Revit</strong> for space and facilities management.</td>
<td><a href="http://www.fmsystems.com">www.fmsystems.com</a></td>
</tr>
<tr>
<td>7</td>
<td><strong>IBM-Maximo</strong></td>
<td>A solution for asset lifecycle and maintenance management. The solution provides an extension that support importing BIM data for a full 3D display</td>
<td><a href="http://www.ibm.com">http://www.ibm.com</a></td>
</tr>
<tr>
<td>8</td>
<td><strong>ONUMA</strong></td>
<td>Web-based BIM tool that utilises IFC to provides 3D platform suit for operation and maintenance of facilities.</td>
<td><a href="http://www.onuma.com">www.onuma.com</a></td>
</tr>
<tr>
<td>9</td>
<td><strong>Planon</strong></td>
<td>Platform compatible provides various FM suits including Maintenance management, space and workplace management. Planon assisted in developing <strong>COBieLite</strong>, a derived version of COBie standard.</td>
<td><a href="http://planonsoftware.com">http://planonsoftware.com</a></td>
</tr>
<tr>
<td>10</td>
<td><strong>TMA Systems</strong></td>
<td>Web-based solution that provides several services for FM including maintenance management and space management, and asset tracking</td>
<td><a href="http://www.tmasystems.com">http://www.tmasystems.com</a></td>
</tr>
<tr>
<td>11</td>
<td><strong>Vizelia</strong></td>
<td>FM platform driven by IFC model that provide asset management, occupant coordination, and property service management</td>
<td><a href="http://www.vizelia.com">http://www.vizelia.com</a></td>
</tr>
</tbody>
</table>
There are additional BIM-based software applications that are not FM-focused but can still be utilised during the operational stage of a facility. Such software applications include *Solibri* (Solibri, 2012) and *Navisworks* (Autodesk, 2012). *Solibri* provides model checking solutions that work as “design-spell-check tool” (Borrmann et al., 2009) for design integrity, quality, assurance and BIM analysis. Uses of *Solibri* in operational stage of a facility include aiding facilities managers to assess building material lifecycle costs and maintainability (Solibri, 2007).

*Navisworks* by *Autodesk* is another application that can be used during the post construction stage of a facility for collaborative activities. *Navisworks* can connect different application packages for information exchange. Such software can also be employed to receive design and construction BIM models in different file formats and consolidate them into a single master model (IFMA, 2013). The master model can then be viewed in *Navisworks* viewer by facility management personnel to identify clashes and coordinate between building components.

The illustrated applications in this section are based on modelling technical data and the geometry of the components in BIM models. Hence, the taxonomy of the stored information is model-based. This approach will, indeed, largely assist the facility managing personnel in performing their activities; however, it will also result in several drawbacks. Firstly, incorporating non-technical and non-geometrical knowledge is not considered fully in the model. Secondly, extracting any information will need two requirements (1) the user has to be acquainted with the building (i.e. one of the professionals working on the project) and (2) permission to access the BIM-based model. In other words, the user has to be working on the same building to be able to extract information from BIM model. Users located in other locations do not fulfil such conditions and in turns will not be able to access and extract information to be used in other projects. (3) Knowledge sharing through FM software between teams located in other projects and locations can be limited due to differences of geometry, shapes, and types of elements between projects.

Such drawback suggest the opportunity to investigate developing and utilising open access hub for sharing non-technical and non-geometrical knowledge through familiar taxonomy between teams located in different projects.
5.8. Summary

This chapter has illustrated several perspectives in defining BIM and discussed the benefits and evolution of BIM in the AEC/FM industry. Methods for sharing BIM data and information have been demonstrated and published BIM based research and commercial based applications with relevance to the BM sector have been reviewed.

The review of BIM-based approaches showed that the focus is limited to performance monitoring and managing technical data and information on building components. Examples of managed data include space allocation, condition status, maintaining cycles, and location. Moreover, no approach was found that investigates managing knowledge related to a facility’s maintenance and management that could be shared and transferred to another project.

According to Leslie and Deshpande (2011), there are three scenarios for information access and exchange in building models: within a project, between projects, and between project and external resource. However, the exchange of information facilitated by the reviewed approaches is limited to stakeholders within a project that maintain a particular facility. Therefore, accessing such data will require a direct access to the facility, either physically or through the representing BIM model. In other words, individuals have to access the model first in order to obtain the information, as it is linked to the components and spaces in the BIM model. Hence, only acquainted and authorised personnel who have access to the model or facility can benefit from stored information. These approaches will thus limit the sharing of knowledge between teams located in other locations. This is especially clear with BIM-based models that represent high profile or high security facilities such as prisons airports, and presidential buildings.

The reviewed approaches to using BIM for FM and BM are based on data and information associated to particular building’s components or spaces. This in turn will affect the type of retrieval method of the stored data and information. The taxonomy of the stored data and information is therefore element and space-based. As a result, retrieving a particular item of data or information will require the search to be element or space-based. For knowledge management systems, retaining, accessing, finding, and retrieving knowledge is mainly case-based. Since the reviewed approaches were either element or space-based, deficiencies found in the reviewed approaches in terms of how
to transfer, retain, access and retrieve knowledge are taken into consideration in this research.

The proposed system in this research should therefore have the ability to utilise the intelligence of BIM, and facilitate professionals to share their knowledge. This can be done by allowing non-geometrical and non-technical knowledge to be shared and utilised in a familiar taxonomy through a knowledge base. In other words, the approach of this research is case-based knowledge utilised from intelligent features of BIM-based models. This approach will help the transformation from ‘Building Information Modeling’ to ‘Building Knowledge Modelling’. Such an approach will indeed facilitate teams located in different sites and locations to benefit from sharing their knowledge without compromising confidentiality or security of buildings.

The following chapter presents arrangements, results, and analysis of field data collection from selected BM departments.
Chapter 6 - Field Data Collection
6.1. Introduction

The previous three chapters carried out thorough review of related literature on Building Maintenance (BM), practices of Knowledge Management (KM) and Building Information Modeling (BIM) in BM sector.

This form of data collection will serve the research objectives as follows: The first objective of this study is to map and examine main processes being carried out by BM departments. The second objective is to explore issues related to KM including current KM techniques, IT usage, and perceptions regarding introducing a KM system for BM. The third objective is to assess BIM implementation in the BM sector.

Based on qualitative methodology adopted for this research, this chapter presents the arrangements and the findings from the interviews conducted with BM departments in Kuwait to address these objectives. The chapter starts by illustrating details of the participating departments and the methodology applied in data collection. After that, the adopted BM process is presented and discussed. Following this, findings on the current KM techniques, usage of technology, and perception towards KM are reported. This is followed by assessment of the extent of BIM implementation in the BM sector. Finally, a taxonomy is identified to manage the knowledge in BM and deficiencies in knowledge sharing are highlighted.

6.2. The Participating BM Departments

The field data collection aimed to investigate the current process and state of KM in the public BM departments in Kuwait. As indicated in section 2.5, the method of semi-structured individual interviews was considered the most suitable method for data collection to develop a BM process model and to explore KM related issues. According to the Kuwait Central Statistical Bureau (KCSB, 2011), 51 public organisations are listed in the Kuwaiti state budget. Recommended sample size for interviews to obtain satisfactory results in phenomenology should be between 6 (Morse, 1994) and 25 (Polkinghorne, 1989; Cited in Creswell, 2007) individuals “who have all experienced the phenomenon” (Creswell, 2007, p.61); hence 10 key professionals working in public BM departments were interviewed in this study. The venues where the interviews were held were the participants’ working offices, meeting rooms, and hotel lounges. The
criteria for selecting venues were based on the participant’s convenience, quietness, and minimal interruptions.

Table 6-1 illustrates the participating departments in the interviews. The size of participating departments was classified based on the number of employees. Departments with less than 50 employees are classified as small, those with 50-249 employees are classified as medium and large refers to departments with more than 250 employees. Moreover, it should be noted that departmental branches vary from a single branch to several branches located in different parts of the country. This feature is significant in examining the communication level between branches of the same department. Similarly, the feature of a number of contracts being supervised in a single department will assist in examining the communication level between teams within same branch.

Table 6-1: Participating BM departments.

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Organisation size</th>
<th>Number of branches</th>
<th>Contracts per branch</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Audit Bureau</td>
<td>Small</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>Kuwait University</td>
<td>Small</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>Ministry of Communication</td>
<td>Medium</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>Ministry of Defence</td>
<td>Large</td>
<td>21</td>
<td>3-4</td>
</tr>
<tr>
<td>E</td>
<td>Ministry of Education</td>
<td>Large</td>
<td>6</td>
<td>2-3</td>
</tr>
<tr>
<td>F</td>
<td>Ministry of Interior</td>
<td>Medium</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>G</td>
<td>Ministry of Justice</td>
<td>Medium</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>H</td>
<td>Ministry of Public Works</td>
<td>Large</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>Ministry of Social Affairs and Labour</td>
<td>Medium</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>J</td>
<td>National Guard</td>
<td>Small</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

In order to have even responses, it was essential that size of participating departments to should be evenly distributed. Therefore, three small, four medium and three large organisations were interviewed to assist in developing the diagram of BM process, to investigate issues related to knowledge and its management, and investigate BIM implementation in BM sector. This approach was taken since no available literature was found that discusses and distributes public BM departments based on size.

Furthermore, selecting the right person to be interviewed is essential to be able to reflect on the organisational process that involves different parties. Therefore, the criterion of
selecting interviewees is based on participants having held a higher managerial position for several years in a BM department. As a result, four managers, one assistant manager and five divisional heads participated in the interviews, all of which had a minimum of eight years of experience. The potential participants were contacted in advance to schedule interview appointments and to check with their work regulations that may restrict participation. Also during a phone conversation, general information was gathered including the number of employees and number of branches. This was done to distribute the organisations evenly prior to commencing the interviews.

6.3. Interviews

6.3.1. Interview approach

Selecting between quantitative or qualitative approaches for data collection is based on the knowledge required and its purpose in the research. While a quantitative approach is more focused on outcomes and depicting statistical interfaces, a qualitative approach is more pivoted around processes and meanings (Creswell, 2008; Merriam, 1988). Moreover, a qualitative approach is employed to explore and develop a detailed understanding of a central phenomenon (Creswell, 2011b).

Therefore, a qualitative approach to acquire relevant data was deemed appropriate since this stage of the research is focused on understanding the BM process, current knowledge sharing techniques, the level of IT usage, perceptions towards KM, and assessment of BIM implementation. Moreover, an additional necessity that led to selecting interviewing was the need for direct involvement and instant feedback from experts to assist in developing the BM process diagram.

Fontana and Frey (1994) believe that fellow human beings commonly and prominently use interviewing as a way to understand each other. Therefore, a series of qualitative interviews were considered as most appropriate approach to obtain the required knowledge at this stage of the study. Scholars have the categorised approaches of interviews in different ways:

1) Structured and unstructured (Fontana & Frey, 1994; Marvasti, 2003; Yin, 2010b).

2) Standardised, semi-standardised and unstandardised (Berg, 2001).
3) Informal, structured, semi-structured and unstructured (Bernard, 2000).

Several levels of formality are used in interviewing. Informal interviewing can occur unexpectedly with no prior preparation, and the interviewee has no control over its course. The researcher in this type of interviewing “just tries to remember conversations heard during the course of a day in the field” (Bernard, 2000). The next level is unstructured or unstandardised interviewing. In this type, the researcher adapts to the progression of the interview by developing and generating questions to serve the exploration of the investigated subject.

The type known as semi-structured or semi-standardised interviews is located between the structured and unstructured interviewing structures (Berg, 2001). The questions and their order are predetermined in an interview outline. However, the researcher has some flexibility to change and alter the questions to further probe significant replies. On the other side of the scale, a structured or standardised interview is the most structured type of qualitative interview. The interviewer in this type of interviewing follows a strict structure where all participants are asked the exact questions in the exactly same questioning context (Bryman & Bell, 2003).

For the purpose of this research, the form of individual semi-structured interviews was selected to carry out the qualitative interviews. Part of the interviews is concerned with developing a current process map adopted by public BM departments. This involves input in the form of descriptions and modifications from several of the participating experts. Therefore, some level of flexibility in interviews in terms of following up questions was needed during the development of the BM process diagram. Semi-structured interviewing can provide much needed flexibility while maintaining the overall structure of interview themes.

6.3.2. Interview protocol

The semi-structured interviewing technique was used to collect data at this stage of this study. The means of communication for the interview has been based on one-to-one face-to-face interaction. As depicted in Figure 6-1 the general structure of the interview is set to explore the following four major topics: (1) understanding and mapping current processes adopted by BM departments, (2) investigating KM related issues in BM including current KM techniques used in BM, technology usage, and perception of
introduction of a KM system, (3) assessing the implementation level of BIM and related issues, and (4) understanding BM taxonomy through reviewing documents from participating departments to assess in developing knowledge taxonomy for the KM system.

**Figure 6-1: Topics covered in the interviews.**

During the arrangement of the interviews and scheduling of appointments, potential interviewees were given brief information regarding the topics to be discussed. This was performed either personally or via phone calls. This was done to allow the interviewees to think about the topics to be investigated in interviews and to provide any useful documents.

The interviews began with friendly conversations including the introduction of the research topic and researcher’s background. Then the researcher asked the interviewees to read and sign the interview consent forms (see Appendix A). The interviews conducted in the Arabic language so that participants can clearly reflect on their views. Next, general questions were asked to gather information about the participating BM department (see Appendix B). This included information regarding the number and location of branches, number of employees, type of contracts and number of
contractors. After that, each of the topics was explored in more depth with a series of general open-ended questions and follow-up sub-questions. Creswell (1994) suggests that questions in exploratory interviewing can be in a form of (1) one or two “grand tour” questions followed by (2) several “sub-questions”. At the end of each interview, interviews were asked if they wish to participate in the further stages of the research.

6.3.3. Reliability

Johnson and Duberley (2000) state that reliability is concerned with the consistency of findings acquired in research. Flick (2009) elaborates this saying that “Reliability gains its importance as a criterion for assessing qualitative research only against the background of a specific theory of the issue under study and about the use of methods”. This statement evaluates reliability of findings against two conditions, background of the related parties to the investigated subject and methods used in reaching such findings. In terms of background, the researcher has considered two criteria for reliable candidate which are: (1) experience in buildings maintenance and (2) managerial position. In terms of reliability of methods used, the mean of digital recording and concurrent note writing was chosen to increase the reliability of data acquisition, interpretation, and comparability. This approach was adopted so that any remarks noted during interviews are later used to assist in clarifying the actual recorded data.

Also, within the context of increasing reliability, the method of semi-structured interviews was adopted so that participants of all interviews are asked questions revolving around the same subjects. Moreover, a conceptual diagram of BM process, developed by the researcher, was modified after each interview and then shown to the next interviewee for further assessment and additions. This was done so that the developed diagram would capture processes of all participating departments.

6.3.4. Validity

Validity is concerned with how well the test actually measures what it sets out to measure (Ereaut, 2002). In quantitative approach, the validity is limited to measurements and requires results in numbers. In this sense, any qualitative approach will become invalid. Lewis and Ritchie (2003) however argue that validity is equally important in qualitative research. According to Easterby-Smith et al. (2008, p.109), a
valid study research should answer the question “Does the study clearly gain access to the experiences of those in the research setting?” The answer for this research is:

- The 10 interviews were conducted with experts who are all currently involved in the research subject (public building maintenance).
- All interviewees are from different departments located in different locations.
- The departments are different in terms of size and number of employees.
- Findings do not contradict with the general knowledge of the investigated topic. This can be recognised when answers are found to be generally recurring about the intended knowledge.

6.4. Interview Results

6.4.1. BM process model

As illustrated in section 1.3, the first objective of this research is to map and examine the main processes and stages of services provided by BM departments. The contribution of interviews in this part of the study was to develop a typical process model adopted by public BM departments. This approach is adopted to identify knowledge management related problems, including investigation of whether the current process encourages or limits the sharing of knowledge. Moreover, the developed process model will also assess to whether principles of KM can be applied to the adopted BM process.

Process mapping involves developing a model that illustrates relationships between the actions, individuals, data, and objects engaged in delivering a specified output (Biazzo, 2002). Different types of flowcharts are used in mapping processes such as Block diagram, American National Standard Institute, Functional flowcharts, and Geographic flowcharts (Harrington, 1991). In this section, a block diagram flowchart is used for mapping the BM process. The reason for that is that the simple notations used in block flowcharting are easily comprehended and understood by individuals.

The researcher developed a conceptual BM diagram to be used as a starting point in the interviews (see Appendix C). The conceptual process diagram was based on the process used by the researcher’s previous employers. During interviews, this conceptual BM model was presented to the interviewees and they were asked to modify the model to
represent their current BM process. After each interview the model was modified and adapted and then taken to the next interviewee for further additions. The idea behind this method was to develop a generic high level model that represents main activities followed by the BM departments. Figure 6-2 depicts the final process map followed by public BM departments.

The developed BM process, as shown in Figure 6-2, consists of the main BM parties (in boxes) and the type of activities and processes that are conducted (arrows linking these boxes). In addition, Figure 6-2 shows boxes and arrows in solid and dashed lines. Solid lines represent activities and parties found in all participated departments. Dashed lines represent activities and parties found in only some of the participated departments.

As indicated in section 6.2, the participating departments have either single or multiple branches. Moreover, the BM departments deal with a single contractor or multiple contractors. However, Figure 6-2 shows a general BM department with only a single branch manager and a single contractor. This is done to simplify the presentation of the process and to indicate that other branches follow the same process. Parties shown in the Figure 6-2 are department general manager, design/planning divisions, branch manager, maintenance team, contractor, in-house team, and finance division. Public employees include engineers, architects, engineers’ assistants, technicians, and administration employees.

Nine of the participating departments mainly follow the corrective maintenance approach in their BM works. In this approach, maintenance work commences after receiving requests from the buildings’ users or maintenance teams. These can be in the form of written request letters, phone calls, and maintenance team observations. A scheduled maintenance approach is taken for mechanical and electrical machines such as heating, ventilation and air-conditioning equipment.
Figure 6-2: Typical public BM process in Kuwait.
The process starts with receiving requests for maintenance works from units or by maintenance teams, (activities 1A and/or 1B). After receiving the requests and prior to maintenance or repair works, several activities are carried out including assessing the problem, issuing approximate quantities, calculating estimated costs, issuing sketches, and obtaining permissions and approvals. Such duties are carried out by the design/planning divisions (activities 2A to 4A). However, when such divisions are absent in BM departments, maintenance teams carry out the above responsibilities (activities 2B to 4B).

Only one BM department follows different route which is department (A). This department employs a call centre that receives calls regarding faults and problems. The call centre then issues maintenance job orders to the contractor. Moreover, routine visits are carried out by the contractor’s team after working hours to check and repair any faults. A “fixed price maintenance contract” is employed by this department which includes lists of agreed “lump sum work and services” carried out by the contractor (definition illustrated in section 3.4). The contractor is responsible for handling any faults and services listed in the lump sum lists directly, without approvals. On the other hand, if the fault is not included in the list, estimated quantities and costs are sent to the management for approval, based on price tables of work packages. This process carried out in department (A) has not been included in the figure since no other participated BM department follows the same route.

Department (G) follows similar routes illustrated in Figure 6-2 but only for mechanical and electrical works. Any maintenance activities that involve civil works are to be outsourced to the maintenance department (H).

As shown in Figure 6-2, when the estimated budget for the project is approved (activity 5), detailed lists of items with their quantities are then issued to the contractors or to in-house teams (activity 6). The approximation of quantities, items, types of works and project total cost included in the job description are based on the contract signed between the department and the winning contractor. To commence the approved maintenance works, the site is handed out to the contractor (activity 7). The designated maintenance team of the department then observes and supervises the works being carried out (activity 8). When there is more than one specialised contractor working in a project, the maintenance team of the BM department manages the contractors, kick-offs and activities.
Upon finishing the project (activities 9 & 10), the contractor/in-house teams and the supervising group submit project completion documents, including a detailed list of re-measured quantities, modified total cost, and issue as-built drawings when required for items and works that were carried out in the project. Next, the branch regional manager checks the submitted quantities then sends the project documents with the payment approvals to headquarters (activity 11). Another verification of the documents is then made to ensure accurate summation of prices (activity 12). Lastly, a payment approval is issued to be included within the agreed contractors’ periodic payments (activity 13).

When asked about the procedure carried out in case of emergency, all the interviewed organisations indicated that they might modify few steps of the process prior to maintenance works in order to speed up reaction times. Project documents that are usually prepared prior to maintenance works, including quantities and cost, are issued after completion of urgent maintenance works.

An example of urgent maintenance works was reported by department (C): “during a weekend in summer time, we had an air conditioning failure in a computerised control room. The temperature could not be allowed to rise above 20 degrees. I had to purchase several portable air conditioning units from my own pocket and installed them in the control room. After repair work was completed and the building air conditioning got back to normal operation, I claimed back the cost of the units.”

6.4.2. KM in BM departments

As demonstrated in section 1.3, the second objective of this study is set to explore issues related to KM including techniques, awareness, perceptions, and IT usage. Hence the second part of the interviews focused on identifying the methods used to manage and share knowledge. All participants indicated that there is no KM strategy adopted by their departments.

However, when participants are asked how knowledge is gained and shared in their departments; several methods were used by the BM departments were pointed out.

The first and most common approach is through mentoring and learning from each other. Nine departments stated that they usually form teams with a mixture of experienced and inexperienced colleagues to create opportunities to share and transfer knowledge. However, it was noticed that such mixing of experience still within the
same branch. In other words, no knowledge is being shared and transferred between different branches.

Moreover, one small department (A) indicated that its professionals independently supervise the maintenance works. The participant revealed that only experienced applicants are accepted to the BM vacancies. Nonetheless, the participant stated that it is currently acknowledging the large impact of IT on BM performance. Therefore the department is considering opening posts in near future for new graduates with IT knowledge.

The second method is by attending training courses. All participants stated that their departments provide regular training programmes for their employees to increase their knowledge of BM works. The training courses were either funded directly by the department or through the BM contract.

The third approach is through storytelling. One branch in a BM department expressed that regular events are organised where experienced engineers give lectures regarding their insights and experiences.

The fourth approach is by daily communication. Three departments (A, C and J) indicated that all maintenance teams are located in one building. Therefore, the participants indicated that BM professionals usually sit together at the beginning, during breaks, and end of a working day. However, the participants affirmed that such gatherings are typically informal in nature. Only when a meeting is called does the gathering become formal and adhere to an agenda. The participant from one small department (B) indicated that divisional heads located at different branches are connected through wireless devices for instant communication and exchange of experiences. The other departments indicated that branches are located in different locations and therefore interaction is largely limited to that between members of the same branch.

In terms of social interaction after working time, six participants indicated that informal gatherings might take place between employees who are already friends at work. Two participants stated that they are unsure whether out of work gatherings take place between their BM professionals. Two participants affirmed that social and informal gatherings and events take place on a regular basis between all of their department employees.
Department (C): “since I have been appointed as a manager to this department, we have been organising trips where we all get together. We also gather from time to time in my Dewaniya\(^1\). We’ve also been constructing temporary camps where we gather during winter and spring seasons of each year. The cost of tents, accessories and food is divided between department employees.”

Department (I): “one of the employees has a Dewaniya where we gather on weekly bases.”

When asked whether colleagues from other branches attend the Dewaniya.

Department (I): “the vast majority of colleagues in our branch attend on almost weekly bases and a few from other branches. But when there is a formal invitation for an occasion, most colleagues from other branches come to the Dewaniya.”

Another means of communication is through “official routine meetings”. Such meetings are considered one of the main events in BM departments for decision making, which can be an approach for KM. Therefore, this topic will be given further detailed analysis in the following section.

### 6.4.2.1. Knowledge sharing in meetings

This part of the interviews investigates knowledge sharing in meetings. When asked about departmental meetings, their occurrence and nature, all participants indicated that they conduct regular meetings with headquarters, their teams and contractors. The participants asserted that regular meetings are conducted at different departmental levels. Several issues are discussed in meetings including those related to maintenance projects, budgets, significant problems and their solutions. Issues of maintenance projects are taken to meetings when problems could not be solved on-site. However, even though insights and solutions can be discussed and shared in meetings, such knowledge is limited to colleagues who are part of the meetings.

The meetings are commonly conducted on weekly or bi-weekly basis. Two departments (E and H) indicated that they have additional monthly meetings in headquarters. The sole purpose of these meetings is for evaluating of materials submitted by the

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\(^1\) = Reception hall in a house with a purpose of hosting guest and business gatherings. The Dewaniya in Kuwait has fundamental role in Kuwaiti social, economic and political life (Wikipedia, 2012; Kuwait Government Online, 2012).
contractors. This is done to limit discrepancies that could arise between different branches in terms of approving and rejecting maintenance materials. Moreover, three departments (B, F, and I) indicated that they have a maintenance committee that meets on weekly basis. The committee consists of all division heads of the departments. Departments (F and I) conduct these meetings after working hours so that such meetings do not obstruct maintenance works. The other five departments (A, C, D, G, and J) do not have a maintenance committee however; general managers meet branch managers either individually or altogether. Also, participants from all departments indicated that branch managers meet their maintenance teams, either individually or altogether.

All participants indicated that meeting agendas and minutes are circulated to participating meeting members and to teams, with whom projects were discussed in the meetings. The archiving of meetings minutes and decisions are project and time based. All administrative circulars, including those resulted from meetings are manual and paper based. They associated that with the regulations of their organisation.

Figure 6-3 demonstrates the meeting structure followed by the participating departments. The figure consists of boxes representing parties involved in meetings and lines representing the meeting network. Solid boxes and lines symbolise parties found in all participating departments; dashed boxes and lines represent parties found in some participating departments.

![Diagram](image)

**Figure 6-3: Typical structure of meetings in a BM department.**
As shown in Figure 6-3, the meetings conducted by participating departments take place at different organisational levels: meetings at high level between department general manager and branch managers, meetings at middle level between branch managers and their maintenance teams, between branch managers and contractors/in-house teams, and meetings at low level between maintenance teams and contractors/in-house teams. Figure 6-3 shows that meetings of frontline employees are conducted within the same branch and between same level colleagues and their supervisors.

6.4.3. Technology usage

Part of the second objective is to assess IT usage in BM departments since this study is proposing an IT based KM system. Therefore it is essential to investigate issues related to IT in BM departments including level of knowledge and usage.

The participating departments were initially asked about the level of knowledge of computer use. All participants stated that their employees have knowledge of computer use. However, two departments feel that level of knowledge is higher among relatively younger professionals. It was stated that the usage is frequent and extended to preparing project documents, filing administrative forms and surfing the internet. In terms of preparation of project drawings, all participating departments use AutoCAD software to prepare sketches and some project drawings.

Regarding the connectivity to internet, all ten departments indicated that most of their computers located in branches have internet connections. However, the usage is mostly for casual use. Nonetheless, only three departments, (A), (B) and (G), have IT infrastructure where computers are connected to organisational network. However, these departments only use commercial facilities management software to manage maintenance activities, departments (B) and (G) use IBM Maximo while department (A) uses CAFM 500. The usage of the FM software only covers the maintenance schedules for buildings equipment. Furthermore, none of the participating organisations has knowledge base where policies, solutions and decisions can be stored, organised or accessed.

The representative of department (F) stated that several employees have formed groups using a social media application “WhatsApp” to discuss problems share experiences and
ask for solutions. However, the knowledge storage, organisation, search, and retrieval are limited to the capabilities of such application and their phones.

6.4.4. Perceptions about KM

Participants believe that there is large area for performance improvement in their departments. Furthermore, the majority of participating organisations believe that the lack of knowledge sharing between employees can lead to additional expenses and lower value for money spent on maintenance projects. Such attitudes could be significant in terms of management support and commitment to implement KM considering the managerial positions held by interviewees.

With regard to willingness to share knowledge, the majority of participants indicated that their employees willingly share their knowledge. However, one participant, department (E), showed a strong position against knowledge sharing without incentives or assurances: “it took me so much hard work to gain this experience. I won’t allow others to take advantage of it so easily.”

Four participants asserted that some employees only share their experiences when asked. Less than half claimed that factors such as citizenship and ethnicity play a significant role in willingness to share knowledge among employees. Such remarks are consistent with Al-Kazemi and Ali (2002) who found that most significant problems in Kuwaiti organisations include dominance of personal relationships over work relationships, influence of personal loyalty and favouritism at work and bias in promotion and evaluation. In addition, it should be considered that foreign workers are hired based on their expertise and that they have to bear with annually renewed contracts. Such issues place, perhaps, a significant pressure on non-citizens to always be at higher standards compared to Kuwaiti colleagues. Further discussion on issues related to barriers of knowledge sharing is beyond the scope of this study.

The majority of participating departments showed a positive perception when asked about their opinion on proposing a knowledge-based system. Nine participants deem that such step is useful and it would improve the performance of their organisations. Only one participant was pessimistic towards the introduction of a KM system. Participant of department (E) stated that: “I don’t think my team will have time to sit and write about their experiences.”
Below are examples of participant replies:

Department (C): “I would definitely support any novel idea that aims at improving the performance of our department.”

Department (F): “Without a doubt, knowledge sharing would eventually benefit everybody.”

Department (H): “During my early days, I have dealt with some expert people who were reluctant to teach me how they figured out their solutions. So yes, I would support introducing a KM-based system.”

Department (J): “I think this system is likely to reduce mistakes.”

The third part of the interviews was focused on assessing the implementation level of BIM and its related issues. The following section illustrates the participants’ responses to this matter.

### 6.4.5. BIM implementation in BM

The third research objective is to assess BIM implementation in the building maintenance sector. Therefore, in this part of the interviews, the first question aimed at assessing the awareness of BIM technology. Seven of the participated departments indicated that they have no idea about BIM. The other three participants (A), (B), and (F) indicated that they have heard of BIM technology as a new tool used in designing and constructing buildings.

The second question focused on participants who expressed that they are aware of the BIM technology. The question investigated the manner of awareness. Two of the participants (A) and (B) mentioned the Revit software and one mentioned ArchiCAD software as BIM-based applications. However, only one of the participants (F) recognised that BIM software is based on constructing a virtual building. Such participant also recognised that the main difference between AutoCAD and Revit is the former is merely a digital drafting tool while the latter is element based technology to construct virtual projects.

When whether their departments have implemented BIM technology in BM projects, all three participants who have an idea about the technology indicated that their
departments had never implemented BIM technology. Moreover, as they have never used the technology, the participants could not identify any benefits of BIM.

When asked to provide a major reason for not using BIM technology, two participants (B) and (F) indicated that the environment of the Kuwaiti public construction sector in general is still dominated by the old mentality of decision makers and therefore is not ready for such new technology. Participant (A) indicated that public organisations need regulations that require implementation of any new concept, including BIM technology. Therefore, public BM departments cannot adopt such new technology without this condition. Moreover, the participant indicated that BM employees deal with a building’s documents including as-built drawings that are transferred from earlier stages. Such drawings have been prepared using drafting tools such as AutoCAD; therefore, the design stage should firstly adopt the technology in order to enable it to other sectors in the construction industry.

The participants who did not have an idea about BIM technology were given a brief description of the concept. After that, the participants were asked whether such technology will eventually be implemented in the Kuwaiti BM sector. Half of the participants (A), (B), (F), and (H) agreed that BIM technology will be used in future. The reason for their answer was competitiveness drives companies into introducing new concepts. Also it was expressed that BIM can be seen as next stage to the evolution of CAD. Two participants (D) and (J) affirmed that BIM will succeed in the sector only when clients start to require buildings to be designed by BIM technology. The remaining three (C), (E), and (G) were extremely sceptical of the success of BIM. The reason for that was, clients, architects and contractors are familiar with CAD tools, therefore it would be hard to shift to another technology. Also, it was expressed that construction industry in general is managed by regressive mentalities. It was also stated that since public organisations do not use BIM it would therefore not be implemented by architects and contractors.

The responses from these key experts provide additional support for the effort of achieving the research objective of developing a KM-based system. The following section illustrates how the KM taxonomy for the proposed has been derived.
6.4.6. KM taxonomy for BM

The main objective of this research is to propose a KM system to be used by professionals working within the public BM sector in Kuwait. Therefore, it is essential for the process of capturing, clustering, retrieving and then presenting the knowledge cases to be carried out in a particularly customised manner for best serving these professionals’ needs. Fong and Wong (2005) emphasise that knowledge in BM is precise and context-based and cannot be generalised. They highlighted that KM web-based systems should provide specific knowledge through containing enough cases within the BM context to enable users to obtain relevant ones in order to facilitate their decision-making process. For the purpose of developing a KM system, a knowledge taxonomy for BM should be developed.

For the above reasons, the essence of knowledge taxonomy to be used in the proposed system will be based on the BM contracts currently used in Kuwait. This is because the indexing of knowledge should be based on a familiar context to the targeted BM professionals. This will facilitate the use of the proposed system to a wide users and organisations while requiring minimal training. Therefore, one part of the interviews was about identifying the level of familiarity of employees with the indexing of tables for maintenance works and collecting copies of the contract documents in use.

The “Measured Term Contract” (MTC) is the standard type of contract employed by the majority of participating departments to fulfil their maintenance duties (definition is illustrated in section 3.4). This form of contract is either applied separately, for the civil, electrical and mechanical works of building maintenance, or as one contract for all specialities. The contractors’ classifications of size and speciality are organised by the Central Tendering Committee (CTC), which also controls the tendering process for the whole State of Kuwait’s public projects (CTC, 2010). Only one department (A) employs a “fixed price maintenance contract” to maintain its building. However, price tables for work packages were also included in the contract, to cover unforeseen work not recorded in the agreed lump sum maintenance lists.

In terms of familiarity with the context of BM contracts, the participants stated that the majority of professionals are familiar with the contents of the contracts. This is because any issues arising between the department and contractors during BM works are discussed based on the relevant clauses of the contract. Moreover, teams
Chapter 6: Field Data Collection

To assist in comparing contracts of the interviewed departments, contract particulars were reclassified in this research into three categories: legal, technical and administrative. This was done to simplify deriving the knowledge taxonomy for the system. Table 6-2 shows the categories and the related sections from the MTC particulars.
Table 6-2: Proposed classification of contract sections.

<table>
<thead>
<tr>
<th>#</th>
<th>Category</th>
<th>Section</th>
</tr>
</thead>
</table>
| 1  | Legal        | Particular legal conditions  
|     |              | General legal conditions  
|     |              | Kuwaiti bidding law and its modified regulations  
|     |              | General Health and safety regulations |
| 2  | Technical    | General specifications for building and its facilities  
|     |              | Particular specifications  
|     |              | Tables of quantities and prices  
|     |              | Drawings |
| 3  | Administrative | Assets of the contract  
|     |              | Appendixes and minutes of the preliminary meeting |

The MTC contract includes different sections, such as earth works, concrete works, wood works and masonry works. The documents examined from the interviewed departments have shown that the contracts’ sections are generally similar, including the contracts’ particulars and the indexing of pricing tables for BM work packages. However, some differences are found in subsections, specifications, items included, and pricings. This is because the MTC form used by public departments is derived from contracts employed by the Ministry of Public Works (MPW). This ministry used to do all maintenance and construction works for the public sector. The majority of organisations have matured and now individually conduct their construction and maintenance works. However, MPW still provides its services to several public organisations. One of which is department (G), which is still outsourcing some of its maintenance works and all of its construction projects to MPW. Moreover, departments (C and I) outsource their large construction projects to be carried out by MPW.

It was also observed that the contract of one large organisation, (H), contains more subsections in its tables of quantities when compared to other organisations. When the interviewee was asked regarding this issue, the reply was that the ministry provides building maintenance services to other public organisations that do not have the capacity to maintain their buildings. Therefore, it was necessary to include more detailed subsections and pricings to accommodate requirements and requests from various organisations.

Table 6-3, Table 6-4, Table 6-5, and Table 6-6 show the indexing sections of BM contracts used by the interviewed departments. These tables will be used to develop the
knowledge taxonomy adopted by the proposed system. Symbol (✓) indicates that the
section is present in the BM contract while symbol (✗) indicates it is not.

Table 6-3: Legal sections.

<table>
<thead>
<tr>
<th>#</th>
<th>Index</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>Particular legal conditions</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>General legal conditions</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>The Kuwait bidding law</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>General health and safety regulations</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 6-4: Administrative sections.

<table>
<thead>
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</thead>
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<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>Assets of the contract</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Appendixes and minutes of the preliminary meeting</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 6-5: Technical sections.

<table>
<thead>
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<th>Organisation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>General specifications for building and its facilities</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Particular specifications</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Tables of quantities and prices</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>Drawings</td>
<td>✓</td>
</tr>
<tr>
<td>#</td>
<td>Index</td>
<td>Organisation</td>
</tr>
<tr>
<td>----</td>
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<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td><strong>Section One -</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Demolition, Dismantling and Removal</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Assembly and Installation</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td><strong>Section Two -</strong></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Earth works</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>Concrete Works</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>Masonry Works</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>Plaster Works</td>
<td>✓</td>
</tr>
<tr>
<td>7</td>
<td>Steel works</td>
<td>✓</td>
</tr>
<tr>
<td>8</td>
<td>Aluminium Works</td>
<td>✓</td>
</tr>
<tr>
<td>9</td>
<td>False Ceiling Works</td>
<td>✓</td>
</tr>
<tr>
<td>10</td>
<td>Roof Covering Works</td>
<td>✓</td>
</tr>
<tr>
<td>11</td>
<td>Flooring and Cladding Works</td>
<td>✓</td>
</tr>
<tr>
<td>12</td>
<td>Bathroom Hardware and Sanitary Works</td>
<td>✓</td>
</tr>
<tr>
<td>13</td>
<td>Water Supply Works</td>
<td>✓</td>
</tr>
<tr>
<td>14</td>
<td>Sewage Works</td>
<td>✓</td>
</tr>
<tr>
<td>15</td>
<td>Insulation layers for Wetness, Humidity and Heat</td>
<td>✓</td>
</tr>
<tr>
<td>16</td>
<td>Wood Works</td>
<td>✓</td>
</tr>
<tr>
<td>17</td>
<td>Paint Works</td>
<td>✓</td>
</tr>
<tr>
<td>18</td>
<td>Glass and Plastic Works</td>
<td>✓</td>
</tr>
<tr>
<td>19</td>
<td>Construction, Design and Landscaping Works</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td><strong>Section Three -</strong></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Use of necessary number of : Labour and Technicians</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td><strong>Section Four -</strong></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Machinery and Equipment</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td><strong>Section Five -</strong></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>HVAC Works</td>
<td>✓</td>
</tr>
<tr>
<td>23</td>
<td>Mechanical Works</td>
<td>✓</td>
</tr>
<tr>
<td>24</td>
<td>Lifts</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td><strong>Section Six -</strong></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Fire Alarm and Extinguishing Works</td>
<td>✓</td>
</tr>
<tr>
<td>26</td>
<td>Phone and Service Bells Works</td>
<td>✓</td>
</tr>
<tr>
<td>27</td>
<td>Electrical Works</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td><strong>Section Seven -</strong></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Roads and external areas and Related Works</td>
<td>✓</td>
</tr>
<tr>
<td>29</td>
<td>Miscellaneous Works</td>
<td>✓</td>
</tr>
</tbody>
</table>
As can be seen in Table 6-3, Table 6-4, Table 6-5, and Table 6-6 the majority of organisations have similar sections and categorisations in BM contracts. This is due to the fact that any public BM contract should comply with the Kuwait bidding law. This has resulted in similar forms of BM contracts. It can be observed that section (19) in Table 6-6 is not included for two departments, (A) and (B). Phone calls were made to the participating professionals, following the examination of BM contracts, to clarify the issues noticed. The participating interviewee explained that this issue is because department (A) comprises of only one smart modern building and still under the warranty period and therefore new construction works within may void the building warranty. Furthermore, the participant of department (B) clarified that his department is focused on maintenance works only; separate departments deal with construction and landscaping works. In addition, it can be noticed in Table 6-6 that organisation (G) has outsourced the works in sections one and two to be carried out by organisation (H). The interviewed participant reported that this approach is taken due to lack of professional capacity and to utilise the expertise of the larger organisation (H).

It was also noticed in Table 6-6 that all departments have a “Miscellaneous Works” section. This section is used to accommodate any work that is not included within the original pricing tables. The BM departments are provided with price proposals of three different contractors or suppliers for a required work or materials that were not included in the original BM contract. The departments then select the lowest priced proposal to conduct the BM works. A fixed percentage of the total cost of work done through the “Miscellaneous Works” section is then given to the main contractor. The “Miscellaneous Works” section can be adopted in the proposed system to hold all knowledge topics that cannot be indexed in another technical category.

This part of the research has been concerned with finding a familiar context for knowledge taxonomy and therefore the level of focus is extended to only the indexing of the contracts sections. Further details on the knowledge taxonomy and its use in developing the proposed system are presented in Chapter (10).
6.5. Identified Deficiencies to Knowledge Sharing

6.5.1. In the BM process

The process followed by the BM departments was illustrated in Figure 6-2 in section 6.4.1. The parties involved in managing the BM process are usually general managers, maintenance division heads, maintenance division teams, planning/design divisions, finance divisions, contractors, and in-house teams.

As indicated in section 6.2, that eight of the participating departments have multiple branches (B, C, D, E, F, G, H, and I), only one of which (department C) with both branches located in the same building. The other seven departments have branches located at different locations. Figure 6-4 shows BM managed by a general department with multiple branches.

![Figure 6-4: General department with multiple branches.](image)

Figure 6-2 and Figure 6-4 show that communication lines between branches are limited to the branch managers. This leads to maintenance teams being isolated within maintenance projects located in their jurisdiction. The interviews found a lack of clear communication links between teams located in different locations. The current practices of knowledge transfer and sharing is mainly limited to face-to-face interactions between employees located in the same location. This limits the knowledge sharing and experiences learnt between the teams working at different locations. This in turn creates...
several drawbacks between branches, such as discrepancies in handling of maintenance projects, repetition of mistakes, and the “reinventing the wheel” situation in problem solving.

Department (F): “I have witnessed several repeated problems in our projects. For example, we keep making the same mistakes during obtaining permissions from other organisations. This always led to delays which benefit the contractor.”

Department (D): “Frankly, I don’t know about other divisions having to deal with same problems as ours.”

6.5.2. In BM meetings

In terms of meetings conducted in BM departments, Figure 6-3 in section 6.4.2.1 showed several parties participate in meetings including general manager, division heads, division teams, and contractors. The Figure showed that such parties deal with a BM project from start to finish. However, Figure 6-2 and Figure 6-3 indicate the lack of communication between BM parties, such as between maintenance teams and design/planning employees, and between maintenance teams and finance employees. This can lead to limited feedback from frontline employees to their design and finance colleagues.

Figure 6-3 shows lack of horizontal communication flow between front line employees located in different teams and branches. Therefore, maintenance teams can be isolated in terms of knowledge sharing and feedback from other teams and divisions. In addition, discussed solutions in meeting minutes are not being extracted and documented for future reference. This in turn could result in repetition of mistakes and problems.

All participants stated that they report their problems and solutions only when such matters are not solved on-site and large enough to be presented and discussed in meetings. Therefore, successful on-site solutions and insights become eventually lost since they have not been documented.

When a problem is discussed or a solution is generated in a meeting, the circulation is paper-based and indexing of documents is project based. In other words, when a problem is raised in a project, a solution is discussed and then approved for this project.
The meeting minutes are then circulated to project members and documented in project files. This solution is usually applied to the discussed project where a problem has been raised. Consequently, members of other branches do not benefit from such experience. In addition, this type of circulation and documentation will lead to difficulty in such solution being retrieved to solve similar future problem. Solutions and decisions can easily be lost when a project is finished or when filed documents are relocated.

6.5.3. In technology

Section 6.4.3 showed that the use of IT tools in BM is mainly extended to preparing and producing project documents and drafting plans. After this stage, the circulation and archiving of project documents are paper-based. Only three BM departments use facilities software. However, this usage is extended only to handling of product technical information and maintenance schedules. Even though all the BM organisations were connected to the internet, only three of them have a network that connects branches to their department. Thus, no knowledge-based system has been found where BM knowledge is accumulated, stored, organised, and retrieved. This creates an opportunity to design a system to address the deficiencies identified and discussed in this section.

6.6. Enhancing BM Performance through the Management of Knowledge

Findings from the interviews revealed several deficiencies related to management of knowledge in BM. One of the main objectives of this research is to propose a KM based system to be utilised by BM professionals. The previous section discussed how the activities of the SECI concept can be applied with the assistance of the proposed system. Moreover, the proposed system offers several performance improvements to BM in terms of management of knowledge, which are as follows:

1) Knowledge sharing:
   
   A. Knowledge capture: the system is designed to facilitate capturing tacit and explicit knowledge in BM. This is done through two methods: knowledge capture through BIM-based projects and directly through the system interface.
B. Knowledge retaining: the electronic storing of knowledge cases provides virtually unlimited storage capacity and instant retention.

C. Knowledge retrieval: the system is developed for easy and immediate retrieval of knowledge cases. This done through several methods: utilising the principal of CBR for similar case retrieval, keywords search, and browsing for retained cases. The taxonomy of knowledge utilised in the system is based on familiar indexing used in BM contracts.

2) Communication: the system is planned to improve communication between professionals through easily locating the most relevant expert. Moreover, the system is designed to reduce team isolation by allowing access to successful solutions and insights provided from branches situated in different locations.

3) Accessibility: the system is developed to be web-based and therefore can be accessed anytime, anywhere, and from any device working on any operation system with internet connection.

4) Usability: the system is designed to offer user-friendly interface that requires minimal or no training.

The features of the above system will help improving performance of a BM department through increasing knowledge sharing between professionals. This is done by assisting in converting BM knowledge from tacit to explicit through standardising the representation of a knowledge case, while also, allowing the reuse of knowledge in other projects, through ease of locating and accessing retained insightful cases.

6.7. Towards Implementing KM in the BM Process

This section further analyses how knowledge activities can be incorporated into the current BM process. With regards to the developed BM process illustrated in Figure 6-2 in section 6.4.1, several opportunities for knowledge capture, reuse, and sharing can be identified in the process of BM, as shown in Figure 6-5. The first opportunity can take place in the process (1B) where a team member conducts routine visits to sites, as his/her comments/ideas can be recorded in this stage. The second opportunity exists in processes (3.1A) and (3B), where a team member visits the site for evaluating and submitting needed repairs, estimating quotes and quantities. The third opportunity is
found in processes (7) and (8) when a team member supervises and/or manages the work of projects. The fourth opportunity exists in process (9) where finalised paperwork is submitted. Lessons learnt and problems solved can be documented in this process. Other knowledge opportunities can take place during meetings conducted in BM departments. Figure 6-5 illustrates the knowledge opportunities identified in the BM process.

Figure 6-5: BM process with knowledge opportunities.
A number of studies have investigated the processes of KM such as: the three processes of generation, codification, and transfer of knowledge, identified by Davenport and Prusak (2000), the four processes of knowledge creation, storage/retrieval, transfer and application by Alavi and Leidner (2001) and the four processes of knowledge reviewing, conceptualising, reflecting, and acting by Wiig et al. (1997). Moreover, Nonaka and Takeuchi (1995) introduced a concept that produces and converts knowledge from tacit to explicit and vice versa through social interactions between individuals. The model, as shown in Figure 6-6, has four main modes: Socialization, Externalization, Internalization and Combination (SECI). The spiral represents the interchange between different SECI modes. The increase of the spiral radius stands for the spread of knowledge through various organisational levels. In our case, knowledge can be spread to different levels and branch locations of a BM department.

![Figure 6-6: The SECI model (Nonaka & Takeuchi, 1995).](image)

Figure 6-7 illustrates the SECI model as an example of how knowledge can be managed in the adopted BM process. The SECI modes can take place as follows:
In the “Socialisation” mode, tacit to tacit, employees can gain the tacit knowledge of dealing with issues and problems by accompanying and learning from seniors when assessing problems and/or managing maintenance projects. The mode can also take place when professionals sit together at the beginning and end of the day discussing their experiences and practices. These activities are already taking place in a number of interviewed departments to facilitate knowledge transfer between employees.

Figure 6-7: Implementing SECI model on the adopted BM process.
In the “Externalisation” mode, tacit to explicit, knowledge is converted from tacit to explicit to facilitate its communication and transfer. Employees can transcribe the gained tacit knowledge into explicit formats to be understood and utilised by others. This can take place during the preparation of project drawings and description. Tacit knowledge can be transformed into explicit through insights shown in project reports, proposed solution, drawings, and estimated work packages. Moreover, this mode can be achieved by reviewing projects at the end of maintenance works since it is the most appropriate method for capturing knowledge (Falqi, 2011). The captured knowledge can be presented in form of instructions, solutions and insights to issues that were faced during a maintenance project. However, since none of the departments currently review their projects when completed, a project review form can be introduced to be included with the other documents submitted to the branch manager when the maintenance project is completed. However, investigating the feasibility and impact of this subject is beyond the scope of this research.

In the “Combination” mode, explicit to explicit, similar knowledge cases are gathered, combined and then organised to be easily accessed by other employees. All interviewed departments run regular meetings at different organisational levels to discuss issues related to maintenance projects. Knowledge cases extracted from problem assessments and project reports can be combined, validated and classified during meetings. This approach is crucial to standardise the organisation and presentation of knowledge cases.

“Internalisation” is the fourth and final mode of knowledge creation. Through this mode, the knowledge is reapplied by other engineers and then adapted to particular situations based on gained experiences (explicit to tacit). The “Internalisation” mode can take place in BM processes before and during maintenance works. This can be achieved when employees retrieve explicit knowledge that is already retained and organised in BM departments to solve current problems. The new adapted and updated knowledge can be shared between employees through “Socialisation” mode to start a new cycle of the SECI spiral.

The proposed system can assist in carrying out these knowledge management activities. In “Externalisation” mode, captured knowledge from all BM branches can be retained in the system in a form of knowledge cases. In “Combination” mode, knowledge cases regarding similar issues are organised and indexed in a taxonomy common to BM professionals. Finally, in “Internalisation” mode, the professionals can access the
system from anywhere, at any time and through any device to retrieve the desired stored knowledge to be adapted and reapplied to current situations.

6.8. Summary

This chapter explored the BM process and KM related issues in Kuwait. The method for data collection was in a form of semi-structured interviews. Ten public BM departments listed in the Kuwait state budget participated in the interviews.

A generic BM model was developed showing the main processes followed by BM departments in maintaining public buildings in the state of Kuwait. It was revealed that BM departments have regular meeting at different organisational levels to discuss problems related to maintenance projects. However, the departments do not organise their meetings’ decisions and records for later use. In addition, several problems related to knowledge and its management were identified such as teams’ isolation, discrepancies and repetition of mistakes. Such issues can be linked to lack of communication and absence of knowledge sharing between employees. By using the model of SECI for knowledge management, it was illustrated how BM employees can perform KM activities to utilise their accumulated knowledge for future use.

In terms of activities, technology use, and perception of KM, it was discovered that there is no formal strategy for KM. It was also revealed that knowledge is mainly learned on the job and transferred during interaction between the experienced and less experienced employees. It was also found that employees are already familiar with computers, their applications and web surfing. Furthermore, a positive attitude was largely shown towards implementing a knowledge-based system to reuse knowledge for future projects. Existing deficiencies to knowledge sharing, the possibility of implementing KM principles and the positive attitude shown by participants have created an opportunity to improve the performance of BM in Kuwait through a KM-based system.

The following four chapters will bring the findings together and develop the proposed KM system. The next chapter introduces the overall architecture of the proposed system.
7.1. Introduction

Chapter (2) illustrated the selected methodology for software development. This chapter and the following three chapters demonstrate the process of developing a prototype system that links the selected KM technique and a BIM based environment.

The proposed prototype is a web-based knowledge management system which is given the name “KMoBM” (Knowledge Management of Building Maintenance). This prototype aims at helping professionals working in public BM departments in Kuwait to share and manage their knowledge through retaining, organising and retrieving past successful solutions to resolve current problems. The KMoBM system links three modules: a CBR module, a BIM module, and a database module. The KMoBM prototype was developed on a personal computer using the open source software environment “EasyPHP”. This software environment includes:

1) PHP (Hypertext Preprocessor): An open-source scripting language used in developing World Wide Web pages.
2) Apache: An open source web server software.
3) MySQL: An open source relational database management system.
4) PhpMyAdmin: An open source tool for managing and administration the MySQL database.
5) Xdebug: An open source extension for PHP used for debugging errors during the course of system development.

MS Expression software was employed to design and build the web pages of the KMoBM prototype. This software has been provided freely by Heriot-Watt University for academic use. Open source text editor Notepad++ was also employed during the programming period of the system. The KMoBM system has been designed to be compatible with browsers including MS Internet Explorer and Firefox.

In order to show the system architecture, flow charting technique is used. Flowcharting technique is defined as “a method of graphically describing an existing process or proposed new process by using simple symbols, lines, and words to display pictorially the activities and sequence in the process” (Harrington, 1991). Table 7-1 illustrates the symbols used to describe processes in this chapter.

<table>
<thead>
<tr>
<th>Symbole</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Terminal block (Start, End): illustrates the beginning and the end of the process." /></td>
<td>Terminal block (Start, End): illustrates the beginning and the end of the process.</td>
</tr>
<tr>
<td><img src="image" alt="Process: any processing function or defined operation that cases changed in input, information, form or location. The name of an activity or task can be written inside the figure." /></td>
<td>Process: any processing function or defined operation that cases changed in input, information, form or location. The name of an activity or task can be written inside the figure.</td>
</tr>
<tr>
<td><img src="image" alt="Decision: shows when a decision must be made leading to different processing paths." /></td>
<td>Decision: shows when a decision must be made leading to different processing paths.</td>
</tr>
<tr>
<td><img src="image" alt="Manual input: demonstrates where data input or command entry is done manually. Usually done through keyboard, dropdown list and switch settings." /></td>
<td>Manual input: demonstrates where data input or command entry is done manually. Usually done through keyboard, dropdown list and switch settings.</td>
</tr>
<tr>
<td><img src="image" alt="Database: depicts a data storage location." /></td>
<td>Database: depicts a data storage location.</td>
</tr>
<tr>
<td><img src="image" alt="Manual operation: illustrates a process or adjustment done manually at a human speed (offline)." /></td>
<td>Manual operation: illustrates a process or adjustment done manually at a human speed (offline).</td>
</tr>
<tr>
<td><img src="image" alt="Flow line: indicates the direction of a sequence for an operation or a process." /></td>
<td>Flow line: indicates the direction of a sequence for an operation or a process.</td>
</tr>
<tr>
<td><img src="image" alt="Display: shows when material is displayed to a user." /></td>
<td>Display: shows when material is displayed to a user.</td>
</tr>
</tbody>
</table>

This chapter begins with an overview of the system architecture. Then details of each of the three modules will be provided in the following chapters.

### 7.2. Overall Prototype Architecture

Figure 7-1 illustrates the overall architecture of the KMoBM which consists of the following components:

- **CBR module**: this module is designed to retrieve the most similar case to a query. This is done through searching the cases stored in knowledge base to find similar solved maintenance cases to an enquired problem. Further details are presented in Chapter (8)

- **BIM module**: this module is designed to retain knowledge cases from in the BIM-based projects. This module utilises IFC protocol to manage
communication between the uploaded file of BIM-based project and the knowledge base as well as identifying relationships between the retained knowledge cases. Chapter (9) provides further details.

- **Database module**: this module provides several options to search for cases and experts. The module also allows users to navigate the system’s taxonomy and browse for maintenance cases. The adopted taxonomy for knowledge cases in KMoBM is illustrated in section 10.5.1. Moreover, this module integrates the CBR and the BIM modules in a user-friendly interface. Additional details are presented in Chapter (11).

- **Knowledge base**: stores knowledge case details, user information and provides access to users through the system modules. This is done by structuring the knowledge base with several linked tables that hold data of “knowledge case details”, “project details”, “knowledge case relationships”, “Taxonomy” and “user details”. Chapter (11) presents further details.

![Figure 7-1: KMoBM prototype architecture.](image-url)
The three modules are accessible through a web-based user-friendly interface. Software applications can be developed on different platforms, including both web-based and desktop. Since FM/BM employees are mobile operatives, by the nature of their work (McAndrew et al., 2005), a web-based platform was considered to be the most appropriate in development of the system. The main benefits of a web-based system include no installation, can be accessed from any location, at any time, and data is remotely stored and maintained. To maintain security of stored data, only approved registered users are permitted access to utilise the KMoBM prototype. Connecting to the KMoBM prototype needs users with devices that have a web browser and internet connection.

7.3. Summary

This chapter has introduced the overall architecture of the KMoBM prototype. The developed prototype aims at managing knowledge of BM and connecting professionals to share their insights and experiences. This is done through providing a web-based interface where professionals can retain and retrieve desired knowledge to solve problems also can search for experts based on experience. The prototype can be utilised from anywhere using any device that has an internet connection and a browser. The prototype functions are based on three modules: CBR module, BIM module and database module. The following three chapters will illustrate the development of the each of the prototype modules, the prototype knowledge base and how they are integrated together.
Chapter 8 - Case Based Reasoning Module
8.1. Introduction

Based on the findings of the interviews in Chapter (6), several deficiencies in KM were identified in the BM sector in Kuwait. They included team isolation, repetition of mistakes, discrepancies between documents, and difficulty in retrieving old solutions. However, the BM process illustrated in Figure 6-5 showed that several opportunities exist for knowledge activities where professionals can benefit from each other’s knowledge.

The objectives of this research include the development of a KM-based system to be used by public BM departments in Kuwait to enhance their performance through the management of knowledge. The proposed system can be used to share knowledge and improve communication through accessibility and user-friendly usability.

This chapter demonstrates the development of the first module of the proposed system, the CBR-based module. As indicated in section 4.7, several IT and non-IT based tools and techniques can be used to manage knowledge in organisations. One of these is Case Based Reasoning (CBR), which is a problem solving concept that adapts previous solutions to solve new problems (Kolodner, 1992). The definition of KM adopted for this research (as discussed in section 4.4) highlights the effective use of KM through proper application of knowledge in organisations. According to the definition by Jennex (2005), proper use of KM can be made through “selectively” employing knowledge from previous experiences to solve current problems. CBR can fulfil this requirement by “selectively” retrieving solutions to solve current problems, i.e. “selectively” retrieving most similar solved case to current problem. Based on this rationale, CBR has been selected as the base for one of the modules in KMoBM.

This chapter will describe the development of the CBR module components. First, the function adopted for similar case retrieval is discussed. Then development of knowledge case attributes and the selection of methodology to weight the attributes are explained. The process of building the conceptual Analytic Hierarchy Process (AHP) model is illustrated. The validation and weighting processes of attributes are then discussed, including information about the venues used in focus group meetings and general analysis of the background of participating experts. The last part presents the results of the AHP methodology conducted by the focus group.
8.2. Adopted Function for Similar Case Retrieval

To build a CBR module that retrieves similar cases to the queried problem, a dominion by which cases are judged in terms of similarity has to be established. A knowledge domain is required to illustrate the scale of similarity between cases and which attributes have more impact than others on similarity (An et al., 2007). In this research, the knowledge domain comprises of the attributes that describe cases and distinguish one from another. The processes of deriving, validating and setting weights of attributes are discussed in the following sections of this chapter. This section explains the development of equations used for similar case retrieval for the module.

Kolodner (1993) defines a case in a CBR system as “a contextualised piece of knowledge representing a previous experience or problem”. The case can be a form of an event, record or a story comprising a problem and solution (Watson, 1997). Moreover, in case-based classification for problem solving, Lenz et al. (1998a) suggest that cases can be grouped as tuples, based on attributes. They used two attributes to group and represent cases: problem description and the corresponding class (solution) as illustrated in the following slogan:

\[ \text{case} = \text{problem} + \text{solution} \]

The assumption of Lenz et al. (1998a) is that if two cases have similar problem descriptions then they should have a similar solution. However, cases may have several influencing attributes that affect the approach to solutions. For example, the type of building (steel, wood, concrete, or combined) may affect the approach to dealing with leaks. Similarly, the location of the building (waterfront or dry location) may affect the approach to dealing with facade issues. Moreover, solving a problem frequently does not start with a complete description of the problem which suffices for the location of a solution (Burkhard, 1998). To improve the work of the proposed system in locating most suitable solution with the minimal problem description/query, the case attributes used for this research were extended from two attributes (problem-solution) to 21 case attributes, as shown in section 8.3.

Two styles are used in the principal of CBR, problem solving and interpretive (Kolodner, 1992). The first approach is when solving current problems by selectively applying solutions as a guide from similar old problems. The latter approach is
evaluating a new case against multiple old cases within the same context to derive a solution. Both approaches are utilised to develop the CBR module in the proposed system. This is done through retrieving and then ranking cases based on their similarity to a query of a problem. The user has then the option of either selecting and applying a solution from the most similar retrieved old case or deriving a solution by evaluating between retrieved solutions.

Several principles can be used for CBR to locate solutions for queried problems, including: induction, SQL and Nearest-Neighbour (Watson, 1999a). In the induction principal, decision trees are produced to classify and index cases. The trees are then used to extract the most similar case to a query. A major disadvantage in induction is that all attribute data have to be provided during case building and retrieving. If a single item of data is missing or unknown, a case would not be retrieved at all. Therefore, when using this approach, users have to fill each of the attribute fields every time a case is being built or a problem being queried. This approach may be suitable for cases with a small number of attributes. However, where there are several attributes to each case in the proposed system, querying for a solution could be time consuming and results may less accurate than they should be.

In the SQL method, database technology is used to retrieve matched cases. The main disadvantage of using SQL is that the database retrieves only exact similarity to a query. In other words, the input has to exactly match the stored attribute, otherwise a case may never be retrieved. Also, cases with less similarity to a query may not be retrieved. Therefore, results of this approach may have low accuracy. To overcome this problem, a solution to make it more likely to retrieve a suitable case is to make a query more general using Boolean terms (and, not, or). However, such an approach is not a measure of similarity (Watson, 1999a).

The third method for case retrieval is the Nearest-Neighbour. The definition for this technique is that it “identifies the category of unknown data point on the basis of its nearest neighbour whose class is already known”(Bhatia & Vandana, 2010). In this approach cases are retrieved based on their level of similarity to a query. The similarity is based on measuring the distance between attributes that form the cases. The most similar case has the shortest distance to a query. In cases that contain texts, the similarity is calculated based on cases with highest matching text. The accuracy of results in this approach is based on the weights assigned to case attributes.
Bearing in mind that users may not be able to fill all attributes as required in an induction approach, the input may not be able to be matched exactly with a stored attribute every time a query is made, the adoption of the weighted Nearest-Neighbour algorithm was considered most suitable for the development of the CBR-based module in this research.

There are several approaches to measure similarity in the Nearest-Neighbour technique including 1) hamming distance, 2) ratio-based similarity measure, and 3) weighted distance (Liao et al., 1998; Watson, 1997). The approach of hamming distances evaluates the difference between bits of two attributes, i.e. attributes of a query and attributes of a stored case. In the context of CBR, the most similar case is the case that has the minimum hamming distance (differences) of attributes between a query and stored case (Pal & Shiu, 2004). The approach of hamming measuring distance does not have weighting values and therefore overlooks the significance of an attribute in a case. Therefore, similar case retrieval may result in low accuracy.

The ratio based approach, proposed by Tversky (1977; Cited in Liao et al., 1998), measures similarity based on the number of attributes that are similar or dissimilar between a query and a stored case. In this approach, a predefined threshold value classifies an attribute as similar or dissimilar to a stored attribute of a case. This condition may hinder accuracy in attributes with large number of text. This can be clearly observed if text being entered comprises of a small number of words and is being measured against attributes with large number of text. The result in such cases will be a low level of matching words, leading to value that is below the required threshold. This will lead to classifying the attribute as dissimilar, resulting in an inaccurate low similarity result. Therefore, this research considers the third approach to measure similarity for nearest-neighbour in the CBR module. A standard algorithm is presented in Watson (1997) and illustrated as:

\[
\text{Similarity} (T, S) = \sum_{i=1}^{n} w_i \times f(T_i, S_i) \tag{Equation 1}
\]

Where:

- \( T \) = The target case
- \( S \) = The source case
- \( n \) = The number of attributes in each case
Chapter 8: Case Based Reasoning Module

\[ i = \text{An individual attribute from 1 to } n \]
\[ f = \text{A similarity function for attribute } i \text{ in cases } T \text{ and } S \]
\[ w = \text{The importance weight of attribute } i \]

In this technique, similarity is computed by Equation 1 to calculate the match index between input texts against each attribute of a case. This is done to each case stored in the knowledge base. The results can fall in the range of 0 to 1, where 0 is completely dissimilar and 1 is exact match. The values resulted from calculating similarity for each attribute of a case are then added up. Cases which accumulate the most similarity percentage are then retrieved from the knowledge base and ranked based on their similarity values.

The weights, \( w \), of attributes, \( i \), define their importance and influence in retrieving similar cases. Determining the weight of an attribute is not straightforward; nonetheless, it can be done by an expert or user within the knowledge domain (Ahmed et al., 2010). Therefore, the processes of setting which knowledge case attributes to be included in the CBR search and then deriving their weights were carried out by experts working in BM departments. The process of weight setting was done using the principle of AHP. Section 8.7 illustrates the processes of validating knowledge case attributes and setting their weights.

The similarity function \( f(T,S) \) for \( i \) in Equation 1 has been developed based on the combination of values for two parts: 1) matching of input text and 2) matching text in attributes fields stored in database. This approach has been adopted because of the diversity of text quantity being used in the query input and the quantity of text stored in attributes. For example, a user may use a few words to describe a problem to search for a similar old case, while another may use numerous words in the CBR query input box. Also some attributes consists of few words while other attributes consist of many words.

The difference in number of words filled in attributes has also been taken into account in the equation \( f(T,S) \). This is done by calculating the number of matches in a case attribute divided by the number of texts of the same attribute. The benefit of adopting this approach is to reduce the impact of the amount of text and repetitive words stored in an attribute on the similarity ratio. For example, an attribute may hold few words as in the attribute of “keywords” and consequently will have a small number of repeated words. On the other hand, another attribute may hold many words such as the attribute
assigned for “problem description” and therefore may have a large number of matches, mainly because of repeated words.

Another benefit obtained is fine-ranking of cases. This can be noticeable when several cases have the same value of similarity results. The second part of the equation $f(T, S)$ adds an additional score based on matched words of case attributes stored in database. This additional value contributes to the total similarity percentage, thus providing fine-ranking of cases retrieved from the knowledge base. By adapting the original function $f(T, S)$ to the search criteria adopted in the system, both the similarity ratio of the CBR-box input and stored knowledge case attributes can be shown in the following equation:

$$f(T_i, S_i) = \frac{1}{2} \left( \frac{I_T}{F_S} + \frac{M_T}{N_S} \right)_i$$  

**Equation 2**

Where:

$I_T$ = Number of matching texts in the input CBR box  
$F_S$ = Number of texts in the input CBR box  
$M_T$ = Total of matches in an attribute  
$N_S$ = Number of texts in an attribute

In the developed CBR module and during similar case query, input attributes have been classified into two types: text attribute and string attribute. The text attribute is the actual CBR input box where users can describe their problems and queries in a natural way. On the other hand, the string attribute is in the form of drop-down list where users can select their best reference from listed options. The string options are derived from the attributes’ details that are already saved in the knowledge base.

The allocation of similarity value is different between text attribute and string attribute. In text attribute similarity can range from 0 to 1 whereas similarity value in string attribute is either 0 or 1. This is because the number of words in the CBR input box varies and, in turn, the number of matches varies as well. However, the selection from the drop-down list is either an exact match or exactly dissimilar to the targeted attribute. Table 8-1 shows types of input in the CBR module.
Table 8-1: Types of input in the CBR-based module in the proposed system.

<table>
<thead>
<tr>
<th>Type of input</th>
<th>Input name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>String list</td>
<td>Building type</td>
<td>Selecting one of drop-down list</td>
</tr>
<tr>
<td>String list</td>
<td>Structure type</td>
<td>Selecting one of drop-down list</td>
</tr>
<tr>
<td>Text field</td>
<td>CBR box</td>
<td>Writing a problem description</td>
</tr>
</tbody>
</table>

Therefore, the modified equation used in the CBR module in the proposed system is illustrated as follows:

\[
\text{Similarity } (T,S) = \left( w_{st} \times M_{st} \right) + \left( w_{bt} \times M_{bt} \right) + \left[ \sum_{i=1}^{n} w_{i} \times f(T_i, S_i) \right] \times 100\% \quad \ldots \ldots \quad \text{Equation 3}
\]

Where:

- \( T \) = the target case
- \( S \) = the source case
- \( w_{st} \) = the importance weight of structure type attribute
- \( M_{st} \) = matching result of structure type attribute (0 or 1)
- \( w_{bt} \) = the importance weight of building type attribute
- \( M_{bt} \) = matching result of building type attribute (0 or 1)
- \( n \) = the number of attributes in each case
- \( i \) = an individual attribute from 1 to \( n \)
- \( f(T_i, S_i) \) = a similarity function for attribute \( i \) in cases \( T \) and \( S \)
- \( w \) = the importance weight of attribute \( i \)

Equation 3 is used for calculating the score of case similarity. Cases with highest scores are ranked and retrieved for user reviewing and reusing. The following section illustrates the case attributes to be used in the similarity function for case retrieval.

### 8.3. Knowledge Case Attributes for Case Retrieval

BM knowledge cases can be represented in a variety of forms using a range of AI representational formalisms such as: frames, objects, predicates, semantic nets and rules (Watson & Marir, 1994). However, the effectiveness and time efficiency of case searching and matching in case retrieving applications are heavily dependent on case representation (Aamodt & Plaza, 1994). For this research, representation of a case is described and illustrated by case attributes. Therefore, the attributes of the cases should
be selected in a way to simplify entering a case description and to enable the retrieval of the most suitable cases. The procedure followed to develop and weight knowledge case attributes for the proposed CBR module is shown in Figure 8-1.

Figure 8-1: The procedure for developing and weighting knowledge case attributes.
As shown in Figure 8-1, the procedure of developing the knowledge case attributes started with deriving them from documents being used in the BM works. In total, 21 attributes were initially set to describe a knowledge case in the proposed system, three of which were set for knowledge taxonomy of a knowledge case. Deriving the attributes of knowledge taxonomy for cases was based on the review of contract documents reported in section 6.4.6. The attributes assigned for knowledge taxonomy of cases are also used in Equation 3 for retrieving similar cases. All proposed 21 attributes were then validated by BM experts in focus group meetings.

Documents reviewed to derive the attributes included forms and letters used in communication between different parties involved in BM works. Five of the ten public BM departments that participated in interviews (as detailed in section 6.2) provided the researcher with examples of documents and forms used in their BM works. The following are examples of documents used in communication between the parties in a typical BM project:

- Maintenance request forms.
- Site hand-in forms.
- Formal letters of communication between parties.
- Written memos.
- Daily maintenance reports.
- BM completion works.
- Approval forms.
- Permit forms.
- Payment forms.
- Progress meetings minutes.
- Final completion forms.

Typical standard forms used in BM projects have empty fields to be filled and are used to inform of situations and obtain authorisations. Formal letters, reports, meeting minutes and memos are more open and used to discuss problems and note decisions. Therefore, examples of the latter types of documents were also reviewed to derive the knowledge case attributes. The reviewed documents were used to identify attributes that describe a knowledge case. The attributes were then classified into five groups, all of which contribute to distinguish between cases. Table 8-2 shows the pre-validation
attributes of knowledge cases. Such attributes were then shown to BM experts in focus group meetings for evaluation.

Table 8-2: Pre-validation attributes of knowledge cases used in CBR module in proposed system.

<table>
<thead>
<tr>
<th>Group name</th>
<th>Attribute name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM Project details</td>
<td>Date</td>
<td>Date of the knowledge case.</td>
</tr>
<tr>
<td></td>
<td>Client Name</td>
<td>Name of beneficiary unit.</td>
</tr>
<tr>
<td></td>
<td>Contractor Name</td>
<td>Name of contractor undertaking maintenance works.</td>
</tr>
<tr>
<td></td>
<td>Address</td>
<td>Location of the building.</td>
</tr>
<tr>
<td></td>
<td>Governorate</td>
<td>Name of province.</td>
</tr>
<tr>
<td></td>
<td>Project name</td>
<td>Name of the maintenance project.</td>
</tr>
<tr>
<td>Building details</td>
<td>Building type</td>
<td>Usage of the building (school, office building, police station).</td>
</tr>
<tr>
<td></td>
<td>Structure type</td>
<td>Concrete, wood, steel, combined</td>
</tr>
<tr>
<td>Knowledge case indexing</td>
<td>Category</td>
<td>Legal, Technical, Administrative.</td>
</tr>
<tr>
<td></td>
<td>Section</td>
<td>Which section within each category.</td>
</tr>
<tr>
<td></td>
<td>Sub-Section</td>
<td>Which sub-section within each section.</td>
</tr>
<tr>
<td>Particular knowledge case details</td>
<td>Topic</td>
<td>General topic of a knowledge case.</td>
</tr>
<tr>
<td></td>
<td>Issue/Problem</td>
<td>Particular issue/problem of a particular case.</td>
</tr>
<tr>
<td></td>
<td>Reaction/Solution</td>
<td>The reaction/solution to a particular case.</td>
</tr>
<tr>
<td></td>
<td>Keywords</td>
<td>Keywords that identify a particular case.</td>
</tr>
<tr>
<td></td>
<td>Related Elements</td>
<td>The closest element affected by the case.</td>
</tr>
<tr>
<td>Author details</td>
<td>Author Name</td>
<td>Name of the case’s author.</td>
</tr>
<tr>
<td></td>
<td>Author Position</td>
<td>Working title of the case’s author.</td>
</tr>
<tr>
<td></td>
<td>Knowledge Interest</td>
<td>Building maintenance category that captures author’s interest.</td>
</tr>
<tr>
<td></td>
<td>Phone</td>
<td>Contact number.</td>
</tr>
<tr>
<td></td>
<td>Email</td>
<td>Contact email.</td>
</tr>
</tbody>
</table>

In order to use the module in problem solving, the retrieval process should work in an efficient manner. Therefore, a weighting score needs to be assigned to each attribute of a knowledge case. Assigning values is based on the influence of an attribute to the retrieving process. For example an attribute with high influence in distinguishing between cases should have a higher weighting value compared to an attribute with a lower influence.

The following section illustrates how the weights were allocated to case attributes to distinguish the importance of each attribute to a knowledge case.
8.4. Assigning Attribute Weights

In order to assign weights to the knowledge case attributes, the weights should be defined and agreed by the field experts. Therefore, a Multi-Criteria Decision Making (MCDM) methodology approach is required to help these experts to reach agreed weights. MCDM can be defined as “the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process.” (International MCDM Society, 2011).

Several methods can be used in MCDA such as the Analytic Network Process (ANP), the Multi-Attribute Utility Theory (MAUT), and the Analytic Hierarchy Process (AHP). The ANP methodology introduced by Saaty (2001). The ANP implements pair-wise comparisons between attributes and is presented as a generalisation decision methodology of the AHP. The main difference between the ANP and the AHP is shown in how the model is structured and how the priorities obtained from ratio scales are computed (Büyükayazıcı & Sucu, 2003). The ANP implements a network model rather than a hierarchical model, hence eliminating the dependence between lower level and higher level elements when performing pair-wise comparisons (Saaty, 2004). Hence, the expression level in AHP is replaced by the expression cluster in the ANP (Büyükayazıcı & Sucu, 2003). The main advantages of the ANP methodology include (1) allowing for complex nonlinear network interrelationships and feedback between attributes placed on different decision levels (Tran et al., 2004) and (2) a looser network structure than that of the AHP, permitting more general representation of problems (Saaty, 1999). However, drawbacks of the ANP include the difficulty of explaining the methodology and process to others and also that it is impossible to verify results due to feedback loops and interrelation, and it is too complex to implement in organisations (Goepel, 2011).

The second methodology is the MAUT which has roots dating back to Churchman, Ackoff and Arnoff (1957) (De Montis et al., 2005). The MAUT assumes that any decision issue contains a utility or function defined by a collection of alternatives (Zietsman et al., 2006). This methodology allocates a utility value to each action in the form of a real number to represent the preferability of such action (Figueira et al., 2006). However, the MAUT methodology has some significant drawbacks, particularly its assumption that the decision maker has perfect knowledge, is consistent in judgement, and rational (Linkov & Steevens, 2008). Moreover, the process of
measuring and weightings in MAUT can be complex and unnatural (Chelst & Canbolat, 2012). It also compares unfavourable with the AHP in several respects. According to Chelst and Canbolat (2012), the advantages of AHP over the MAUT are that it is less data intensive, structured with respect to its evaluations and calculations, more flexible in the data required for measuring assessment, and contains a measure of consistency. In additions to these considerations, the AHP has the highest growth in MCDA-related research (Wallenius et al., 2008) making it a standard and dependable approach for knowledge acquisition (Das et al., 2009).

The third methodology is the AHP, which is a mathematical methodology developed by Saaty (1980) to aid in decision making. This methodology is an analysis tool that uses judgments of experts to develop ratio scales of decision criteria through performing pair-wise comparisons. The methodology uses Eigen Vector and Eigen Value of the decision matrix to produce the ratio scales and consistency index. The AHP has several advantages, including using a single model for a wide range of unstructured problems; synthesising outcome from diverse judgments; and enabling experts to reconsider and refine judgments to improve results. A major advantage of the AHP is that it is harmonious with human nature. This has been achieved by tolerating a small inconsistency in judgment and reflecting a natural tendency of a mind in grouping and sorting elements into different levels. Another key benefit is that the AHP is a flexible method and permits tangible and intangible parameters to be considered in the decision process (Wedley, 1990). For example, qualitative considerations can include opinions and feelings, while quantitative considerations, can comprise scale and size. This allows tangible and intangible parameters to be compared against each other for priority weighting. Disadvantages of the AHP include the requirement to call back individuals to reconsider decisions when results exceed the permitted consistency limit of 10%.

While no MCDA methodology is perfect for all requirements, the AHP methodology has consequently been considered in this research to assign weights for knowledge case attributes based the following reasons.

- The AHP can handle group input.
- The AHP has a marginal flexibility towards inconsistency of user input.
- The hierarchical model for knowledge case attributes of this research can be structured and illustrated in a in a clear way to participants.
• The process of the AHP methodology is relatively straightforward and can be clearly explained to participants.

• The availability of supporting literature.

• The availability of software.

It is worth noting that “case attributes” mentioned earlier will be referred to as “criteria” in following sections of this chapter. This is to be consistent with the terms used in the AHP methodology employed for this study. The following section discusses the AHP methodology.

8.5. AHP Methodology

The AHP methodology has been widely used in research related to the areas of construction, Facilities Management (FM) and Building Maintenance (BM). Lai et al. (2008) implemented the AHP to develop a budget determination model for public building construction projects. Additionally, An et al. (2007) utilised AHP methodology to determine the weight of attributes for a CBR-based construction cost estimating model. Their research compared the results of three approaches in determining weights of model attributes. An et al. (2007) used the methods of assumed equal weight, gradient descent, and the AHP to weigh the attributes of the model. They found that the outcome of the AHP-based method was more accurate, reliable and explanatory than the other approaches.

To evaluated FM services in residential buildings, Lai and Yik (2011) used the AHP concept to isolate responses with inconsistency of judgment. Das et al. (2009) also implemented the AHP to develop a standard method for acquisition of tacit knowledge in FM. The aim of their research was to elevate the AHP from merely a multi-criteria decision tool to a decision enhancement tool. Within the area of BM and restoration, Wang et al. (2008) utilised the AHP in developing a CBR-based cost estimation model for restoration of buildings. In the present research, the AHP concept is implemented to elicit weighted attributes of knowledge cases from professionals working in public BM sector.

According to Saaty (1980), the essence of the AHP process is the breakdown of a complex problem into a hierarchical model that contains a decision goal, criteria, and alternatives. Therefore, the first step of the process involves building the AHP model.
This step consists of setting the decision objective (goal) on the top of the hierarchy (level 0), the criteria at a lower level (level 1), while the alternatives are placed at the bottom of the hierarchy (level 2). Based on the complexity of the problem, the AHP model can have sub-levels for sub-criteria. Figure 8-2 illustrates a typical model for AHP process, with its different hierarchy levels.

Figure 8-2: A typical model for AHP representation.
The second step comprises of constructing matrices to conduct pair-wise comparisons for elements of a given hierarchy level. Weighting of the elements is based on their relative preference to elements of the next higher level. Saaty (1980) presented the calculation technique for weighting of elements when pair-wise comparison is implemented. The weighting of an element is measured on a scale of 1 to 9. The weighting decision is based on its importance or dominance over other elements at the same hierarchal level. Table 8-3 illustrates the rating scale used in weighting elements.

Table 8-3: AHP fundamental rating scale (Saaty, 2008).

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two elements contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgement slightly favour one element over the other</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>Experience and judgement strongly favour one element over the other</td>
</tr>
<tr>
<td>7</td>
<td>Very strong or demonstrated importance</td>
<td>An element is favoured very strongly over the other; its supremacy demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favouring one element over the other is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate importance of values listed above</td>
<td>When a compromise is needed for a difficult value of dominance</td>
</tr>
<tr>
<td>1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9</td>
<td>Reciprocals of the above</td>
<td>If element $x$ has one of the above values assigned to it when compared with element $y$, then $y$ has the reciprocal value when compared with $x$</td>
</tr>
</tbody>
</table>

The following section illustrates the development of the AHP model used in this research.

8.6. Developing the conceptual AHP model

Based on the typical AHP model shown in Figure 8-2, a conceptual model has been developed in this research for weighting the knowledge attributes of the CBR module in the proposed system. The conceptual model is based on the objective of retrieving the most similar knowledge case when an inquiry is made. Therefore, the importance of an
attribute in distinguishing between knowledge cases has been set as the goal by which attributes are weighted against each other.

As mentioned in section 8.4, the knowledge case attributes will be referred to as criteria to be consistent with terms used in the AHP methodology. Therefore, the attributes and their groups illustrated in section 8.3 were reorganised and referred to as first and second level criteria in the conceptual AHP model. The attributes were set as Sub-Criteria (SC), their groups were set as Criteria (C), and knowledge cases as alternatives. Figure 8-3 displays the conceptual model with the hierarchical structure of its goal and criteria. The criteria along with their conceptual AHP model were used in the focus group meetings for validation and then for setting the weights, as will be discussed in the following section.
Figure 8-3: Pre-validation AHP hierarchal model of the CBR module in proposed system.
8.7. Focus Group Meetings for Structuring the AHP Model

Two focus group meetings were conducted with professionals working in public BM departments. The first meeting focused on building the AHP model through validating its goal, criteria and then weighting the knowledge case attributes. The second meeting was conducted because results of the AHP exercise in the first meeting were not satisfactory. Therefore, the focus group needed to have second meeting to reconsider their responses.

8.7.1. The venue and participants details

Focus group meetings were conducted in a venue provided by the Kuwait Society of Engineers (KSE). The venue of the meeting was a large meeting room with presentation facilities. A portable whiteboard and projector were used in both meetings to conduct demonstrations in the best possible manner.

Unlike the narrow participation requirements for the interviews described in section 6.2, participants in the focus group meetings were a mix of relatively experienced and inexperienced professionals working in BM departments of various sizes. The reason behind such a combination of participants is that targeted users of the system could consist of BM employees of all experience levels working in BM departments of diverse sizes and with various numbers of branches. The main categories of potential users could include managers, team leaders, engineers, assistant of engineers, and architects. Thus, the main requirements of the participants in the focus group meetings were that they should be professionals working in a BM department within public ministries and organisations, who were enthusiastic, and agree to attend the meetings when needed.

The participants were approached through personal contacts. The participating professionals were debriefed on their rights and responsibilities and signed the consent form, shown in Appendix E, prior to commencing the workshops. Eight professionals participated in both workshop meetings, some of whom had already participated in the interviews reported in Chapter (6).

The participants’ details are shown in Table 8-4, Table 8-5 and Table 8-6.
Table 8-4: Information on participants in focus group meetings.

<table>
<thead>
<tr>
<th>Name</th>
<th>Organisation</th>
<th>Position</th>
<th>Years of experience</th>
<th>Computer usage per week (hrs)</th>
<th>Number of employees</th>
<th>Number of branches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 1</td>
<td>Audit Bureau</td>
<td>Engineer</td>
<td>5</td>
<td>25</td>
<td>Small&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1</td>
</tr>
<tr>
<td>Participant 2</td>
<td>Ministry of Communication</td>
<td>Division Head</td>
<td>10</td>
<td>5</td>
<td>Medium&lt;sup&gt;2&lt;/sup&gt;</td>
<td>2</td>
</tr>
<tr>
<td>Participant 3</td>
<td>Kuwait Oil Company</td>
<td>Specialist Engineer</td>
<td>10</td>
<td>25</td>
<td>Large&lt;sup&gt;3&lt;/sup&gt;</td>
<td>4</td>
</tr>
<tr>
<td>Participant 4</td>
<td>Ministry of Public Works</td>
<td>Trainee Engineer</td>
<td>7 months</td>
<td>18</td>
<td>Large&lt;sup&gt;3&lt;/sup&gt;</td>
<td>6</td>
</tr>
<tr>
<td>Participant 5</td>
<td>Ministry of Communication</td>
<td>Manager</td>
<td>11</td>
<td>18</td>
<td>Medium&lt;sup&gt;2&lt;/sup&gt;</td>
<td>2</td>
</tr>
<tr>
<td>Participant 6</td>
<td>Ministry of Interior</td>
<td>Division Head</td>
<td>10</td>
<td>14</td>
<td>Large&lt;sup&gt;3&lt;/sup&gt;</td>
<td>7</td>
</tr>
<tr>
<td>Participant 7</td>
<td>Ministry of Interior</td>
<td>Consultant</td>
<td>21</td>
<td>15</td>
<td>Large&lt;sup&gt;3&lt;/sup&gt;</td>
<td>7</td>
</tr>
<tr>
<td>Participant 8</td>
<td>Ministry of Social Affairs and Labour</td>
<td>Engineer</td>
<td>3</td>
<td>0</td>
<td>Medium&lt;sup&gt;2&lt;/sup&gt;</td>
<td>7</td>
</tr>
</tbody>
</table>

<sup>1</sup> 1-49 Employees, <sup>2</sup> 50-249 Employees, <sup>3</sup> >249 Employees

Table 8-5: Distribution of participating BM departments, based on number of branches.

<table>
<thead>
<tr>
<th>Number of Branches</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.5%</td>
</tr>
<tr>
<td>2</td>
<td>25.0%</td>
</tr>
<tr>
<td>3</td>
<td>0.0%</td>
</tr>
<tr>
<td>4</td>
<td>12.5%</td>
</tr>
<tr>
<td>5</td>
<td>0%</td>
</tr>
<tr>
<td>6</td>
<td>12.5%</td>
</tr>
<tr>
<td>7</td>
<td>37.5%</td>
</tr>
</tbody>
</table>

Table 8-6: Distribution of participating BM departments, based on size.

<table>
<thead>
<tr>
<th>Size</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>12.5%</td>
</tr>
<tr>
<td>Medium</td>
<td>37.5%</td>
</tr>
<tr>
<td>Large</td>
<td>50%</td>
</tr>
</tbody>
</table>
8.7.2. First focus group meeting with AHP results

The first focus group meeting, shown in Figure 8-4, commenced with introducing the research topic and features of the proposed system. Objectives of the focus group meeting were then explained with a brief background on the AHP methodology. After that, the participants were asked to perform the tasks provided on the workshop form (see Appendix F).

![Figure 8-4: Focus group meeting held at KSE to build AHP model for the CBR module in the proposed system.](image)

8.7.2.1. Task 1: Validating the goal and criteria of knowledge case attributes

The first stage of this task was to build the AHP model for pair-wise comparisons. The participants used Figure 8-3 to validate the goal, Criteria (C) and Sub-Criteria (SC) of the proposed conceptual AHP model.

The participants approved the goal and criteria by which the AHP model is developed.

The approved goal for the AHP:

- Retrieving the most similar case from the CBR module.
Chapter 8: Case Based Reasoning Module

The approved criterion for pair-wise comparison for is:

- Most influencing in distinguishing between knowledge cases.

Furthermore, the participants validated, removed and added to the model Criteria (R.) and Sub-criteria (SC.). Table 8-7 shows the validation results to be used in the conceptual AHP model.

Table 8-7: Validation of knowledge case criteria for AHP model.

<table>
<thead>
<tr>
<th>Criteria (C.)</th>
<th>Sub-Criteria (SC.)</th>
<th>validated</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM Project details (C1)</td>
<td>Date</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Client Name</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Contractor Name</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Address</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Governorate</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Project name</td>
<td>✓</td>
</tr>
<tr>
<td>Building details (C2)</td>
<td>Building type</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Structure type</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Number of storeys</td>
<td>Added</td>
</tr>
<tr>
<td>Knowledge case Indexing (C3)</td>
<td>Category</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Section</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Sub-Section</td>
<td>✓</td>
</tr>
<tr>
<td>Particular knowledge case details (C4)</td>
<td>Title</td>
<td>✓ Changed</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>✓ Changed</td>
</tr>
<tr>
<td></td>
<td>Solution</td>
<td>x Changed</td>
</tr>
<tr>
<td></td>
<td>Keywords</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Related Elements</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Cause of problem</td>
<td>Added</td>
</tr>
<tr>
<td>Author details (C5)</td>
<td>Author Name</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Author Position</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Knowledge Interest</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Phone</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Email</td>
<td>x</td>
</tr>
</tbody>
</table>

The reason for removing criteria from CBR module was due to their negligible impact on distinguishing between knowledge cases. The Sub-Criteria (SC.) removed are: date, governorate, solution, phone and email. In the Criteria of “project details” (C1), the validated criteria were client name, contractor name, address, and project name. The reason behind this decision was to allow users to retrieve cases related to a particular project when these criteria are entered in the CBR search box. This approach may
become useful when the maintenance history of a building is required to derive a solution.

The participants believed that the “building address” (SC4) and its “governorate” (SC5) are similar, and therefore it was agreed for criterion (SC5) to be removed. The “solution” criterion (SC15) in the group “case details” was also removed. The participants argued that users would describe problems in order to retrieve a solution, and therefore it would be ineffective to search the solution fields in database.

The participants agreed to add two criteria that could have an impact on distinguishing between the cases. The participants added “number of storeys” (SC9) as a criterion in the Criteria “building details” (C2), as some maintenance problems may be affected by the number of storeys of a building. Such problems include electricity, elevators, water leaks, and HVAC. In the Criteria “case details” (C4), the Sub-criterion (SC18) “cause of a problem” was added to further distinguish between cases. The participants acknowledged that a problem may be caused by different sources, leading to a different approach to resolution. For example, a leak from an air conditioning system needs a different method of solution compared to a leak from toilets.

The process has resulted in validating five Criteria (C), which include a total of 17 Sub-Criteria (SC). Figure 8-5 shows the validated AHP conceptual model for the CBR module in the proposed system.
Figure 8-5: Validated AHP model of the CBR module in proposed system.
Based on the validated AHP model shown in Figure 8-5, the professionals weighted the case criteria using the pair-wise comparisons. The following section illustrates the results of the AHP for weighting the knowledge case criteria.

### 8.7.2.2. Task 2: Weighting of knowledge case criteria for CBR model

In the first meeting, the participants assessed and weighted the first and second level criteria through pair-wise comparisons. This is done by following the steps illustrated in section 8.5.

The researcher used a projector to guide the participants and illustrate the allocated pair-wise comparison tables. Time was offered for discussion then each participant was asked to weigh the criteria using the pair-wise comparison tables; an example of table is shown in Figure 8-6.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C1.</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2.</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3.</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4.</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>C5.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure 8-6: Example of pair-wise comparison table.**

Weighting scores for each criteria were then aggregated using the geometric mean formula as recommended by Saaty (2008). A typical geometric mean formula is given by:

\[
GM = \sqrt[n]{W_1 \cdot W_2 \cdot \ldots \cdot W_n} \quad \text{Equation 4}
\]

Where:

- \(GM\) = Geometric Mean
- \(W_n\) = Weighting scores
- \(n\) = number of scores
In our case, the weighting scores were obtained from eight participants. Therefore, eight weighting scores for each criterion were computed using the geometric mean formula to obtain an averaged single weighting score for each criterion.

The priority matrices results from the first meeting were analysed through calculating Eigen vectors of weighting values. Next, the inconsistency test is applied, since the judgments are subjective and may produce inconsistent results. The following Consistency Index (CI) and Consistency Ratio (CR) equations (Saaty, 1977) were used to calculate the inconsistency of judgments:

\[ CI = \frac{\lambda_{max} - n}{n - 1} \]  \hspace{1cm} \text{Equation 5}

Where:

- \( n \) = Dimension of a matrix, (number of criteria)
- \( \lambda_{max} \) = Maximal eigenvalue.

The CR is then calculated using the following equation:

\[ CR = \frac{CI}{RI} \]  \hspace{1cm} \text{Equation 6}

Where:

- \( RI \) = Random index.

The resulted pair-wise matrices from the first meeting were calculated and then tested for inconsistency. Several calculation steps are involved to obtain the Eigen vector. This can be done either through using modified excel sheets or employing AHP applications such as Expert-Choice. The results in this section were obtained using the AHP-based application Expert-Choice. The model structure illustrated in Figure 8-5 was created in the application. Then the pair-wise comparison values from participants were entered into the created model. The application was then employed to calculate the resulted weights and consistency of judgments. An example of calculations of how to obtain Eigen vector and consistency index of judgments is illustrated in Appendix G. Table 8-8 illustrates the CR results obtained from first workshop.
Table 8-8: Consistency ratio for criteria matrices of the first workshop.

<table>
<thead>
<tr>
<th>Matrix name</th>
<th>CR</th>
<th>CR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria group</td>
<td>0.17</td>
<td>17%</td>
</tr>
<tr>
<td>Project details</td>
<td>0.03</td>
<td>3%</td>
</tr>
<tr>
<td>Building details</td>
<td>0.13</td>
<td>13%</td>
</tr>
<tr>
<td>Knowledge case indexing</td>
<td>0.05</td>
<td>5%</td>
</tr>
<tr>
<td>Knowledge case details</td>
<td>0.21</td>
<td>21%</td>
</tr>
<tr>
<td>Author details</td>
<td>0.00</td>
<td>0%</td>
</tr>
</tbody>
</table>

According the Saaty (1977), results from pair-wise comparison matrices should be rejected when CR exceeds 0.10 (or 10 %). Table 8-8 shows the CR exceeding the 10% consistency limit for matrices of “Criteria group”, “building details”, and “knowledge case details”. Unfamiliarity with the AHP methodology and the number of criteria in each category were perhaps the reasons for such high inconsistency. Therefore, judgments are needed to be reconsidered.

4. Second focus group meeting with AHP results

Since the consistency results of first meeting were inconsistent, a second meeting was conducted to reconsider participants’ answers regarding the weightings of knowledge case criteria.

The meeting commenced with a review of the research topic, meeting objective, and the reason for conducting the second meeting. A background demonstration on the AHP methodology was then given. The participants were asked to reconsider their judgments on assessing weights assigned to knowledge case criteria. This was done through pair-wise comparisons between criteria based on the approved goal “most influencing in distinguishing between knowledge cases”. The consistency test was then calculated using the AHP-based application Expert-Choice. Table 8-9 indicates the CR from pair-wise matrices of the second workshop meeting.
Table 8-9: Consistency ratio for criteria matrices of the second workshop.

<table>
<thead>
<tr>
<th>Matrix name</th>
<th>CR</th>
<th>CR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria group</td>
<td>0.053</td>
<td>5 %</td>
</tr>
<tr>
<td>Project details</td>
<td>0.052</td>
<td>5 %</td>
</tr>
<tr>
<td>Building details</td>
<td>0.006</td>
<td>1 %</td>
</tr>
<tr>
<td>Knowledge case indexing</td>
<td>0.015</td>
<td>2 %</td>
</tr>
<tr>
<td>Knowledge case details</td>
<td>0.057</td>
<td>6 %</td>
</tr>
<tr>
<td>Author details</td>
<td>0.000</td>
<td>0 %</td>
</tr>
</tbody>
</table>

As shown in Table 8-9, the CR ranges from 0% to 7% to all pair-wise matrices and therefore, all judgments are acceptable. Table 8-10 to Table 8-15 and Figure 8-7 to Figure 8-12 show the resulted weight averages of Criteria (C) and Sub-Criteria (SC) of knowledge cases.

Table 8-10: Pair-wise comparison matrix of criteria group.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C1.</td>
<td>Project details</td>
<td>C1.</td>
<td>1</td>
<td>0.301</td>
<td>0.462</td>
<td>0.325</td>
<td>5.575</td>
</tr>
<tr>
<td>C2.</td>
<td>Building details</td>
<td>C2.</td>
<td>3.318</td>
<td>1</td>
<td>1.426</td>
<td>0.36</td>
<td>6.126</td>
</tr>
<tr>
<td>C3</td>
<td>K-Case Indexing</td>
<td>C3.</td>
<td>2.163</td>
<td>0.701</td>
<td>1</td>
<td>0.373</td>
<td>4.61</td>
</tr>
<tr>
<td>C4.</td>
<td>K-Case details</td>
<td>C4.</td>
<td>3.078</td>
<td>2.776</td>
<td>2.683</td>
<td>1</td>
<td>7.26</td>
</tr>
<tr>
<td>C5.</td>
<td>Author details</td>
<td>C5.</td>
<td>0.179</td>
<td>0.163</td>
<td>0.217</td>
<td>0.138</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 8-7 shows that the criterion of “knowledge case details” gained the highest weight among the criteria group with 42.3% of total 100% weight. The second criterion was “building details” followed by “knowledge case indexing” with weights of 24.3% and 17.9% respectively. The least weight was awarded to the criterion of “author details” due to its minimal influence on distinguishing between cases.
Chapter 8: Case Based Reasoning Module

Figure 8-7: Weights of criteria group.

<table>
<thead>
<tr>
<th>Code</th>
<th>Sub-Criteria Name</th>
<th>Comment</th>
<th>Weights</th>
<th>Rk</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1.</td>
<td>Client name</td>
<td></td>
<td>11.8%</td>
<td>4</td>
</tr>
<tr>
<td>SC2.</td>
<td>Contractor name</td>
<td></td>
<td>24.3%</td>
<td>2</td>
</tr>
<tr>
<td>SC3.</td>
<td>Address</td>
<td></td>
<td>17.9%</td>
<td>3</td>
</tr>
<tr>
<td>SC4.</td>
<td>Project name</td>
<td></td>
<td>42.3%</td>
<td>1</td>
</tr>
<tr>
<td>#</td>
<td></td>
<td>for 8&amp;10 unprotect the input sheets and expand the question section (“*” in row 65)</td>
<td>3.7%</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 8-11: Pair-wise comparison matrix of sub-criteria for project details.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1.</td>
<td>1</td>
<td>1.729</td>
<td>0.485</td>
<td>2.65</td>
</tr>
<tr>
<td>SC2.</td>
<td>0.578</td>
<td>1</td>
<td>0.278</td>
<td>2.107</td>
</tr>
<tr>
<td>SC3.</td>
<td>2.06</td>
<td>3.591</td>
<td>1</td>
<td>2.324</td>
</tr>
<tr>
<td>SC4.</td>
<td>0.377</td>
<td>0.475</td>
<td>0.430</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 8-8 reveals that within the sub-criteria for “project details”, the participants awarded the sub-criterion of “project address” the highest value with 45.1% of total weight. The reason for that is that location factors may affect knowledge cases. For example, the approach to solving a problem may differ when a project is close to humid waterfront location compared to a dry desert. The second sub-criterion in importance was the “client name” with 26.2% of total weight. The sub-criteria of “contractor name” and “project name” obtained the least weights with 16.8% and 11.9% respectively.
Chapter 8: Case Based Reasoning Module

Figure 8-8: Weights of sub-criteria for project details.

<table>
<thead>
<tr>
<th>Table</th>
<th>Criterion</th>
<th>Comment</th>
<th>Weights</th>
<th>Rk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Client Name</td>
<td></td>
<td>26.2%</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Contractor Name</td>
<td></td>
<td>16.8%</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Address</td>
<td></td>
<td>45.1%</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Project Name</td>
<td></td>
<td>11.9%</td>
<td>4</td>
</tr>
<tr>
<td>#</td>
<td></td>
<td>for 9&amp;10 unprotect the input sheets and expand the question section (“*” in row 66)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Result</th>
<th>Eigenvalue</th>
<th>lambda:</th>
<th>Consistency Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.37</td>
<td>4.142</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>CR</td>
<td>0.52</td>
<td></td>
</tr>
</tbody>
</table>

Table 8-12: Pair-wise comparison matrix of sub-criteria for building details.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SC5.</td>
<td>Building type</td>
<td>SC5.</td>
<td>1</td>
<td>0.249</td>
<td>0.688</td>
</tr>
<tr>
<td>SC7.</td>
<td>Number of storeys</td>
<td>SC7.</td>
<td>1.454</td>
<td>0.453</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 8-9 illustrates the sub-criteria for “building details”. The sub-criterion “structure type” obtained the highest weight, with 59.2%. The participants believe that the type of structure can largely affect the problem and its solution and therefore this has been awarded the highest weight. For example, the approach for maintaining a wooden structure is different from that for a concrete structure. The sub-criteria of number of storeys and building type obtained 24.9% and 15.9% respectively.
The values in Figure 8-10 indicate that experts assessed the “category” sub-criterion with 59.3%. The “section” sub-criterion came in second place with 24.9% of the total weight. The sub-criterion “Sub-section” obtained the least weight with 15.8%. The knowledge taxonomy in the proposed system was categorised into legal, technical and administrative. The AHP assessment results suggest that indexing a knowledge case in the correct category was the most important to experts. It was agreed that a problem related to the same building element could be seen very differently from legal and technical viewpoints.
Figure 8-10: Weights of sub-criteria for knowledge case.

Table 8-14: Pair-wise comparison matrix of sub-criteria for knowledge case details.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SC11.</td>
<td>Title</td>
<td>1</td>
<td>2.046</td>
<td>3.212</td>
<td>3.221</td>
<td>1.609</td>
</tr>
<tr>
<td>SC12.</td>
<td>Description</td>
<td>0.489</td>
<td>1</td>
<td>3.988</td>
<td>2.065</td>
<td>2.847</td>
</tr>
<tr>
<td>SC13.</td>
<td>Keywords</td>
<td>0.311</td>
<td>0.251</td>
<td>1</td>
<td>0.484</td>
<td>0.395</td>
</tr>
<tr>
<td>SC14.</td>
<td>Element</td>
<td>0.311</td>
<td>0.484</td>
<td>2.065</td>
<td>1</td>
<td>0.356</td>
</tr>
<tr>
<td>SC15.</td>
<td>Cause of problem</td>
<td>0.621</td>
<td>0.351</td>
<td>2.530</td>
<td>2.810</td>
<td>1</td>
</tr>
</tbody>
</table>

The participants were asked to compare and weigh the sub-criteria for knowledge case details. Figure 8-11 shows that “title” of a knowledge case has the most importance, with 34.5% of the total weight. The sub-criteria of “description” and “cause of a problem” came in second and third place with 28.6% and 18.8% respectively. This is consistent with the findings of Leouski and Croft (2005), which indicated that a title appears to have higher contextual significance compared to the rest of the document. They found that text body could be discarded altogether and clustering documents could be based on titles only (Leouski & Croft, 2005).
Figure 8-11: Weights of sub-criteria for knowledge case details.

Table 8-15: Pair-wise comparison matrix of sub-criteria for author details.

<table>
<thead>
<tr>
<th>Code</th>
<th>Sub-Criteria name</th>
<th>Code</th>
<th>SC16</th>
<th>SC17</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC16.</td>
<td>Author name</td>
<td>SC16.</td>
<td>1</td>
<td>0.128</td>
</tr>
<tr>
<td>SC17.</td>
<td>Knowledge interest</td>
<td>SC17.</td>
<td>7.837</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 8-12 indicates that participants believe that the “knowledge interest” of an expert is more important than the “expert’s name” with a large weight of 76.4%. However, the total weight of the author details merely accounted for 3.5% compared to other criteria. The participants agreed to add the author name to allow users to retrieve knowledge cases based on expert’s name and interest.

Figure 8-12: Weights of sub-criteria for author details.
8.8. Adjusting weights of criteria and sub-criteria

The values of Sub- Criteria (SC) need to be adjusted according to the weight of their corresponding Criteria (C). This step is needed so that each criterion is normalised to allow it to be ranked against other criteria located in different groups. This is done by normalising the values using the following equation.

\[ W_i = W_{i(SC)} \times W_{i(C)} \]  \hspace{1cm} \text{Equation 7}

Where:
- \( W_i \) = Adjusted criteria weight
- \( W_{i(SC)} \) = Weight of Sub-Criteria
- \( W_{i(C)} \) = Weight of corresponding Criteria

It should be noted that the sum of weights for all criteria should equal to 1 (or 100%). Table 8-16 illustrates the normalisation of knowledge case criteria based on group weight. Figure 8-13 shows the adjusted values for criteria (C.) and sub-criteria (SC.). The modified weighting values of the hierarchy are the weights adopted in the CBR module of the proposed system.

Table 8-16: Normalisation of weighting values for knowledge case criteria.

<table>
<thead>
<tr>
<th>Criteria number</th>
<th>Criteria name</th>
<th>Sub-criteria before normalisation</th>
<th>Criteria weight</th>
<th>Sub-criteria after normalisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1</td>
<td>Client Name</td>
<td>26.2%</td>
<td>11.8%</td>
<td>3.09%</td>
</tr>
<tr>
<td>SC2</td>
<td>Contractor Name</td>
<td>16.8%</td>
<td>1.98%</td>
<td>5.32%</td>
</tr>
<tr>
<td>SC3</td>
<td>Address</td>
<td>45.1%</td>
<td>5.32%</td>
<td></td>
</tr>
<tr>
<td>SC4</td>
<td>Project name</td>
<td>11.9%</td>
<td>1.41%</td>
<td></td>
</tr>
<tr>
<td>SC5</td>
<td>Building type</td>
<td>15.9%</td>
<td>3.86%</td>
<td></td>
</tr>
<tr>
<td>SC6</td>
<td>Structure type</td>
<td>59.2%</td>
<td>14.39%</td>
<td></td>
</tr>
<tr>
<td>SC7</td>
<td>Number of storeys</td>
<td>24.9%</td>
<td>6.05%</td>
<td></td>
</tr>
<tr>
<td>SC8</td>
<td>Category</td>
<td>59.3%</td>
<td>10.61%</td>
<td></td>
</tr>
<tr>
<td>SC9</td>
<td>Section</td>
<td>24.9%</td>
<td>4.46%</td>
<td></td>
</tr>
<tr>
<td>SC10</td>
<td>Sub-Section</td>
<td>15.8%</td>
<td>2.83%</td>
<td></td>
</tr>
<tr>
<td>SC11</td>
<td>Title</td>
<td>34.5%</td>
<td>14.59%</td>
<td></td>
</tr>
<tr>
<td>SC12</td>
<td>Description</td>
<td>28.6%</td>
<td>12.10%</td>
<td></td>
</tr>
<tr>
<td>SC13</td>
<td>Keywords</td>
<td>7.2%</td>
<td>3.05%</td>
<td></td>
</tr>
<tr>
<td>SC14</td>
<td>Element</td>
<td>10.8%</td>
<td>4.57%</td>
<td></td>
</tr>
<tr>
<td>SC15</td>
<td>Cause of problem</td>
<td>18.8%</td>
<td>7.95%</td>
<td></td>
</tr>
<tr>
<td>SC16</td>
<td>Author name</td>
<td>19.4%</td>
<td>0.72%</td>
<td></td>
</tr>
<tr>
<td>SC17</td>
<td>Knowledge interest</td>
<td>76.4%</td>
<td>2.83%</td>
<td></td>
</tr>
</tbody>
</table>
Figure 8-13: Resulted weighting values for criteria and sub-criteria of knowledge cases.
8.9. Summary

This chapter described the development of the Case-Based Reasoning (CBR) module in the proposed system. The CBR methodology was adopted in the proposed system for similar case retrieval. The Nearest-Neighbour technique was used to measure similarity between cases. This is done through calculating matching text between a query and case attributes. Initially, a knowledge case comprised of 21 attributes, covering its project details, building details, case details, indexing, and author details. A validation process was conducted with group of professionals working in public BM departments in Kuwait. The focus group meeting resulted in 17 validated attributes acting as descriptors to knowledge cases. The focus group then weighted the attributes using the AHP methodology. The weighted attributes are used in the similarity function for the CBR module of the case retrieving module in the proposed system. This module with other two modules forms the components of the proposed system. The next chapter discusses the development of the second module of the proposed system: the BIM module.
Chapter 9 - BIM Module
9.1. Introduction

The previous chapter demonstrated the process of developing the CBR module for retrieving most similar case to a query. This chapter illustrates the process of developing the second module of the proposed system. This module aims at facilitating retaining knowledge cases from projects developed using the BIM environment.

This chapter begins with a description of the steps in preparation of BIM model to enable capturing knowledge cases. This is followed by explaining how the module in the proposed system utilises the BIM technology to identify relationships between captured knowledge cases. Finally, the chapter illustrates the process of retaining knowledge cases from BIM-based projects in the proposed system.

9.2. Knowledge Case Attributes for BIM

Chapter (8) identified the approved knowledge case attributes (were referred to as criteria and sub-criteria) to be used in the proposed system. However, a challenge was faced during the development of the proposed system, with regard to retaining/retrieving cases based on knowledge and information from a BIM-based model. The BIM environment produces element-based models. For example, virtual projects developed in a BIM based environment comprise elements such as wall, door, footing, etc. However, retrieving maintenance case details is based on knowledge cases utilised by professionals that may include one or more building elements. Therefore, in order to deal with this discrepancy, additional attributes are used for the elements in the BIM model, (Autodesk Revit is the BIM environment used for this research). “Attributes” are named in this section “parameters”, to be consistent with the term used in the BIM environment “Revit”.

Two forms of parameters are used to represent building elements in Revit; instance and type parameters. The software facilitates users to add, remove, edit, and organise properties of each parameter, which include format and data. For the proposed prototype, custom instance parameters are created to manage the discrepancy between the proposed KM system and the BIM models. Figure 9-1 illustrates the process of defining these parameters, which includes the creation of parameters and then specifying their properties. Defining the properties of each parameter involves selecting its type, data format, and categorisation.
Figure 9-1: New parameter setting in Revit.

Two groups of parameters were created in a way to be consistent with what should be read and retained by the proposed prototype. The groups are parameters of project information and parameter of knowledge case. Once the BIM model is uploaded to the prototype, the filled parameters fields should be uploaded automatically to designated fields in the knowledge base. Table 9-1 shows the first set of parameters that contains the generic project information to be extracted from a BIM-based maintenance project.

Table 9-1: Parameters of project information in BIM model.

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Date of the knowledge case.</td>
</tr>
<tr>
<td>Client Name</td>
<td>Name of beneficiary unit.</td>
</tr>
<tr>
<td>Contractor Name</td>
<td>Name of contractor undertaking maintenance works.</td>
</tr>
<tr>
<td>Address</td>
<td>Location of the building.</td>
</tr>
<tr>
<td>Project Name</td>
<td>Name of the maintenance project.</td>
</tr>
<tr>
<td>Building Type</td>
<td>Usage of the building (school, office building, police station).</td>
</tr>
<tr>
<td>Structure Type</td>
<td>Concrete, wood, steel, combined, Etc…</td>
</tr>
<tr>
<td>Number of Storeys</td>
<td>Number of storeys of a building.</td>
</tr>
</tbody>
</table>
The second set of parameters, shown in Table 9-2, is associated with building elements which comprise the knowledge case details and its categorisation. Chapter (10) will illustrate the adopted taxonomy for the proposed KM system.

**Table 9-2: Parameters of knowledge cases in BIM-based project.**

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>General topic of a captured case.</td>
</tr>
<tr>
<td>Description</td>
<td>Issue/problem description of the case.</td>
</tr>
<tr>
<td>Cause of problem</td>
<td>The root cause of the problem.</td>
</tr>
<tr>
<td>Solution</td>
<td>The reaction/solution to the case.</td>
</tr>
<tr>
<td>Keywords</td>
<td>Keywords that identify the case.</td>
</tr>
<tr>
<td>Element</td>
<td>The element affected by the case.</td>
</tr>
<tr>
<td>Category</td>
<td>Legal, Technical, Administrative.</td>
</tr>
<tr>
<td>Section</td>
<td>Which section within each category.</td>
</tr>
<tr>
<td>Sub-Section</td>
<td>Which sub-section within each section.</td>
</tr>
</tbody>
</table>

Figure 9-2 also shows how such parameters are displayed on the Revit interface.

![Figure 9-2: Representation of knowledge case details on Revit interface.](image)
9.3. Case Relationship

It is common that several other building elements may be affected during maintaining a building element. For example, when a wall is treated because a leak occurs, several building elements are affected such as walls, floors, ceiling…etc. Therefore, the proposed system has been developed to have the ability to identify related elements for a knowledge case. This is done by tracing how different building elements are affected by certain BM work and how problems can be related to each other. When using this feature, professionals can gain comprehensive understanding of issues related to their maintenance works.

Since the BIM model has the intelligent feature of recognising the relationships between building elements, the proposed system will make use of this feature by utilising the function of intelligent objects in BIM models. Revit software produces BIM models in different formats. Industry Foundation Class (IFC) is one of the formats supported by BIM applications for file exporting. The IFC is an open source neutral data model being developed by “buildingSMART alliance” to increase interoperability between BIM software (BSA, online).

According to BSA (online), there are several functions used for relationships of connections in the IFC data model which are based on a physical or logical principle. The “IfcRelConnects” is a connectivity entity that connects elements under criteria based on semantics of usage. This entity includes “IfcRelVoidsElement”, “IfcRelFillsElement”, “IfcRelSpaceBoundary”, “IfcRelContainedInSpatialStructure”, “IfcRelConnects-Elements”, and “IfcRelConnectsPorts”. However, complicated relationships frequently exist in the IFC schema. For example several intermediate entities are introduced to define a simple relationship between a wall and a window. These entities include “IfcOpeningElement”, “IfcRelVoidsElement” and “IfcRelFillsElement”. The entity “IfcRelContainedInSpatialStructure” on the other hand uses different approach. This entity separates a project into smaller manageable subsets. Hence, the subset types of spatial structure are: site, building, building storey and space. This entity was used in perusing related knowledge cases captured and stored in the BIM model. The reason for selecting this entity was that fewer relationships are involved in connecting building elements. This leads to less complexity in defining relationships and less time consumed by the proposed system to identity relationships.
between cases. The following section shows the process of storing knowledge cases in the BIM module and identifying their relationships.

**9.4. Retaining knowledge cases in the BIM module**

The process of retaining knowledge cases in the BIM module involves several steps. The first step consists of users capturing knowledge cases in BIM models. Section 9.2 illustrated how parameters are set in the BIM software to be consistent with knowledge cases. Next, as shown in Figure 9-3, the process involves uploading the BIM model onto the proposed system using the IFC file. The BIM module then reads the file, extracts details of project and captured knowledge cases, and stores them in designated fields in the knowledge base of the proposed system.

![Figure 9-3: Process of retaining knowledge cases in BIM module.](image)

As shown in Figure 9-3, after completing the process of storing project and case details, the system then utilises the BIM’s intelligence to recognise relationships between knowledge cases. This is done through identifying spatial relationships between elements provided by the uploaded IFC schema. This step involves finding the element
associated with a knowledge case. Next, the system identifies the space of such element through pursuing the entity “IfcRelContainedInSpatialStructure”. After that, the system assigns an ID to the identified space and searches for all of elements of those spaces. After repeating this process for all identified knowledge cases, the system will have distinguished knowledge cases, their associated elements and the related space.

The system then clusters elements along with the associated knowledge cases into groups based on similar spaces. By the end of this process, related knowledge cases of a single space are linked to each other. Whenever a case has been searched and displayed, links to related cases are shown on the system interface. Consequently, professionals will be able to navigate between cases based on their relationship to a BM work. Figure 9-4 illustrates the system interface of a knowledge case with links to related cases.

Figure 9-4: Representation of knowledge case details with links to related cases.
As can be seen from Figure 9-4, the retrieved knowledge case has two related knowledge cases. The user can view the related case by clicking on the links provided.

9.5. Summary

This chapter explained the development of the BIM module. It also discussed how differences between the knowledge-based environment and the BIM-based environment were resolved. This was done through assigning case parameters in the BIM model to be read in the proposed system. The chapter then demonstrated the process of retaining knowledge cases from BIM models. It was also illustrated how the proposed system would utilise the intelligent capacity of BIM to identify related knowledge cases of a project. Such an approach could help professionals to obtain wider perspective of BM works in a building. The following chapter describes how CBR and BIM modules were integrated with each other and describes the database module and the development of the proposed system.
Chapter 10 - Prototype Development
10.1. Introduction

The three previous chapters demonstrated the overall architecture of the KMoBM and development of the CBR and BIM modules. This chapter explores how these modules are integrated in KMoBM, along with the database module, as shown in Figure 7-1. The integration of the modules allows them to communicate with the knowledge base, leading to utilisation of the prototype.

The chapter first describes the processes of the CBR module and the BIM module. The development and the process of the database module are then described, followed by details of the KMoBM knowledge base and the knowledge taxonomy adopted in the KMoBM.

10.2. The CBR Module

The purpose of using CBR in this module is to assist BM professionals in finding solutions to new maintenance problems through retrieving similar, past solved problems. This is done through a series of processes being carried out by the system in order to locate and retrieve the most similar solved case to a query. Chapter (8) described the development of the CBR module. The integration of the CBR module in the prototype system “KMoBM” is described by the flowchart in Figure 10-1.
As illustrated in Figure 10-1, the searching process starts by users selecting the CBR module in the KMoBM interface. Users can then describe their problem in the allocated field and select options from the lists to identify building details including type,
structure and number of storeys, as shown in Figure 10-2. The search process then commences by preparing the entered problem description by eliminating articles that may affect results such as “the, a, an ... etc” and special characters such as “!@£$%”.

![Figure 10-2: CBR module interface.](image)

The module then employs the similarity function to calculate the matched text between input and stored cases, for similar case retrieval; the adopted function was described in section 8.2. This function utilises the Nearest-Neighbour technique to retrieve the most similar case. The calculation for similarity is performed for each case stored in the knowledge base. A list of solved knowledge cases is then retrieved along with computed score results.
After that, the knowledge cases are ranked based on the resulting score values, from highest to the lowest. Figure 10-3 illustrates an example of retrieved knowledge cases including the matching scores and summary of the main case attributes. The summary aims to help users evaluate and select the best possible solved case to the queried problem. The attributes displayed are: project name, date, title, description, and matching percentage and solution are also displayed on the interface. In this stage of the process, the matched text is highlighted to assist users identifying the effect of their input on the retrieval procedure.

Figure 10-3: Summary of CBR search results.

Next, if these results are not satisfactory to the users, they are allowed to return to the CBR module to modify their input. This can be done through modifying some of the text to be used in the CBR search.
On the other hand, if one of the shown cases in the summary page is believed to be satisfactory, it can be selected from the summary page for full details to be displayed to the user. As shown in Figure 9-4, details of a knowledge case include project details, case details, author details, related cases, updates, comments and attachments.

Figure 10-4: Details of a retrieved knowledge case.
As explained in Chapter (4), the CBR methodology involves four functions: retrieve, reuse, revise, and retain knowledge cases. The CBR module automates the retrieval function for the most similar case to a query. Users can then perform the functions of revising and reusing the case for evaluation. The retaining function is when users update cases as new cases in the prototype. The KMoBM prototype automates the retaining function as well. Retaining new cases in KMoBM can be done through either the BIM module or the database module. The following section explains the retaining function in the BIM module and how the BIM module is integrated in the KMoBM prototype.

10.3. The BIM Module

Figure 10-5 shows how the BIM module is integrated into the KMoBM system. As the BIM module of the prototype concerns the retaining function, case retention begins with users selecting the BIM module in the KMoBM interface. Users then upload the BIM model of the building from the BIM environment “Revit” to the prototype. IFC protocol is employed to read details of the project and knowledge cases from the BIM models. Chapter (9) provided details on developing the BIM module with additional element properties. After that, the project and the extracted knowledge cases are stored in the prototype knowledge base and assigned unique ID’s. The users can attach documents to the newly stored knowledge case. The KMoBM prototype allows different types of attachments to be added such as pictures, records, report documents, video/audio clips and drawings. Upon attaching the document, a unique ID is then assigned to associate the attachment to its related knowledge case.
Figure 10-5: BIM module in KMoBM prototype.

Next, relationships between knowledge cases are identified based on the intelligent features of the building elements that are associated with the stored knowledge cases. The stored element name and line number is searched, then the prototype searches for the relevant space of each recognised element through the entity “IfcRelContainedInSpatialStructure”. Space details are then stored which include IDs of all the elements of the entity. Next, a space ID is assigned for each of the identified spaces. This step is repeated for each of the elements and their spaces.
By the end of this process, the prototype will have stored and assigned IDs for the knowledge cases, their projects, related elements, and associated spaces. A relationship is then established between the knowledge cases of elements located in same space. The CBR and database modules are linked with the knowledge base to utilise and retrieve the retained cases and their relationships in searching for solutions. The following section discusses the database module of the KMoBM system.

10.4. The Database Module

The aim of the database module is to retain new knowledge cases if the BIM environment is not available. However, the system, in this case, will lose some of the functions provided by the BIM environment. The database module also facilitates finding the required knowledge or experts to solve problems by filtering the data stored in the prototype knowledge base.

The search function is done through providing several options to search and locate the needed knowledge. The stored information can be about knowledge cases, expert details, documents…etc. Searching through the module has three options: browsing the knowledge taxonomy, searching by keywords, searching by author name, and searching by building name. Figure 10-6 illustrates the architecture of the database module.
As shown in Figure 10-6, the retaining function permits users to create knowledge cases to either a new or stored maintenance project. For creating knowledge cases to a new project, users firstly add project details then knowledge case details. IDs are then assigned to the project and its knowledge case. On the other hand, for a stored project, users first submit a project number to retrieve the details of a stored project. Knowledge case details can then be entered and assigned an ID that is associated with the retrieved project. Validation of the project and knowledge case details are explained in Chapter (8).

As shown in Figure 10-6, users can attach documents to the newly created knowledge case. Upon attaching the document, a unique ID is then assigned to link the attachment to its related knowledge case. The method of assigning IDs to projects, knowledge
cases, and attachments can provide two benefits: (1) maintaining the organisation of cases when updates are made and (2) allowing multiple and simultaneous storing of cases to a particular project. This is due to the fact that a BM project can last for an extended period of time and may face several problems and solutions. As a result, multiple insights could be captured as knowledge cases during the progress of a project. Moreover, BM departments can have several maintenance projects concurrently taking place and a single maintenance team may supervise multiple projects at the same time. Having different ID’s for projects will allow different team members to add knowledge cases to a single project.

The second part of the database module comprises the search functions. As shown in Figure 10-6, the first search option is through “keywords”. When a search by keyword is made, the function reads data from keyword fields of cases stored in the knowledge base. A list of cases is retrieved and displayed based on the matching keywords. The user then has the option of either selecting a case or going back to refine the search input. When a case is selected, the details of the knowledge case are displayed, as shown in Figure 10-7.

Figure 10-7: Interface of “Knowledge Case Details” page.
The second option in the search function is “browsing” the knowledge taxonomy for the stored knowledge cases. Details regarding the knowledge taxonomy adopted in KMoBM will be discussed in section 10.5.1. As shown in Figure 10-6, in this option, users can search for a particular case by navigating through categories (Legal, Technical, and Administrative) and the sections listed under each category. When a section is selected, the list of cases stored under the section is displayed and organised based on the identified sub-sections. Users can then filter cases based on the sub-section classifications. When a particular knowledge case is selected, all details of the case are then displayed to the user, as shown in Figure 10-7.

The third option provided in the search function is by “author name”. In this option, users can search for knowledge cases based on a particular author. When an inquiry is submitted, all cases written by the searched author are displayed. The users can also go back to modify input to different search results. This option can be useful when list of cases written by a particular expert is needed.

The fourth option is searching by building details. Users can use this option to display a list of all stored cases related to a particular building. This option can help professionals to have an overview of the building history. When a case is retained in the system, the building menu is automatically updated with the building name. The user can then select a case from the list to display its details or go back to select another building. The following section discusses the organisation of the knowledge base in KMoBM.

10.5. KMoBM knowledge base

The type and use of a system determine the structure and organisation of data. Numerous database management software applications are available to design and develop system databases. This includes desktop databases such as MS Access and FileMaker Pro, and server databases such as MySQL, MS SQL and Oracle. The MySQL server has been selected in this research to develop the knowledge base for the KMoBM system. The reason behind this decision is that MySQL can handle the web-based requirements of the proposed system and it is offered freely under general public licence for personal use.

The structure of the knowledge base has been developed based on the details centred on knowledge cases that need to be stored and retrieved. Tables were created and linked in
a way that would allow efficient storage and retrieval of the knowledge related to BM. Several tests were made to ensure that the knowledge base can handle the processes of the KMoBM system. This included testing that all data is stored and retrieved, and that no multiple entries are made. The structure of the tables in the knowledge base, shown in Figure 10-8, was modelled using the open source software “MySQL Workbench”. Several tables were created and linked using unique identifying names. The main table in the knowledge base is the table of knowledge case details. This table is linked to the tables of knowledge classification, related element, attachments, project details, and expert details. The following section discusses the adopted knowledge taxonomy by which knowledge cases are organised.

10.5.1. Knowledge taxonomy for KMoBM

The previous three sections showed the modules developed in the KMoBM prototype. As discussed in Chapter (9), a difficulty was encountered in terms of how to categorise cases from the BIM-based taxonomy to a knowledge-based system. This issue was resolved by assigning additional parameters in BIM to categorise cases in the system’s
database, based on a taxonomy consisting of category, section and sub-section. The following section firstly reviews several information-and knowledge-based taxonomies available in the industry. Then details of the taxonomy adopted in KMoBM are given.

10.5.2. Information based taxonomies

The aim to improve efficiency in the AEC/FM industry through organising, indexing and facilitating access to this considerable quantity of information is not new. One of the first schemes to achieve this aim is the indexing manual for construction information named Construction Index/SFB (CI/SFB), dating back to 1959 when the CIB recommended a manual for filling and indexing information (Lima et al., 2007). Updated versions to expand the sections of the CI/SFB indexing manual were developed by Karlén (1973) and then Ray-Jones (1974). The CI/SFB currently consists of five categories of tables each with its relevant sections. The classifications of tables are Table 0: Physical Environments, Table 1: Elements, Table 2: Construction Form, Table 3: Materials, and Table 4: Administration and Law.

In 1997, the Royal Institute of British Architects (RIBA) published a wider indexing manual for the construction industry named Unified Classification for the Construction Industry (Uniclass) to replace the original CI/SFB manual. This manual is mainly based on four indexing schemes: EPIC (Electronic Product Information Co-operation), CESMM3 (Civil Engineering Standard Method of Measurement, third edition), CAWS (Common Arrangement of Work Sections for building works), and CI/SFB (Crawford et al., 1997). The Uniclass manual contains 13 classification tables that represent different broad facets of construction information (RIBA, 1997). The classification tables are: Table C (Management), Table D (Facilities), Table E (Construction entities), Table F (Spaces), Table G (Elements for Buildings), Table H (Elements for civil engineering works), Table J (Work sections for buildings), Table K (Work sections for civil engineering works), Table L (Construction products), Table M (Construction aids), Table N (Properties and characteristics), Table P (Materials), and lastly Table Q (Universal decimal classification).

The American based Construction Specifiers Institute (CSI) presented, in 1995, a master format with 16 categories to organise construction information. In 2004 the indexing system was then extended to 50 sections to handle the increased density of construction information. The CSI indexing format has been adopted for the BIM software, Revit, to
be the default formatting for categorising. Even though Revit supports 1995 and 2004 versions, the default formatting of keynotes in Revit is based on the 1995 CSI formatting (Autodesk Revit, Online). However, the software still allows users to modify keynote indexing to suit individual and organisational particular needs (Wing, 2010).

Another scheme for the classification of information of building construction works was provided in 2001 by the International Organisation for Standardisation (ISO). The ISO 12006-2:2001 report proposes generic classes for the organisation of information that can be used as an initial point to produce a detailed taxonomy that suits local needs. This classification applies to the whole lifecycle of construction works, which includes design, construction, operation, and decommissioning (ISO, 2001).

One of the first attempts to construct a taxonomy specifically for BM, was by the Royal Institution for Chartered Surveyors (RICS) who published the Building Maintenance Price Book (BMPB) in 1980. The BMPB has been promoted to be used in BM projects in combination with the JCT Standard of Measured Term Contract. The current edition of BMPB is based on two categories, labour constants and measured rates. Each of the categories consists of 12 similar sections. The maintenance sections of BMPB are as follows:

- Section 1: Scaffolding.
- Section 2: Demolitions and Alterations.
- Section 3: Excavations and Concrete.
- Section 4: Brickwork, Underpinning and Stonework.
- Section 5: Roofing.
- Section 6: Woodwork.
- Section 7: Plumbing.
- Section 8: Electrical Work.
- Section 9: Internal and External Finishes.
- Section 10: Glazing.
- Section 11: Painting and Decorating.
- Section 12: External Works and Drainage.

As can be seen, such generic schemes are concerned merely with organising and classifying data and information in the construction industry. Moreover, such schemes
are general and can be used to form more specified classifications. As the proposed system is for knowledge management, the following section reviews how knowledge-based taxonomies are structured, with examples.

10.5.3. Knowledge based taxonomies

With the increasing recognition of the value of effective information and knowledge management in the industry (Anumba et al., 2008), utilising knowledge about solutions, insights and decisions to improve performance has also been the focus of several academic studies. This includes proposing taxonomies and domains to organise construction knowledge and facilitate its accessibility and increase its knowledge sharing within organisations. One of the first attempts to establish a domain ontology which can be deployed for knowledge management in construction is the e-COGNOS project (COntistent knowledGe management across prOjects and between enterpriSes in the construction domain) (Lima et al., 2005). The e-COGNOS classifies construction knowledge into three dimensions: domain knowledge, corporate knowledge, and project knowledge. Domain knowledge includes administrative information, standards, technical rules, product database; organisational knowledge is the intellectual capital of the corporate body and project knowledge consists of the knowledge that each organisation has about a project (Lima et al., 2005; Wetherill et al., 2002).

El-Diraby et al. (2005) devised a domain taxonomy for construction concepts, to support KM applications involved in semantic indexing and retrieval of information, and ontology-based collaborative project development. This taxonomy employs seven main domains to categorise construction concepts: Process, Product, Project, Actor, Resource, Technical Topics, and Systems (El-Diraby et al., 2005). El-Diraby (2013) also proposes an ontological model that categorises knowledge in construction across three main domains: concept, modality, and context. According to El-Diraby, (2013) the concept dimension consists of five key terms: entity, environmental element, abstract concept, attribute, and system. Modality refers to the methods for producing a diversity of types for each of the illustrated concepts. Context is employed for connecting concepts by a variety of means to create different domains.

Other academic studies have proposed systems and applications to organise and manage knowledge in the BM sector. For example, the system More Productive Minor Construction Projects through Information Technology (MoPMIT) developed by Ali et
al. (2004) adopts the approach of organising and managing the knowledge context in a familiar manner to be easily utilised by the targeted users. To achieve this aim, the MoPMIT system divides knowledge in the field of reactive maintenance into three main levels: building maintenance, equipment maintenance and services.

In examining the need for developing a web-based portal for the BM Community of Practice, Fong and Wong (2009) categorise knowledge and experience based on project location and proximity, type of repair work, reaction time, functioning of materials and products, details of contractors and suppliers and health and safety issues.

Fong and Wong (2005) emphasise that knowledge in BM is precisely context-based and cannot be generalised. They also highlight that web-based knowledge management systems should provide specific knowledge through containing enough cases from within the BM context to enable users to obtain relevant ones in order to facilitate their decision-making process.

The indexing schemes and academic approaches reviewed were developed to facilitate the information and knowledge flows in AEC/FM sectors. The manuals and taxonomies described above are found to be either broad indexing manuals for data and information to serve the sector in general or specific classifications of knowledge made particularly by scholars to aid their studies.

In order for the prototype to be used by BM departments in Kuwait, it was necessary for a KM taxonomy to be developed specifically for users in such departments. This is because capturing and clustering knowledge cases should be indexed so as to be easily searched for and retrieved by the professionals when needed. The following section illustrates the knowledge taxonomy adopted for KMoBM.

10.5.4. The knowledge taxonomy adopted in KMoBM

For this research, the knowledge taxonomy adopted for BM was designed based on the currently used contracts of BM in the public sector in Kuwait. Chapter (6) presented the reviewed contracts, used by participating BM departments.

Capturing and clustering knowledge and indexing cases in a manner familiar to users will facilitate the use of the system to a wide range of users and organisations while requiring minimal training. The proposed taxonomy was thus verified by focus group
meetings comprised of professionals working in BM departments to identify the most suitable format for work categories. Chapter (11) describes the evaluation of the knowledge taxonomy of the prototype. Figure 10-9 shows the adopted taxonomy of knowledge, which includes legal, technical, and administrative categories.

**Figure 10-9: Adopted knowledge taxonomy in KMoBM.**

The legal category has four related sections to classify the knowledge based on contract conditions, bidding regulations, and health and safety related issues. Legal knowledge such as recommendations, clarifications, and actions can be classified and entered in each section of the category.

For the BM technical work packages, there are 29 work packages as shown in Table 10-1. Each work package includes a sub-section of further classifications that
contain knowledge topic, product knowledge, specifications and standards, and warranties & insurance, as shown in Figure 10-9. The proposed system allows such sub-section classifications to be altered, based on the particular needs of an organisation. For example, knowledge that can be entered in the “knowledge topic” sub-section of the “concrete works” section located in “technical” category includes: issues related to concretes works, such as insights, problems experienced and their solutions, recommendations, how-to, precautions. Other details on technical specifications for the same section can be entered in the sub-section “specifications & standards”, including durability, method of construction, components/materials quantity and costs, maintenance data and responsibilities.

Table 10-1: BM technical work packages.

<table>
<thead>
<tr>
<th>Section One -</th>
<th>Section Three -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section Two -</td>
<td>Section Four -</td>
</tr>
<tr>
<td>3. Earth works</td>
<td>21. Machinery and Equipment</td>
</tr>
<tr>
<td>4. Concrete Works</td>
<td>Section Five -</td>
</tr>
<tr>
<td>5. Masonry Works</td>
<td>22. HVAC Works</td>
</tr>
<tr>
<td>6. Plaster Works</td>
<td>23. Mechanical Works</td>
</tr>
<tr>
<td>7. Steel works</td>
<td>24. Lifts</td>
</tr>
<tr>
<td>8. Aluminium Works</td>
<td>Section Six -</td>
</tr>
<tr>
<td>10. Roof Covering Works</td>
<td>26. Phone and Service Bells Works</td>
</tr>
<tr>
<td>11. Flooring and Cladding Works</td>
<td>27. Electrical Works</td>
</tr>
<tr>
<td>12. Bathroom Hardware and Sanitary Works</td>
<td>Section Seven -</td>
</tr>
<tr>
<td>15. Insulation layers for Wetness, Humidity and Heat</td>
<td></td>
</tr>
<tr>
<td>16. Wood Works</td>
<td></td>
</tr>
<tr>
<td>17. Paint Works</td>
<td></td>
</tr>
</tbody>
</table>

The administrative category covers information about internal and external administrative processes. Examples of information about internal processes can include forms, a maintenance task database, the replacement period of a component, approval procedures, recruitment plans and general financial processes, in addition to information relevant to the human resource department. Information about the external processes can include forms, knowledge of how to communicate with external organisations obtaining approvals and obtaining permits.
The administrative category also includes “Expert Directory”. This section holds details of experts working in BM branches. When a solution cannot be found in the system or further clarification is needed, users can search the “Expert Directory”, based on the experience of the appropriate expert. The knowledge taxonomy is set to be the default formatting for work classification in the prototype. However, other classifications can also be adopted in the prototype with any necessary modifications to the structure of the database, if required.

10.6. Summary

This chapter explained the development of the KMoBM prototype and its knowledge base. The integration of the knowledge base with the prototype modules, the CBR, the BIM and the database, facilitates knowledge sharing through allowing retaining, retrieving and browsing knowledge cases. Retaining knowledge can be done through the BIM module or the database module, while retrieving knowledge cases is carried out through the CBR module. The database module also provides additional options to search for knowledge cases and experts. Users can also navigate the system taxonomy for knowledge cases. The knowledge taxonomy adopted in KMoBM was based on a review of the maintenance contracts currently used by BM departments in Kuwait. This was done to simplify browsing the cases stored in the system. The next chapter will describe how the prototype functions were tested and evaluated.
Chapter 11 - Prototype Testing and Evaluation
11.1. Introduction

The previous chapter demonstrated the development of the KMoBM prototype. However, this research cannot be considered as complete without the developed prototype being tested and then evaluated by its potential users. Therefore, this chapter is divided into two parts. The first part describes the process undertaken for prototype testing. The second part presents the results of the prototype evaluation. The evaluation was conducted by a selection of industry professionals who participated in the focus group meetings described in Chapter (8).

11.2. Prototype Testing

Software testing is a very complex practice and its main objective is to find defects (Morgan et al., 2010). Therefore, software testing can be extensive and time consuming. Thus, due time constraints; basic testing was conducted to ensure that prototype is functioning properly for the purpose of this research. However, in this research, constant runs, tests, and refinements were made during the whole development stage of KMoBM.

Testing software involves two procedures, namely verification and validation (Watson, 1997; Pressman, 2010):

- Validation is concerned with developing the correct system.
- Verification is about developing the system correctly.

The system validation is to assess the usability of the system and its concepts in improving the performance of BM departments. The process of system validation is discussed in section 11.3. This section is concerned with the stage of system verification. The goal of the verification stage is to ensure that the prototype system has been developed to achieve its purpose and is ready to be validated by the participated professionals working in public BM sector in Kuwait. Several predefined tasks were done to test the workability of the prototype functions. Errors were examined and fixed when expected outputs from the prototype functions were not achieved. The following sub-sections describe the tests:
11.2.1. Interface testing

The KMoBM interface pages were checked for the following:

1. The layout is correctly displayed in a web browser. Testing browser was Mozilla Firefox.
2. Registering a user, logging into the system using the registered name and password, and then logging out of the system.
3. Browsing the system pages and sections by clicking designated buttons.
4. Checking for spelling mistakes and rephrasing text.

11.2.2. Testing the CBR retrieve function

Testing the sensitivity of the retrieve function was carried out in two stages. This was done because system verification commenced prior to the validation of knowledge case attributes used in the CBR module.

The first stage comprised setting all attributes to equal weights. In this stage, the sum of weights for all attributes had a total value of 1 (100%). This value was then divided equally between the attributes. With initially 21 attributes per case, a weight value of 0.0476 (4.76%) was assigned to each attribute.

Table 11-1 shows the tests that were performed during the development of the module, which are generally based on the suggestions of Watson (1997) for testing CBR-based systems. All these tests were conducted and expected outputs were achieved, indicating that the retrieval function is working properly.
Table 11-1: Testing results for CBR retrieve function

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Testing the accuracy of case retrieval: the module in this assessment was tested, refined and passed in the following:</td>
<td>Achieved</td>
</tr>
<tr>
<td>• The system was tested to see if it would give a 100% similarity score per field when a target field has matched itself in the knowledge base. This is done by copying a field from the knowledge base and then pasting it in the CBR search box in KMoBM.</td>
<td>Achieved</td>
</tr>
<tr>
<td>• The system was tested to see if it would give a correct similarity score. This is done by providing half of the source field information in the CBR search box. The system should give a 50% score.</td>
<td>Achieved</td>
</tr>
<tr>
<td>2. Testing the consistency of case retrieval: The module was checked to see if it would give the same result when the same search is repeated.</td>
<td>Achieved</td>
</tr>
<tr>
<td>3. Ranking of retrieved cases: The module was checked to see if it would rank the retrieved cases from highest score to the lowest.</td>
<td>Achieved</td>
</tr>
<tr>
<td>4. Testing of case multiplication: The module was tested to check that the retrieved cases are not duplicated in the results page.</td>
<td>Achieved</td>
</tr>
<tr>
<td>5. Testing that summary of cases is shown correctly.</td>
<td>Achieved</td>
</tr>
<tr>
<td>6. Testing that case details are shown correctly.</td>
<td>Achieved</td>
</tr>
<tr>
<td>7. Testing that case files are attached and can be downloaded.</td>
<td>Achieved</td>
</tr>
<tr>
<td>8. Retain a new case thorough CBR module.</td>
<td>Achieved</td>
</tr>
</tbody>
</table>

As mentioned earlier, the retrieving function tests were conducted based on attributes that have equal weights. The following section illustrates the change of matching results based on the outcome of the focus group meetings.
11.2.2.1. Testing retrieving results before and after focus group meeting

This section illustrates the results of testing case retrieval before and after the focus group meetings to show the change of accuracy in retrieving the most similar knowledge case to a query. Eight professionals working in the public BM industry participated in focus group meetings (described in Chapter 8) to validate knowledge case attributes and setting their importance weights to be used in the similarity function in the CBR module.

Initially 21 pre-validated attributes were set to describe a knowledge case. Because testing the developed system commenced prior conducting the focus group meetings, the attributes were given equal weights in the similarity function formula illustrated in Chapter (8). The pre-validated attributes and their given weights were used in the testing process. However, in the focus group meetings, the participating experts reduced the attributes to be used in the similarity function to 17. By using the AHP exercise, the validated attributes were given different weights based on their importance in distinguishing between knowledge cases.

As illustrated in Figure 11-1, a similar sentence was used for both testing exercises “I have a problem with door handle”. Also similar building details were given for both exercises. Building details were “Office” for building type, “Combined” for structure type and “3” for number of storeys.
Figure 11-1: Screen shot for “Search” page with a problem query.

Figure 11-2 and Figure 11-3 depict a summary of the CBR results for the same query before and after attribute validation and weight setting in the focus group meetings.
Figure 11-2: Summary of the CBR results before attribute validation and weight setting.
Figure 11-3: Summary of the CBR results after attribute validation and weight setting.

As can be clearly seen from the above two figures, the similarity values have significantly changed. Table 11-2 illustrates the difference between the similarity results.

Table 11-2: Change in similarity values between before and after attribute validation and weight setting.

<table>
<thead>
<tr>
<th>Knowledge case title</th>
<th>Similarity value before validation</th>
<th>Similarity value after validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problems with door handle</td>
<td>18.8 %</td>
<td>46.8 %</td>
</tr>
<tr>
<td>Problems with doors</td>
<td>16.9 %</td>
<td>42.1 %</td>
</tr>
<tr>
<td>Problem with door lock</td>
<td>16.1 %</td>
<td>39.3 %</td>
</tr>
<tr>
<td>Instructions and tips</td>
<td>12 %</td>
<td>25.8 %</td>
</tr>
</tbody>
</table>
As shown in Table 11-2, the change in similarly value is up to 150%. This is for two reasons: reducing the attributes to be measured in similarity from 21 to 17 and the different weights assigned to attributes based on their importance in distinguishing between knowledge cases. This has resulted in a significant change in similarity values.

11.2.3. Testing the retaining function

The function of retaining cases was tested in terms of the following operations:

1. Retaining cases directly through the system interface:
   - Adding details of a new project, then adding details of several new cases.
   - Adding new cases details to an existing project.
   - Attaching files to case.
   - Checking that the date and registered author details are added correctly to a case.

2. Retaining cases though BIM:
   - Uploading an IFC file of a BIM-based project that contains several knowledge cases. Testing that all case details are correctly identified and displayed in their designated fields.
   - Checking that the prototype identifies relationships between cases and connects related cases together.
   - Editing project and case details.
   - Attaching files to a case.
   - Checking that the date and registered author details are added correctly.
   - Accessing knowledge case details and checking that all related cases are displayed correctly.

The errors that arose during this test were dealt with to ensure that the retaining function was working properly.

11.2.4. Testing the search function through database module

The database module was tested during the development of KMoBM for the following:

1. Searching for knowledge cases using keywords.
2. Searching for expert details using name or knowledge interest.
3. Navigating the knowledge taxonomy for a particular case. This was done by selecting a category, section, and sub-section to retrieve and display details of a knowledge case.

4. Checking that cases are grouped and shown correctly in the sub-section page.

5. Accessing a knowledge case and checking whether all case details are correctly returned including: attached files, related cases, author details, etc.

Errors that resulted from testing the search function were fixed during the development of the prototype.

11.2.5. **Testing the KMoBM knowledge base**

The knowledge base was repeatedly tested and errors arising were fixed during the development of the system for the following:

1. The knowledge base accepts all details entered, directly or through BIM file.
2. The knowledge base transfers all relevant details when needed.
3. No multiple entries of a case when created directly or when uploaded through BIM file.
4. Tables are correctly linked by unique IDs
5. The data entered is correctly stored in its designated field.
6. The correct unique IDs are given to cases, elements, spatial relationships, authors, etc.
7. Cases are given the correct sub-section unique IDs.
8. Categories, sections, and sub-sections are correctly connected by unique IDs.
9. Attached files are provided and correctly linked with related case unique ID.

11.3. **Prototype Evaluation**

The aim of the evaluation is to allow potential users to assess the developed prototype. A focus group meeting was therefore conducted with professionals working in public BM departments, to evaluate the KMoBM prototype. A usability testing procedure was formed, based on guidance provided by Pressman (2010) which include the following five steps, with the researcher’s responses to follow this procedure.

1) Defining a set of usability testing categories and identifying goals for each:
For this research the goal for usability testing was to assess the following prototype functions: (1) Adding new knowledge cases, (2) Retrieving similar case to a query, (3) Browsing for knowledge cases, and (4) Overall evaluation of the KMoBM.

2) Designing tasks that enable the evaluation for each goal:
   - Three tasks were designed to evaluate the functions of the KMoBM prototype. Then an overall evaluation was carried out on the prototype.

3) Selecting participants who will carry out the tests:
   - Eight professionals working in public BM departments participated in focus group meeting to evaluate the developed prototype. Further information and the analysis regarding focus group participants are described in Chapter (8). The focus group meeting venue was provided by KSE and was facilitated with computers so that participants could personally perform tasks found in the assessment document. However, due to lack of internet connection during the first meeting, each computer in the venue was prepared to work as a local server for the developed application.

4) Instrument participant’s interaction with the WebApp while testing is conducted.
   - A recording method was carried out to record the discussion made by participants after each task.

5) Develop mechanism for assessing the usability of the WebApp.
   - A questionnaire based assessment form was prepared for participants to provide their feedback after each task: Appendix (H) illustrates the evaluation form.

The following sections will describe the evaluation exercise.
11.3.1. The focus group meeting

The focus group meeting was conducted in a venue provided by Kuwait Society of Engineers (KSE). The selected venue for the meeting was facilitated with computers so that participants could personally perform the tasks designed in the assessment document (Appendix H). However, due to lack of internet connection during the first meeting, each computer in the venue was set up by the researcher to work as a local server to access the developed prototype. Eight professionals working in public BM departments participated in focus group meeting to evaluate the KMoBM prototype. Details of the participants are given in section 8.7.1. The researcher commenced the focus group meeting, (in Figure 11-4), by introducing the research topic, and providing a brief background on the core of the KMoBM system. Then the aim and objectives of the workshop were explained to the participants.

![Figure 11-4: Focus group meeting held in KSE to evaluate KMoBM.](image)

After a demonstration on how the KMoBM system works, participants took part in the usability testing tasks to validate the usability of the prototype. The purpose for this was to allow the professionals to provide their views and feedback based on observation and usage. With the guidance of the researcher, the participants were requested to perform tasks included in the designed form (Appendix H). After performing each task, the participants were asked to rate the usability of the prototype, report any errors, and give
feedback or suggestions. The prototype validation and usability testing consisted of three tasks:

**11.3.1.1. Task 1: Assessing the function of adding a new knowledge case**

The first task was to assess the function of adding new knowledge case. This task comprised two sections, adding knowledge cases directly through the system interface and loading cases though BIM software. A demonstration was given on how to add and index a new knowledge case along with an attachment. Participants were then asked to personally add realistic knowledge cases experienced during their BM work.

The second part of this task aimed at loading knowledge cases through the BIM environment. This part was demonstrated to the participants over a projector since only one machine had the BIM software due to licensing restrictions. This task consisted of a demonstration of how to add knowledge cases to a BIM project using “Revit” software. A saved BIM project in IFC file format with pre-saved knowledge cases was provided to the participants for system uploading. Upon completing the case retaining task, a period of time was allocated for discussion. Following the completion of the task and discussion, participants were required to rate the function of adding new knowledge cases in terms of the following aspects:

1) Practicality of adding new knowledge case (directly).
2) Practicality of adding new knowledge case (using BIM).
3) Comprehensiveness of details for knowledge cases to be retained.
4) Clearness of knowledge cases details to be retained.
5) Suggestions to improve this function.

**11.3.1.2. Task 2: Assessing the function of knowledge case retrieving**

The second task was designed to assess the function of knowledge case retrieval. In this task, participants were asked to describe a BM problem in the CBR box, as shown in Figure 11-5, which is related to the cases added in the previous task.
Figure 11-5: Screen shot of an example for problem query used in focus group meeting.

The process for retrieving results and the similarity measure to the enquired problem was explained to the participants. Following the completion of this task, a period of time was allowed for discussion. Subsequently, the function of case retrieval and presentation of “Knowledge Case Details” page were rated in terms of the following aspects:

1) Practicality of knowledge case retrieval using CBR search method.
2) Presentation and organisation of “Knowledge Case Details” page.

11.3.1.3. Task 3: Assessing the function for knowledge case browsing

The third task aimed at assessing the function of browsing for knowledge cases. This task involved participants navigating the knowledge taxonomy adopted in KMoBM for pre-saved knowledge cases. The focus was to rate the ease of locating a desired case.
This is because the performance of a system can be judged by its effectiveness in finding the correct solution to a problem in a simple manner. Then the participants were asked to search for an expert’s details using “Expert Directory”.

After completing this task, the participants had a discussion time on how to improve this part of the system. This was followed by assessing and rating of the knowledge taxonomy used in the KMoBM prototype in the following aspects:

1. Classification of knowledge taxonomy (i.e. categories, sections and sub-sections) for knowledge base.
2. Practicality of locating a desired knowledge case.
3. Practicality of locating a desired professional’s details.

After completing the tasks and assessing each part of the system, the participants were expected to be familiar with the prototype functions, its concepts, and how it works. The following section will discuss the feedback given by the participants on these tasks.

11.3.2. Evaluation results:

The aim of the three tasks was to evaluate the performance of the KMoBM prototype through usability testing. Following each task, the participants were asked to answer questions containing performance rating scales ranging 1 to 5 representing system evaluation, where 1 is very poor, 3 is neutral, and 5, is excellent. Furthermore, open questions were also provided to allow participants to provide their suggestions and feedback.

11.3.2.1. Task 1: Adding a new knowledge case

This task aimed at assessing the function of adding a new knowledge case. Following completion of this task, participants were asked to answer five questions. The first four questions focus on rating their satisfaction level in terms of the performance of practicality of case retaining, comprehensiveness and clearness of case details. The results of responses are shown in Table 11-3, demonstrating valid responses, missing responses, mean and Standard Deviation (STD) values.
Table 11-3: STD and Mean values of the evaluation for function of adding new knowledge case.

<table>
<thead>
<tr>
<th>Number of responses</th>
<th>Valid</th>
<th>Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prototype evaluation</th>
<th>STD</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Practicality of adding knowledge case (directly).</td>
<td>0.53</td>
<td>4.50</td>
</tr>
<tr>
<td>2) Practicality of adding knowledge case (using BIM).</td>
<td>0.52</td>
<td>4.38</td>
</tr>
<tr>
<td>3) Comprehensiveness of details for knowledge cases to be retained.</td>
<td>0.46</td>
<td>4.25</td>
</tr>
<tr>
<td>4) Clearness of knowledge cases details to be retained.</td>
<td>0.53</td>
<td>4.50</td>
</tr>
</tbody>
</table>

As can be clearly seen from Table 11-3, the results for adding new knowledge cases (directly & using BIM) have a corresponding high mean score (4.50 & 4.38 out of 5.00) and STD (0.53 & 0.52) respectively. This indicates that the functions of adding new cases were perceived as highly practical. Moreover, comprehensiveness and clearness of knowledge case details also received high mean scores (4.25 & 4.50 out of 5.00) with STD (0.46 & 0.53). This indicates that details of knowledge cases are highly comprehensive and clear.

All participants evaluated the process as either good (4) or excellent (5). The highest score was given to practicality of direct case retaining and the clarity of knowledge case details. The lowest score was given to the comprehensiveness of details for knowledge cases. Although its value does not indicate that the comprehensiveness of details was considered excellent, the score shows that the amount of details was considered very good. It can also be noticed that adding new knowledge cases through BIM was given a lower value compared to adding new knowledge directly through the KMoBM interface. This is perhaps due to the participants’ unfamiliarity with the relatively new BIM concept. This function involves capturing the knowledge details in Revit software then uploading the file to the system using IFC format.

In the fifth question in task 1, the participants were asked to provide their feedback and suggestions on how to improve the case retaining section. The feedback was as follows:

1) Excellent approach to solve problems.
2) It would be better to add the facility of reading from scanner to attachments
3) To add spelling identification and correction capabilities when adding knowledge cases.

11.3.2.2. Task 2: Knowledge case retrieving

The aim of this task is to assess the function of knowledge case retrieving. Following completion of this task, the participants were asked to rate the practicality of case retrieving, and presentation of knowledge details. The results of the responses are shown in Table 11-4.

Table 11-4: STD and Mean values of the evaluation for function of knowledge case retrieving.

<table>
<thead>
<tr>
<th>Number of responses</th>
<th>Valid</th>
<th>Missing</th>
<th>Prototype evaluation</th>
<th>Std</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1) Practicality of knowledge case retrieving using CBR method.</td>
<td>0.53</td>
<td>4.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2) Presentation and organisation of knowledge case details.</td>
<td>0.52</td>
<td>4.38</td>
</tr>
</tbody>
</table>

As shown from Table 11-4, the external evaluation results for practicality of retrieving knowledge case has high mean score (4.50 out of 5.00) and STD (0.53) indicating that the process was considered to be highly practical. Similarly, the presentation and organisation of knowledge case details received high mean score (4.38 out of 5.00) and STD (0.52). Thus, the results indicate that the function for retrieving a similar case to a query is very practical. Also, the results show that presentation of knowledge case details is acceptable and highly organised.

All the professionals evaluated the function with scores of 4 and 5. The participants felt positively towards the ease of case retrieving function and the resulting arrangement of the summary of CBR results. This is shown in the results for practicality of knowledge case retrieving obtaining a higher satisfaction level than presentation and organisation of knowledge details.
In the third question in task two, the participants were asked to provide their feedback and suggestions on how to improve the case retrieving section. The feedback was as follows:

1) Adding auto detecting feature for case words while writing the description of the case.

2) Using the word “title” instead of the word “topic” and to use the word “Description” instead of the word “Problem”. This is to generalise knowledge cases.

3) Adding comments and updates sections to knowledge cases. This is to inform users with remarks posted by the authors or other interested professionals.

11.3.2.3. Task 3: Knowledge case browsing

The aim of this task was to assess the function of knowledge case browsing. Following completion of this task, participants were requested to indicate their level of satisfaction regarding knowledge taxonomy and practicality of this function. The results of this task are shown in Table 11-5.

Table 11-5: STD and Mean values of the evaluation for function of knowledge case browsing.

<table>
<thead>
<tr>
<th>Number of responses</th>
<th>Valid</th>
<th>Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prototype evaluation</th>
<th>STD</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Taxonomy of categories, sections and sub-sections for knowledge base</td>
<td>0.53</td>
<td>4.38</td>
</tr>
<tr>
<td>2) Practicality of locating a desired knowledge case</td>
<td>0.52</td>
<td>4.38</td>
</tr>
<tr>
<td>3) Practicality of locating a desired professional’s details</td>
<td>0.46</td>
<td>4.75</td>
</tr>
</tbody>
</table>

The majority of responses rated this section with a 4 or 5 score. As shown in Table 11-5, the evaluation for taxonomy had STD (0.53) and high mean value (4.38). Practicality of locating knowledge case and professional details received STD scores (0.52 & 0.46) and high mean value (4.38 & 4.75 out of 5.00) respectively. Only one professional felt neutral towards the taxonomy of knowledge in the KMoBM system.
The highest score was given to the practicality of locating the desired expert’s details. This indicates that the knowledge taxonomy adopted in KMoBM is highly acceptable. Also, the functions of locating knowledge cases and professional’s details are very practical.

Regarding the fourth question in this task, the participants provided their feedback on how to improve this section. Their responses are as follows:

1) To add more sections to cover more subjects.
2) To add the word “Environment” in the health and safety section.
3) To cluster tabs in the technical section into groups based on work packages. The grouping fields can be civil works, electrical works, mechanical works, and other.
4) Combine the contract legal conditions into one section with sub-sections of general and particular contract legal conditions.

### 11.3.2.4. Overall rating of KMoBM system

Following completion of the above tasks, the participants were asked to rate the overall performance of the system. The evaluation results are shown in Table 11-6.

**Table 11-6: Mean and STD values for the evaluation of overall rating for KMoBM prototype.**

<table>
<thead>
<tr>
<th>Number of responses</th>
<th>Valid</th>
<th>Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype evaluation</td>
<td>STD</td>
<td>Mean</td>
</tr>
<tr>
<td>1) Ease of use</td>
<td>0.53</td>
<td>4.50</td>
</tr>
<tr>
<td>2) Organisation of interface layout for the KMoBM system</td>
<td>0.53</td>
<td>4.00</td>
</tr>
<tr>
<td>3) Efficiency in reducing additional workload when adding knowledge cases.</td>
<td>0.52</td>
<td>4.38</td>
</tr>
<tr>
<td>4) Expected improvement of knowledge sharing between employees</td>
<td>0.89</td>
<td>4.25</td>
</tr>
<tr>
<td>5) Expected improvement of communication between employees</td>
<td>0.53</td>
<td>4.00</td>
</tr>
<tr>
<td>6) Expected level of reuse of captured knowledge in same or another project</td>
<td>0.89</td>
<td>4.25</td>
</tr>
</tbody>
</table>
Table 11-6 shows responses with high mean values (4.00 to 4.50 out of 5.00) regarding the overall rating for KMoBM prototype. The highest score was given to the ease of use of the prototype. All responses for this question indicated either a 4 or 5 rating score. The lowest scores were given to the organisation of the interface layout and expected improvement to communication. One participant indicated a neutral rating for expected level of reusing captured knowledge in future projects.

11.3.2.5. Open discussion on prototype evaluation

Through open discussion on the prototype evaluation, the participants were asked to express their views regarding the main strengths and weaknesses of the system. This was to allow participants to provide additional remarks and assessment comments not covered in the closed questions. The views are classified into two categories: application strengths and weaknesses.

- Strengths of KMoBM prototype:
  1. Using this system will facilitate finding solutions to problems we face.
  2. The browsing function could be most useful to freshly qualified engineers. This is because the browsing function is organised similarly to that in BM contracts.
  3. This prototype may increase knowledge sharing between employees.
  4. The prototype helps the employees to exchange their knowledge to solve problems.
  5. The login feature provides privacy to the organisation.
  6. The prototype can carry large number of knowledge cases which in turn can make problem solving and knowledge exchange easier.
  7. The prototype can improve communication between employees and may help in reusing knowledge in future projects.

The participants showed a positive attitude towards the notion of a web enabled knowledge management system for building maintenance. The most repeated strong point acknowledged by participants is that this system will increase knowledge sharing between employees (points 1, 3, 4, 6 and 7). The aim of this system is to allow employees to share this knowledge. Thus recognition of this issue from potential users validates its goal and provides confidence in the prototype usability. Furthermore, a
participant indicated that freshly qualified engineers are the highest beneficiaries of using such systems, (point 2). Indeed, utilising this system can facilitate knowledge transfer from experts to inexperienced professionals.

- Weaknesses of the KMoBM prototype and suggestions for improvement:

1. Mistakes might occur when storing and indexing cases: this problem should be addressed when storing cases.
2. Some solutions may not be realistic. They need to be validated by experts before storing cases in the knowledge base.
3. Terminologies used in the system are in English; they should be developed in Arabic.
4. The system needs to use English words more familiar to BM employees.
5. Changing the section words “browse”, “retrieve” and “retain” to more user friendly words “find”, “search” and “add”
6. A help function is needed to show users how to use the system.
7. The system needs to show the name of the logged-in user.
8. The system does not contain a tab for any given building to show the history of its cases.
9. The taxonomy can be clustered into groups to ease navigation and locating knowledge cases
10. The knowledge taxonomy should have the ability to be modified by different organisations, based on their needs.
11. The department should be prepared with hardware to have this system working.
12. The prototype needs at least 5 years of experienced engineers’ input to be valuable in problem solving for trainee engineers.
13. This system is more important to large organisations with many branches.

11.3.2.6. Responses to feedback

Responses to the open discussion comments and suggestions:

Participants indicated several weak points and provided suggestions for the prototype. However, their remarks confirm that no major issues exist with the functions of the prototype. The comments and suggestions received from the participants are useful for enhancing user experience as well as prototype performance. Some of such remarks
were dealt with, while others were related to future developments. It is noticeable that most of weak points mentioned by participants were related to improving the usage experience of the system (remarks 1 to 9). The following section will illustrate how the prototype was updated to respond to feedback given by participants.

Points (1) and (2) raised the issue of errors being made when saving knowledge cases. This issue can be resolved by assigning a committee or individuals that accept, reject, modify, combine and index knowledge cases submitted by employees of the maintenance department. Chapter (6) revealed that BM departments conduct regular meetings on different levels to discuss and decide on matters related to BM works. Such meetings can be utilised to validate knowledge submitted by BM professionals. However, investigating the feasibility of implementing this suggestion is beyond the scope of this research.

Point (3) raised the issue of the whole system being translated into Arabic language, since the targeted users are native Arabic speakers. This research has been conducted in English and therefore the development of this prototype used the same language. Future developments of the system could include a bilingual ability to facilitate the management of knowledge in BM.

Points (4) to (9) were considered feasible to deal with in the concluding stage of this research. These included using words more familiar to users (points 4&5); including a help section (point 6); showing the name of the logged in user in the system interface to provide more privacy to users (point 7); addition of a filtering tab for a given building, to show cases related to a building to provide a better understanding when conducting maintenance works (point 8); and clustering sections in the taxonomy into groups to facilitate navigation and browsing (point 9). Figure 11-6 illustrates the modifications made based on the suggestions of points (4, 5, 6, 7, 8, and 9).
Figure 11-6: Screen shot of KMoBM interface with modifications.

Point (10) suggested that the application should have a flexibility to modify the adopted indexing of knowledge. Such flexibility is required when different organisations with different indexing needs use the system. It was explained during the meeting that the knowledge indexing is dynamically connected to the knowledge base. Therefore, any modification to the taxonomy in knowledge base will instantly be shown in the prototype interface.

Point (11) addressed capacity of organisations to utilise this prototype. This issue is beyond the scope of this research and IT prerequisites should be available before operating any IT system in organisations.

Point (12) acknowledged that the prototype needs several years of experts’ input and use, in order to become of value to new engineers. The scope of this research is extends
only to proposing a KM management system for BM departments. Further research is therefore required that would investigate the impact of implementing the KM system on the performance of BM departments.

Point (13) mentioned that this system is more beneficial to large organisations with many branches. Even though organisations with multi-branches and a large number of employees can generate large input of knowledge cases, storing cases for future retrieval and use will benefit organisations whatever their size and number of branches. The KMoBM is an online-based prototype and therefore can be equally useful to single or multi-branched BM departments. This was recognised by three of the participants working in BM departments with one and two branches.

- Responses to task (1) suggestions:
  1) It would be better to add the facility of reading from scanner to attachments.
  2) To add spelling identification and correction capabilities when adding knowledge cases.

These suggestions would require significant development to be carried out, and were not, therefore integrated into this version of the prototype.

- Responses to task (2) suggestions:
  1) Adding auto detecting feature for case words while writing the description of the case.
  2) Using the word “title” instead of the word “topic” and to use the word “Description” instead of the word “Problem”. This is to generalise knowledge cases.
  3) Adding comments and updates sections to knowledge cases. This is to inform users with remarks posted by the authors or other interested professionals.

The first suggestion made in task (2) requires extensive development and therefore was not included in this version of prototype. Suggestions (2) and (3) have been incorporated into the KMoBM prototype. Figure 11-7 illustrates the modifications based on these suggestions.
Responses to task (3) suggestions:

1) To add more sections to cover more subjects.
2) To add the word “Environment” in the health and safety section.
3) To cluster tabs in the technical section into groups based on work packages. The grouping fields can be civil works, electrical works, mechanical works, and other.
4) Combine the contract legal conditions into one section with sub-sections of general and particular contract legal conditions.
Regarding point (1), the knowledge taxonomy is directly connected to the knowledge base. When a section is added or deleted in the knowledge base, the taxonomy will automatically be updated to match the knowledge base. The suggestions mentioned in points (2), (3) and (4) were dealt with and incorporated into the KMoBM.

11.4. Summary

This chapter discussed the prototype testing and outcomes of the evaluation exercise for the developed prototype. The KMoBM was tested to verify that all of its functions are working correctly. Errors during the testing stage were fixed when identified. Moreover, the prototype testing stage was extended to test the CBR search function in KMoBM. For this function, a focus group meeting was conducted to validate and subsequently weigh knowledge case attributes to be used in the CBR search function for case retrieval. The focus group meeting validated several knowledge case attributes and assigned different weights, based on their importance distinguishing between the knowledge cases.

The prototype was then evaluated through usability testing by potential users. Several tasks were undertaken to assess and evaluate the functions of KMoBM. Evaluation feedback and comments were received from participants after completing each task. The prototype received highly satisfactory results for each of the functions. The results indicate that KMoBM has achieved the aim of the research. However, several concerns were raised, some of which were dealt with while others were set for future development. The following chapter presents a complete case study application of the developed prototype.
Chapter 12 - Prototype Application
12.1. Introduction

The previous six chapters demonstrated the development, testing and evaluation of the KMoBM. This chapter will illustrate the application of the developed prototype. This is done through a case study application in a project provided by the researcher’s sponsor.

The applications of the KMoBM in this chapter are for demonstration only. This is because BIM-based models and BIM environment were unavailable during the operation of the prototype system. This chapter is set to firstly present the prototype potential users and their use cases. This is followed by a description of the case. The chapter will then illustrate the applications of the system with the assistance of relevant interface shots.

12.2. KMoBM Potential Users and their Use Cases

In order to recognise how the system would interact with its users, it was essential to identify who are the potential users and their roles in the system. The KMoBM prototype is aimed at connecting BM employees located at different locations. It allows the employees to ask for knowledge, transfer knowledge and share knowledge. A use case diagram is introduced in this section to identify the users and their roles in the proposed KM using the “Unified Modeling Language” (UML). A UML is a notation coding which was introduced in the 1990’s to act as a standard language in IT to simplify the development of computer systems (Booch et al., 1998). Figure 12-1 depicts the potential users of the KMoBM prototype and their expected roles.

Through examining the process of BM in Chapter (6), several public parties were identified for the system, based on their functions, which include:

- **System administrators**: System developers for IT development and support.

- **General users**: These include: Engineers, Architects, engineers’ assistants and technicians working as managers, division heads or frontline employees in BM branches and the general department, and engineers and their assistants working in planning design divisions. As they carry out their duties in different locations, the professionals may require solutions for problems arising, introduce new solutions, share opinions or merely improve on self-experience. The users can
use the system to retain and retrieve knowledge and to identify professionals, based on their experience.

![KMoBM System](image)

**Figure 12-1: KMoBM potential users their roles.**

Also, general users include employees working in administrative sections such as the divisions of finance, contracts and human resources. The administrative employees will use the system to retain, retrieve knowledge and identify experts.

- **Special users:** Authorised users such as BM Committee members can access the system to validate, reclassify, add, retrieve and amend submitted knowledge. The newly added cases will not be disclosed in the prototype until being validated (as pointed out by the focus group meeting). The validation process can take place during meetings to approve, amend, combine, reject and classify submitted knowledge. As discussed in Chapter (6), all interviewed BM departments have confirmed that they carry out regular meetings in their branches as well as in headquarters on different levels to discuss problems and make decisions related to BM works.
12.3. Case study description

12.3.1. The BM department

The BM department in this case study consists of headquarters and six branches located in different parts in Kuwait. The process followed by the BM department is illustrated in Chapter (6). The professionals working in the department include a general manager, branch managers, engineers, architects, assistant engineers, technicians, and administrative professionals.

The department provides its BM services to maintain buildings owned or leased by the ministry. The ministry uses both ordinary and special structures, such as office buildings, police stations, border centres, coastguard ports, state prisons and academic campuses. Therefore, BM services provided by the department can range from single repair works to bespoke refurbishment and reconstruction projects. The department employs seven MTC contracts (one per branch) to provide its BM services to the ministry.

12.3.2. Project description

The project sample used in this case study is designed to be used by the Immigration General Department in Kuwait. This department provides its services to foreigners living and working in Kuwait (non-Kuwaitis represent 68.5% of the total population (PACI, 2014)). As shown in Figure 12-2 and Figure 12-3, the project comprises three storeys and a basement. The site area is 7728 m² and built area is 19468 m². The building comprises offices, reception halls, counters, citizens’ services hall, control rooms, archiving rooms, training rooms, a multi-purpose hall, a meeting room, a prayer room, a printing/copying centre, general services rooms, a cafeteria, and car park.
The following section illustrates the applications of the KMoBM using the project sample of this study.

Figure 12-2: Project sample used in case study

Figure 12-3: Project sample during construction stage.
12.4. Prototype Application

This section illustrates the prototype applications on the project with the support of appropriate screen shots. It is worthy of note that the project used in this case study has been designed using AutoCAD software. Therefore, the researcher has recreated part of the project in the BIM environment “Revit” to demonstrate the applications of the KMoBM.

12.4.1. Logging in

The KMoBM login page is the first to be displayed, as shown in Figure 12-4. All system functions will not work without logging in and registration. New users are required to register by filling in their details prior to using the system function. Registered users can login to the system using the registered email and password. If the password is forgotten, users can click on “Forgot Password?” link where they will be requested to submit their registered email to receive a user’s password, as shown in Figure 12-5.

Figure 12-4: KMoBM “Login” page.
12.4.2. **KMoBM main page**

Following a successful logging into the prototype, the user is redirected to the KMoBM main page, shown in Figure 12-6. On the main page, a list of the latest additions of knowledge cases is displayed on the left side of the page. In this list, the listing date and knowledge case title is displayed. The user can click on “more information” link to be redirected to the relevant knowledge case. Moreover, three main functions are displayed on the middle section of the main page: “Browse”, “Search”, and “Add”. These main functions are accessed from any page in the prototype. By clicking any of the functions, the user is redirected to the relevant page. The following three sections illustrate options provided in each of the functions.
12.4.3. Retaining knowledge cases using “Add” page

A user can utilise the “Add” page to retain new knowledge cases. As depicted in Figure 12-7, the left side of the interface shows two options to retain knowledge cases: (1) directly through KMoBM and (2) loading cases through BIM. The option of retaining knowledge cases directly runs the database module discussed in section 10.4. Moreover, the option of loading knowledge cases through BIM runs the BIM module described in section 10.3.
12.4.3.1. Directly adding new cases through the KMoBM interface

By clicking on the “New Case” button, the user will be redirected to the page designated to adding cases directly through KMoBM interface. As shown in Figure 12-8, on the left side of this page two options are provided: (1) retaining knowledge case to an existing project or (2) retaining knowledge cases to a new project.
Figure 12-8: Screen shot of the direct retaining page.

If the case to be retained is for an existing/saved BM project, the user is asked to insert the project number into the designated field on the left side of the page. After inserting the project number, the user is then redirected to a page for adding new knowledge case details. As illustrated in Figure 12-9, the left side of the page contains the retrieved project details of the submitted project number. The project details shown cannot be edited, as can be seen in the figure. This is done since only authorised users have the permission to amend stored information and knowledge. In this page, the user will need to type in all knowledge and information into the fields provided (i.e. title, description, cause of problem). The fields represent the validated knowledge case attributes
discussed in Chapter (8) and the classification method of the adopted knowledge taxonomy discussed in section 10.5.1.

![Figure 12-9: Screen shot for adding a new knowledge case into KMoBM.](image)

After typing in all fields, the user has the option to attach files to the knowledge case at the bottom of the interface, as illustrated in Figure 12-10. This can be after saving the knowledge case, so that any attachments are linked to the knowledge case unique ID.
Figure 12-10: Screen shot displaying added new knowledge case with attached file.

12.4.3.2. Loading knowledge case through BIM

The other option for adding knowledge cases is through loading cases using the BIM environment. The process of this option runs the BIM module discussed in section 10.3. The process starts when an insight has been obtained during the works of a maintenance project and believed to be worth capturing as a knowledge case. The user can fill in the designated fields of element parameters in the BIM-based software used (Revit). Steps for preparing the BIM model to handle additional element parameters as knowledge case attributes were illustrated in Chapter (9). Figure 12-11 illustrates the parameters which contain knowledge case details (i.e. title, description, cause of problem, solution) and associated element. The user then types in category, section and sub-section in
which the case is to be stored in the knowledge base. All captured cases along with information related to the affected elements will be uploaded to the KMoBM via the IFC file format.

![Figure 12-11: The BIM-based model of the case study with captured knowledge case details.](image)

When the BIM model is loaded into the prototype, the project information is identified, organised, and stored in the prototype knowledge base. In addition, building elements, their relationships, and related knowledge cases are also identified and stored in the prototype knowledge base. As depicted in Figure 12-12, the left side of the KMoBM interface shows the knowledge cases for this project that have been identified and stored in the prototype knowledge base. The right side of the interface shows the project details gathered from the BIM-based project.
12.4.4. The contents of KMoBM “Browse” function

The “Browse” function runs the database module described in section 10.4. In the “Browse” page, several functions are provided to the user, as shown in Figure 12-13. The user can utilise this page either to navigate for a knowledge case by using the knowledge taxonomy located on the left or by using the search boxes of keywords, expert details, and the building name located in the middle of the page.
12.4.4.1. Navigating cases using knowledge taxonomy

On the left side of the “Browse” page, users can navigate through categories, sections and sub-sections of the knowledge taxonomy to find the desired knowledge case. The adopted knowledge taxonomy for KMoBM is given in section 10.5.1. As depicted in Figure 12-14, if a user clicks a section, s/he will be redirected to the selected section showing a legend for sub-section classification of knowledge cases and a list of all knowledge cases that fall under this section. The legend of the sub-section shows number of cases stored in each of the sub-sections.
Figure 12-14: A list of knowledge cases stored in “Aluminium Works” section.

Four sub-section classifications were validated by participating experts: Knowledge topics, Product knowledge, Specifications & Standards, and Warranties & Insurance. The cases list underneath the legend shows a list of stored cases in this section and their main details which include: project name, addition date, topic, and problem. The legend and cases list is created automatically when a case is retained in the knowledge base of the prototype. The user can click on the link “Topic” of each case to be redirected to the page “Knowledge Case Details”, as illustrated in Figure 12-15.
Chapter 12: Prototype Application

The page of “Knowledge Case Details” shows the following:

- Project details: which are general information about the BM project (project name, contractor name, client name, location, building name, building type, structure type, number of storeys and project number).
- Case details: fields by which knowledge is described (title, description, cause of problem, solution, keywords, category, section, sub-section).
- Author name.
- Attachments: any attached documents to the knowledge case.
- Related cases: other cases in same building space which are connected through BIM technology.
Updates: any updates that the author wishes to add.
Comments: any comments peers wishes to add.
Knowledge taxonomy: on the left side of the page knowledge taxonomy is displayed to allow users to continue navigating the contents of the prototype.

12.4.4.2. Search using keywords

A user can search the KMoBM knowledge base for a case using the keywords field, as shown in Figure 12-13. When a keyword search field is used in this option, lists of cases are displayed that contain the searched keywords. Figure 12-16 shows a list of cases with their brief details. The displayed brief details include project name, addition date, title, description and solution. When a user selects the link “Topic”, s/he will be redirected to the knowledge case details page, as illustrated in Figure 12-15 above.

Figure 12-16: A list of retrieved knowledge cases based on the “Keyword” search option.
12.4.4.3. Search using author name

Users can utilise this option in the browse page in order to search for cases based on author details, as shown in Figure 12-13. When author name is entered in the author name search field, a list of all cases, with their brief details, written by the searched author is displayed. Figure 12-17 shows a list of retrieved knowledge cases based on author name. The user can then select “Title” link to be redirected to the knowledge case details page.

Figure 12-17: A list of retrieved knowledge cases based on “Author name” search option.
12.4.4.4. Search using building name

As shown in Figure 12-18, users can search for cases using the name of a building. The related dropdown menu is automatically updated whenever a knowledge case is stored in the knowledge base. When a user selects the building name from the dropdown menu then clicks on the search button, a list is displayed showing all cases involving the selected building. As illustrated in previous sections, the user can then select a particular case to be redirected to the knowledge case details page.

Figure 12-18: Screen shot of the “Browse” page with building name dropdown menu.
12.4.4.5. Search for experts

The Prototype allows users in the “Browse” page to search for particular experts and retrieve their contact details. As shown in Figure 12-19, the “Expert Directory” link is located on the bottom left side of the “Browse” page.

![Image of the Prototype Application](image)

**Figure 12-19: Screen shot illustrating “Expert Directory” in “Browse” page.**

When the link is selected the user is then redirected to the directory, where details of experts are listed, based on expert’s name or registered knowledge interest, as shown in Figure 12-20.
The following section illustrates the prototype application for the “Search” function.

**12.4.5. Exploring the contents of KMoBM using the “Search” page**

The “Search” function runs the CBR module discussed in section 10.1. The “Search” comprises of three options for building details and the CBR search box. The search function in this page starts with the user selecting the building type (i.e. office building, police station, healthcare facility), structure type (i.e. concrete, steel, wood, combined), and number of storeys (i.e. 1,2,3,4). Then the user describes the experienced problem as illustrated in Figure 12-21.
Chapter 12: Prototype Application

Figure 12-21: Interface of the “Search” page with a described problem.

When the problem is submitted, the KMoBM retrieves similar cases to the described problem. As shown in Figure 12-22, “Summary of CBR Results” page is displayed with retrieved cases ranked from higher in similarity percentage to the lower. The summary page also shows brief details of retrieved cases, including project name, date, title, description, and solution. The user then has the option to select a case from the list to be redirected to the “Knowledge Case Details” page or go back to the “Search” page to modify the input.
12.5. Summary

This chapter has demonstrated the functions of the KMoBM. This is done through a case study application using a project provided by the researcher’s sponsor. The demonstration showed that the KMoBM functions are working properly in real life project. The following chapter sums up the thesis and provides conclusions and recommendations for further research.
Chapter 13 - Conclusion and Recommendations
13.1. Introduction

The aim of this research was to develop a BIM-based knowledge management system for building maintenance management. This aim has been achieved through completion of the five stages illustrated in this thesis. This chapter represents the sixth stage, which summarises the evolution of the study and concludes its findings. The chapter addresses the research aim and objectives linked with the methodology to achieve them. The features of KMoBM are described. The limitations and subsequent contribution to knowledge are then demonstrated. Finally, recommendations for future research are presented.

13.2. Research Aim and Objectives

This research was conducted to develop a valid and reliable knowledge management system for building maintenance. Six objectives were set to achieve the research aim. Figure 13-1 depicts each objective with its related stage leading to achieving that research aim.

![Figure 13-1: Research objectives with corresponded stages and chapters.](image)

13.2.1. Research Methodology

Five main stages were planned to achieve research aim and objectives: (1) literature review, (2) interviews (to investigate the BM process and issues related to KM and
assessment of BIM implementation), (3) KM prototype building, (4) prototype evaluation, and (5) prototype application.

In terms of the research ontology, the research attempts to understand the phenomenon (i.e. the process of BM) and its knowledge originating from the experience of individuals. Moreover, individuals participating in this research are part of the world being studied (i.e. the public BM sector). In terms of epistemology, a subjectivist approach, gathering data through people to understand this phenomenon (BM process), was considered appropriate. This research is therefore in the nominalist position in ontology and subjectivist in epistemology.

The mixture of these ontological and epistemological assumptions forms the philosophy of phenomenology, also known as Interpretivism. Based on this perspective, a qualitative approach was deemed best for understanding the working nature of BM. Therefore, the primary data needed to address the first three objectives (stage 2) were collected from experts through qualitative interviews. Data for attributes validation and weighting (stage 3) and prototype evaluation (stage 4) were collected from experts through focus group meetings. The following sections illustrate the research objectives achieved.

**13.2.2. Objective one: To map and examine main processes of services provided by BM departments**

Due to lack of studies that investigate the process of BM in Kuwait, process mapping and analysis (Chapter 6) was conducted to understand the procedures carried out in BM and to identify deficiencies in processes related to the management of knowledge. Experts from ten different public BM departments participated in qualitative semi-structured interviews. It was decided that selected participants should hold a managerial position in their organisation and have several years of experience in the sector. This approach was adopted to enrich the study and to obtain most trustworthy results.

A generic BM process diagram was mapped out based on the analysis of data obtained from the interviews. A traditional block diagram technique was used to sketch the process diagram. This technique was selected due to its clarity in representing processes common to individuals. Several findings were revealed by mapping out and analysing BM processes. The first finding is particularly related to the BM departments with multiple branches. It was found that communication links were limited to the formal
paperwork lines between branches and their department headquarters. This has created isolation between branches. Moreover, maintenance teams within the same branch were also found to be isolated within their projects. These issues have constrained the sharing of knowledge and experiences which usually create the issue of “reinventing the wheel” in problem solving.

The second finding was related to meetings conducted in BM departments. It was revealed that the participating departments conduct meetings on a regular basis. However, the meetings are conducted at different organisational levels. This has led to a lack of feedback and knowledge sharing between maintenance teams and other departmental divisions, such as planning/design and finance. It was also discovered that decisions and solutions discussed in meetings are embedded within meeting minutes and not extracted for future use. Also the archiving and filing of documents is time and project based. This approach leads to difficulty in retrieving solutions to be utilised in other projects.

Several possible opportunities to capture, organise, reuse and share knowledge were recognised in the BM process. Activities to exploit these opportunities can be carried out before, during, and after maintenance projects to better manage the knowledge in the organisations. A conceptual example of how knowledge can be managed was developed based on the generic BM process diagram.

13.2.3. Objective two: To explore issues related to KM, including techniques, IT usage, and perceptions regarding introducing a KM system for BM

The review of the literature showed that there is a lack of studies investigating issues related to knowledge management in Kuwait. Therefore, this stage of the research was set to explore certain elements of KM in Kuwaiti public BM.

Part of the interviews conducted for objective two was designed to explore KM techniques used in participating departments, technology usage, perceptions towards KM, and to obtain currently used contract documents for review. It was found that several methods to facilitate knowledge gain, share, and transfer were being adopted by participating departments. The methods include mixing experienced with inexperienced professionals, face-to-face interactions in meetings, training courses, daily communication within branches, and storytelling. However, it was also found that
knowledge sharing occurs only on a small scale, such as among employees in the same branch and the circle of meeting members.

In terms of technology usage, it was revealed that the departments’ employees regularly use computers. The use is extended to administrative work, project documentation, preparing of project drawings, and internet surfing. Moreover, it was confirmed that computers located in branches have internet connectivity and that employees working in branches have either personal computers or devices that are connected to the internet. It was found that only one third of the departments have an Intranet system. These departments also employ FM software for maintenance scheduling. None of the participating departments have knowledge bases to assist their BM works. Some employees of only one department employ social media applications to form groups for knowledge sharing and assistance in decision making.

In terms of perception towards KM, it was found that participants recognise the benefits of knowledge sharing between employees. Moreover, the majority of participants showed positive attitude towards proposing a knowledge-based system. Such an encouraging attitude had a significant impact in terms of the feasibility of the study’s aim and supported the implementation of a KM system. In terms of barriers to knowledge sharing, it was found that residency restrictions and ethnicity have a large influence on willingness to share knowledge among employees. Such findings are consistent with those of Al-Kazemi and Ali (2002) who found that personal relationships, bias, and loyalty were among the organisational problems in Kuwaiti organisations. Moreover, it is worth noting that foreign professionals working in public organisations have to bear with annual renewal of their employment contracts. This type of employment arrangement restrains employees from sharing their knowledge, to maintain their own value in organisations.

Part of this objective includes developing a taxonomy for the proposed KM prototype. The aim here was to find a knowledge taxonomy that is based on a context familiar to BM employees. In order to achieve this goal, several BM contracts being used by participating BM departments were reviewed. Eight of the participating departments provided parts of their contracts to be examined. It was found that all public contracts have to follow general guidelines set by the Kuwaiti Biding Law and go through similar processes set by the Central Tendering Committee. It was revealed that public contracts consist of four volumes that contain legal, technical and administrative aspects of a BM
project. The main finding was achieved when pricing tables for BM packages were compared against each other. It was found that the sections in pricing tables were generally similar to each other in terms of indexing. Also from the interviews, it was confirmed that BM employees use the pricing table in a regular manner; that is before, during and after completing the BM project. Based on such findings, it was decided to base the taxonomy of the KM prototype on the indexing of pricing tables found in the majority of the examined contracts.

13.2.4. Objective three: To assess BIM implementation in the building maintenance sector

To achieve this objective, the same round of interviews investigated several issues related to BIM implementation. Majority of participants have no awareness of BIM technology. A few participants had low awareness about BIM. The second finding was that none of the BM departments have implemented BIM technology and therefore no benefits could be recognised by these BM employees. The major reasons for not implementing BIM were lack of experience, lack of regulations to enforce this, high expenditure, and dominance of the drafting tool (CAD) in the design, construction, and operational stages.

It was also emerged that half of the participants believed that BIM technology will eventually be implemented in future. The reason for such belief was the need to pursue a competitive edge between companies and that BIM is a natural evolution of CAD. A condition for BIM success which was acknowledged is the demand by clients to use BIM in projects. On the other hand, sceptic views to BIM success were based on the familiarity of project parties with the current CAD tools. Moreover, regressive mentalities in the construction industry and absence of public demand were also seen as reasons for unsuccessful implementation to BIM.

13.2.5. Objective four: To develop a prototype BIM-based system to manage knowledge in Kuwaiti public departments to overcome challenges arising in their BM projects

The KM prototype was developed based on the results obtained from the interview analysis. The prototype was named “Knowledge Management of Building Maintenance” (KMoBM). The main idea for the KM prototype is to assist BM employees located in different locations to share their knowledge through a web-based
KM system. This is done through facilitating the retaining of knowledge cases, organising the retained cases in a familiar taxonomy, simplifying the retrieval of similar solved problems, and facilitating locating experts.

The development processes of the prototype comprised of developing three modules: CBR module, a BIM module and a database module. The development of the CBR module is based on the Nearest-Neighbour function for measuring similarity between queries and stored knowledge cases. The similarity measuring process is based on matching values between query and case attributes. The case attributes were validated and weighted by potential users participating in focus group meetings. Eight BM professionals participated in the focus group meeting which assessed the attributes through the AHP concept.

The BIM module was developed to read files of BIM-based models, extract captured knowledge cases, index knowledge cases, and identify relationships between the retained cases. The database module was developed to allow users to use the prototype (if the BIM environment is not available) and add new knowledge cases. The module also provides several functions to surf for knowledge cases; it also allows users to search through the expert directory. By incorporating the KM principles embedded in the CBR module with the intelligent capabilities of BIM models, it was concluded that the transformation from ‘Building Information Modelling’ to ‘Building Knowledge Modelling’ can be achieved.

13.2.6. Objective five: To validate the developed BIM-based system through the process of evaluation by potential users working in the public BM sector in Kuwait

There are several methods to validate prototypes. In this research, potential users were invited to participate in a focus group meeting to evaluate the developed KM prototype. The participants were from organisations differ in size. Also, the experience of the participating professionals varied from trainee level to expert level. This step was taken to generalise the results of evaluation. Several predefined tasks were designed in the evaluation process to allow users to test the usability of the prototype functions. The tasks performed led to discussions between the participants.

Several recommendations were offered and most of which were taken into account in system modifications while others were useful for future developments. In general, the
evaluation results were positive with high overall score ratings. This indicated that the prototype is a valid and reliable KM system for BM.

13.2.7. **Objective six: To demonstrate the usage of the developed BIM-based system**

A case study method was used for prototype applications. This was done to demonstrate the functions of the KMoBM in the actual project. The researcher’s sponsor provided the sample project. However, due to the lack of a BIM models and environment, the researcher recreated part of the project for demonstration purposes. All the system functions were employed in the cases study and showed that they are working properly.

13.3. **Features of KMoBM**

KMoBM was developed to provide public BM departments with a useful tool to manage knowledge. This section highlights several features of KMoBM that can be useful to public BM departments:

- Providing a tool for minimise loss of project knowledge and avoiding the need to “reinvent the wheel” to solve problems in future projects.

- The prototype is developed in a clear and simple organisation for the use of BM professionals. As this approach requires minimal or no training, it encourages users to operate the prototype to share their knowledge.

- The prototype resolves location barriers by providing users with an expert directory to aid professionals in communicating and locating assistance when required.

- The current handling of, recording of, and searching for BM related knowledge are paper based, which is inefficient and time consuming. This can be avoided through utilising the prototype to handle storage and retrieval of knowledge.

- The knowledge taxonomy adopted in KMoBM allows users a quick retrieval process which saves time in searching for specific knowledge.
• The CBR-based search provides users with similar case retrieval for a query. This approach saves time in finding solved cases similar to queried problem.

• KMoBM utilises BIM technology where knowledge is retained through linking related cases for better understanding of building history.

• KMoBM allows users to update and comment on a stored knowledge case to improve its interpretation.

• Given that managing maintenance projects is knowledge demanding work, knowledge build up in the prototype over time could enhance KMoBM features in assisting BM professionals handling of their works.

13.4. Limitations of the Research

Meeting the research aim and objectives involved specific research design and careful consideration of the procedures of executing the study stages. However, producing a perfect output is an impossible aim to achieve; hence this research has a number of constraints which are expressed as follows:

• The developed BM process map is based on opinions drawn from experts working in public BM departments in Kuwait. Therefore, the developed process map is limited to this sector.

• The developed prototype was based on data analysis obtained from a specific population sample, experts working in public BM departments in Kuwait. Moreover, the processes for KMoBM evaluation and knowledge case attributes validation and weighting were carried out by a sample from the same population. Therefore, the KMoBM prototype may need to be validated further in other sectors or countries.

• The developed prototype is limited to storage and retrieval of knowledge. Other knowledge management processes (i.e. knowledge creation, capturing,
validating and sharing) were considered and demonstrated merely for the purpose of understanding the context.

- KMoBM is only a prototype application. Therefore, its knowledge base may not be reliable to handle large archiving over time and this could slow down the running of the prototype. Moreover, further security tools (software and hardware) will be much needed whenever the prototype goes live on the internet.

- A number of cases were stored in the KMoBM knowledge base for the purposes of testing and demonstrating. However, to show the real potential of KMoBM, a knowledge build up with more knowledge cases based on realistic resolutions related to BM problems is required. This can be done through extracting and converting solved cases from paper based documents into electronic knowledge cases to be archived in the KMoBM.

13.5. Contribution to Knowledge

The findings from this research provide several contributions to the current body of literature. These contributions are as follows:

- Developing an innovative prototype that integrates case-based reasoning as a KM technique with BIM for building maintenance is an approach that can establish the transformation from ‘Building Information Modelling’ to ‘Building Knowledge Modelling’. This will open new research area to benefit from BIM technology and its use in the industry.

- Developing a process map for BM is a new contribution for public departments in Kuwait. By examining the developed BM process, several deficiencies related to KM were identified and several potential opportunities to undertake KM practices were also identified. Moreover, this research has presented a general indication of the current state of BIM implementation in the BM sector. Therefore, the developed BM process and the state of implementation of BIM contribute to the current practices on BM, BIM and KM in public departments in Kuwait.
13.6. Recommendations for Future Research

Several areas were identified in this research that could be further developed. Suggested areas include the following:

- Knowledge management covers many aspects in organisations such as processes, tools and technology. This research has shed light on such aspects and then focused on developing a KM prototype to be used in BM departments. The other aspects can be investigated in more depth to develop an implementation strategy for the developed prototype.

- Developing components to be integrated with KMoBM to improve the usability of the prototype. This includes integrating audio dictating options for knowledge retaining. Moreover, participants of the focus group who evaluated the prototype made several suggestions for improvement which include:
  - Adding an auto detecting feature of works while writing the description of a knowledge case.
  - Add the feature of reading from a scanner to the file attaching feature.
  - Spelling identification and correction feature.

- Improving the CBR-based search in terms of accuracy and speed. This could be done through integrating additional CBR concepts, such as inductive retrieval to work with the current similarity measuring formula. Also other techniques can be used to further adjust the weights of knowledge case attributes.

- Relationships between knowledge cases in KMoBM are based on the zonal relationships of building elements in BIM models. This approach for grouping can be investigated to improve relationships among knowledge cases.

- Further research is needed to investigate the improvement in performance when implementing BIM-based knowledge systems such as using key performance indicators.
References –


References


Construction and 6th CIB W102 Information and Knowledge Management in Building. 26 October 2011, Sophia Antipolis, France.


Chartered Surveyors (RICS). 7 September 2004, Leeds Metropolitan University: COBRA.


References


Appendix A – Interview Consent Form

Knowledge Management for Public Building Maintenance

- I will be fully debriefed about research nature, aim and expected contribution.
- All questions about the research will be satisfactorily answered.
- I understand that my participation will be voluntary.
- I am aware of my entitlement to refuse to participate or withdraw from the project at anytime, without providing any reason and without being penalised or disadvantaged in any way.
- I understand that my participation will be anonymous and I will not be identified in the research without my approval.
- I understand that personal and identifiable information will remain completely confidential.
- I am giving permission for the interview to be recorded/videotaped.
- I understand that data, information and views provided in the interview will be used for research purposes only.

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

I have read, understood and fully consent to all of the above and I agree to participate in the above titled PhD research project.

Participant…………………………….

Signature…………………………….

Date…………………………………

Researcher…………………………….

Signature…………………………….

Date…………………………………
Appendix B – Interview Sheet

• **Self-talk:** self-introduction, purpose of the interview

**General information**
- Name:
- Position:
- Organisation:
- Number of employees:
- Number of branches:
- Contracts per branch:

**BM process**
- Could you explain the process of BM works of your department?
- Could you modify the presented BM process diagram to match your process?
- How do you deal with BM projects in case of emergency? (Excluded processes and/or modified processes)

**KM in BM**
- KM strategy: do you have a strategy to capture, retrieve and manage knowledge?
- Knowledge gain: (How knowledge is gained in your organisation?)
- Knowledge share: (How knowledge is shared in your organisation?)

**Meetings**
- Does your department conduct meetings?
- Who are the parties participating in your meetings?
- What is the occurrence rate of your meetings?
- What are issues discussed in you meetings?
- How do you organise and archive your decisions made in meetings?
- How do you circle meeting minutes, and to whom?

**Technology**
- What is the employees’ level of knowledge for computer use?
- What are uses of computer in your department?
- Do you have a network between branches and head quarter?
- Do you and your branches have internet connectivity?
- Do you use FM management software?, if yes, what are its uses?
- Do you have a knowledge base to assist in decision making?
- How can your employees discuss problems?

**Perception towards KM**
- What do you think of lack of knowledge sharing between your employees?
- Do you think your employees are willing to share their knowledge?
- What do you think of proposing a KM system to facilitate knowledge sharing between employees?

**BIM implementation**
- Have you heard of BIM technology?
- What do you know about BIM?
- Has your department implemented BIM technology in BM projects?
- (If not) Why BIM concept hasn’t been implemented in your department?
- Do you think BIM technology will be implemented in Kuwaiti BM sector future?

⇒ *(Ask to participate for system validation, end of interview)*
Notes:
Appendix C – Conceptual BM Process

Start

Problem reporting from unit
1. Verbal
2. Written
1A

Approval from branch manager (within authorised budget). Otherwise top management approval.

Region A branch manager (nationwide administration)

Department general manager

Approval
5

Assessment request
2A

Approval for payment
10

Approval for payment
11

Approval for payment

End

Outsourced contractor

In-house team

Supplier

1. Calculating overall project budget.
2. Notifying contractor or in-house team of maintenance job.

1A

Problem reporting From maintenance team
1. Scheduled
2. Observed
1B

Civil Team
Mech. Team
Elect. Team

Finance division

1. Visiting site and evaluating problem.
2. Preparing job description with estimated quotes based on MTC contract pricings.

Assessment request
2B

Authorization from branch manager (within authorised budget), Otherwise top management approval.

Approval for payment
4A

Approval

1. Submitting a finalised detailed quote
2. Notifying contractor or in-house team of maintenance job.

Outsourced contractor

In-house team

Supplier

1. Supervising and observing work
2. Managing work between contractors

Carryout and completing work

Submitting a finalised detailed quote

1B

1B

1B

1B

1B

1B
Appendix D – Example of BM contract in Kuwait.
## الفهرس

### مقدمة
- نموذج المعلومات الخاصة بالمناقشة
- مستندات المناقصة

### المباني
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<tr>
<td>(ج)</td>
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### الوثائق
- الوثيقة 1-1: الإعلان أو الدعوة للمناقشة
- الوثيقة 2-1: التعليمات إلى المناقصين
- الوثيقة 3-1: العطاء والملحق
- الوثيقة 4-1: لائحة المعدات والآلات
- الوثيقة 5-1: لائحة جهاز المقاول
- الوثيقة 6-1: إقرار من المقاول عن أعماله في الكويت
- الوثيقة 7-1: نموذج الكفالة الأولية
- الوثيقة 8-1: نموذج الكفالة النهائية
- الوثيقة 9-1: صيغة العقد
- الوثيقة 10-1: كشف بيان مستندات العطاء
- الوثيقة 11-1: الإجراءات
يسن الله الرحمن الرحيم

يرجى من السادة المناقشين تعبئة هذا النموذج:

مناقصة رقم:

موضوعها:

<table>
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<th>رقم الفاكس</th>
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التلمس

رقم إيداع شراء مستندات المناقة

تنبيه إلى جميع المناقشين

العطاء غير قابل للإلغاء وغير مسموح بتقديم أي عروض بديلة ويجب التقيد بما جاء في مستندات المناقة.

اسم المناقص:

توقيع:

ختام:

tاريخ:

لجنة المناقشات المركزية

المستند (I) أصول المناقصة

صفحة رقم (ب) مناقصة رقم:
## مسندات المناقصة

المستند رقم (I) **أصول المناقصة**: ويتضمن الوثائق التالية:

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<tr>
<th>رقم</th>
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</thead>
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<td>الإعلان أو الدعوة للمناقصة</td>
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<tr>
<td>2-I</td>
<td>تعليمات إلى المناقصين</td>
</tr>
<tr>
<td>3-I</td>
<td>العطاء والملحق</td>
</tr>
<tr>
<td>4-I</td>
<td>لائحة المعدات والأدوات</td>
</tr>
<tr>
<td>5-I</td>
<td>لائحة جهاز المقاول</td>
</tr>
<tr>
<td>6-I</td>
<td>إقرار من المقاول عن أعماله في الكويت</td>
</tr>
<tr>
<td>7-I</td>
<td>نموذج الكفالة الأولية</td>
</tr>
<tr>
<td>8-I</td>
<td>نموذج الكفالة النهائية</td>
</tr>
<tr>
<td>9-I</td>
<td>صيغة العقد</td>
</tr>
<tr>
<td>10-I</td>
<td>كشف بيان مسندات العطاء</td>
</tr>
<tr>
<td>11-I</td>
<td>الإجراءات (إن وجدت)</td>
</tr>
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المستند رقم (II) **شروط العقد**: ويتضمن الوثائق التالية:

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<td>الشروط العامة (الشرعية القانونية لسنة 1971 طبعة يناير 2003) وما يطرأ عليها من تعديلات حتى تاريخ إقالة المناقصة</td>
</tr>
<tr>
<td>2-II</td>
<td>الشروط الخاصة من القانون المناقصات العامة (الساري المفعول)</td>
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المستند رقم (III) **شروط الفنية**: ويتضمن الوثائق التالية:

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<th>الوثيقة</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-III</td>
<td>المواصفات العامة للمباني والأشغال الهندسية العائدة لوزارة الأشغال العامة (السنة 1990) وما يطرأ عليها من تعديلات حتى تاريخ إقالة المناقصة</td>
</tr>
<tr>
<td>2-III</td>
<td>المواصفات الخاصة (3 مجلدات)</td>
</tr>
<tr>
<td>3-III</td>
<td>المخططات (3 أجزاء)</td>
</tr>
<tr>
<td>4-III</td>
<td>جداول الكميات وجداول الأسعار (3 مجلدات)</td>
</tr>
<tr>
<td>5-III</td>
<td>الملاحق</td>
</tr>
<tr>
<td>6-III</td>
<td>المتطلبات الفنية (إن وجدت) وآية تعليمات يصدرها صاحب العمل.</td>
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</tbody>
</table>

المستند رقم (IV) **مواصفات العامة لأنظمة السلامة**: ** الصفحة رقم (ج) **

## Appendix D: Example of BM contract in Kuwait

The document contains a list of documents that constitute the bid document in Kuwait. It includes the announcement or invitation to tender, instructions to the bidders, offer, equipment sheet, inspection body, Kuwaiti inspectors, approvals by the Kuwaiti authorities, approval of the contractor’s work in Kuwait, first draft guarantee, final guarantee, contract delivery, contractor’s statement, contractor’s guarantees, contract delivery (if any), and the tendering documents (if any).
Appendix E – AHP Meeting Consent Form

Usability testing and AHP attribute weighting for Knowledge Management of Building Maintenance system (KMoBM)

- I have been fully debriefed about the workshop’s nature, aim and expected contribution.
- All questions about the workshop were satisfactorily answered.
- I understand that my participation is voluntary.
- I am aware of my entitlement to refuse to participate or withdraw from the workshop at anytime, without providing any reason and without being penalised or disadvantaged in any way.
- I understand that my participation will be anonymous and I will not be identified in the workshop without my approval.
- I understand that personal and identifiable information will remain completely confidential.
- I have agreed to respect the confidentiality of identifiable information, discussions and personal views expressed in the workshop.
- I am giving permission for the workshop to be recorded/videotaped.
- I understand that data, information and views expressed in the workshop will be used for academic research purposes only.

I have read, understood and fully consent to all of the above and I agree to participate in the above titled workshop.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
</table>

Researcher

Signature

Date
Appendix F – AHP Workshop Form

Knowledge case attribute validating and weighting for KMoBM system

<table>
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<th>معلومات شخصية</th>
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<td>1. الإسم: ……………………………………….</td>
</tr>
<tr>
<td>2. Position:……………………………………………………………………………..</td>
<td>2. المسمى الوظيفي: ……………………………………..</td>
</tr>
<tr>
<td>3. Years of experience:………………………………………………………………..</td>
<td>3. عدد سنوات الخبرة: …………………………………………..</td>
</tr>
<tr>
<td>4. Computer usage at work:……………………………………………………………..</td>
<td>4. استخدام الحاسب الآلي في العمل: …………………………………………..</td>
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<tr>
<td>(Hours/week)</td>
<td>(ساعة بالاسبوع)</td>
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</table>

<table>
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<tr>
<th>Details of the organisation</th>
<th>معلومات عن المؤسسة التي تعمل بها</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Organisation:………………………………………………………………………..</td>
<td>1. المؤسسة: ………………………………………………………………..</td>
</tr>
<tr>
<td>2. Sector / Department:………………………………………………………………</td>
<td>2. القطاع / الإدارة: ………………………………………………………</td>
</tr>
<tr>
<td>3. Number of employees working in the maintenance sector:</td>
<td>3. العدد التقريبي للعاملين في قطاع الصيانة</td>
</tr>
<tr>
<td>□ 0-49 □ 50-249 □ More than 250</td>
<td>□ أكثر من 250</td>
</tr>
<tr>
<td>4. Number of maintenance branches:…………………………………………………... (Geographically)</td>
<td>4. عدد فروع الصيانة: …………………………………………………………..</td>
</tr>
</tbody>
</table>

AHP for attribute validating and weighting
The objective is to validate and weigh attributes of knowledge cases.

This part of the workshop has two tasks:

Task 1: validate the proposed attributes.

Task 2: weight attributes using Analytical Hierarchy Process (AHP) concept.

<table>
<thead>
<tr>
<th>المعيار</th>
<th>تفاصيل الظاهرة</th>
<th>فهرسة الظاهرة</th>
<th>نوع المبني</th>
<th>تفاصيل المشروع</th>
<th>المعيار</th>
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</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
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</tr>
</tbody>
</table>

مثال:

1. يمكن لأي معيار أن يأخذ الدرجة من 1 إلى 9
2. يأخذ المعيار الأول من 2 إلى 9 حسب درجة الأهمية مع المعيار الثاني
3. إذا تساوى المعيارين في درجة الأهمية تأخذ الدرجة 1
4. إذا قلت أهمية المعيار الأول عن المعيار الثاني تأخذ قيمة المعكوس الضريبي

Task 1

Participants will validate the proposed attributes based on the following criteria:

• Most influencing in distinguishing between knowledge cases.
• Eliminate attributes which do not have an effect on distinguishing between knowledge cases.
## Appendix F: AHP Workshop Form

### Group Details

<table>
<thead>
<tr>
<th>Group</th>
<th>Group name</th>
<th>Code</th>
<th>Attribute name</th>
<th>Description</th>
<th>Validated for case</th>
<th>Validated for CBR</th>
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</thead>
<tbody>
<tr>
<td>C1.</td>
<td>Project Details</td>
<td>SC1.</td>
<td>Date</td>
<td>Date of the knowledge case.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SC2.</td>
<td>Client Name</td>
<td>Name of beneficiary unit.</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>SC3.</td>
<td>Contractor Name</td>
<td>Name of contractor undertaking maintenance works.</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>SC4.</td>
<td>Address</td>
<td>Location of the building.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SC5.</td>
<td>Governorate</td>
<td>Name of province.</td>
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<td>SC6.</td>
<td>Project name</td>
<td>Name of the maintenance project.</td>
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<td>SC8.</td>
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<td>Concrete, wood, steel, combined</td>
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<td>SC19.</td>
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<td>Maintenance category that captures author’s interest</td>
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<tr>
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<td>Contact number.</td>
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<td></td>
<td>SC21.</td>
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<td>Contact email.</td>
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### Knowledge Case Details

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<tbody>
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<tr>
<td>SC5.</td>
<td>Author Details</td>
</tr>
</tbody>
</table>

### Knowledge Case Indexing

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1.</td>
<td>Project Details</td>
</tr>
<tr>
<td>SC5.</td>
<td>Author Details</td>
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</table>

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<td>SC5.</td>
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<td>SC5.</td>
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</table>

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<td>SC5.</td>
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<tr>
<td>SC5.</td>
<td>Author Details</td>
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</table>

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<th>Description</th>
</tr>
</thead>
<tbody>
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<td>Project Details</td>
</tr>
<tr>
<td>SC5.</td>
<td>Author Details</td>
</tr>
</tbody>
</table>
Appendix F: AHP Workshop Form

<table>
<thead>
<tr>
<th>Are there any other attributes to be added to the group?</th>
<th>هل هناك أي سمات أخرى يمكن أن تضاف إلى المجموعات؟</th>
</tr>
</thead>
</table>

Task 2

In this task, Analytical Hierarchy Process (AHP) concept is implemented to weight the validated attributes of knowledge cases.

Criteria for weighting: Most influencing in distinguishing between knowledge cases.

Alternatives: Knowledge case groups and individual attributes.

<table>
<thead>
<tr>
<th>الشرح</th>
<th>التعريف</th>
<th>مدى الأهمية</th>
</tr>
</thead>
<tbody>
<tr>
<td>يساهم الشغف بنفس المقدار للهدف (النشاط متساويان من حيث الأهمية بالنسبة للهدف)</td>
<td>متساويان في الأهمية</td>
<td>1</td>
</tr>
<tr>
<td>الخبرة والتقدير يفضلان نقطة على الآخر بدرجة بسيطة</td>
<td>أهمية معتدلة</td>
<td>3</td>
</tr>
<tr>
<td>الخبرة والتقدير يفضلان نقطة نقاطاً على الآخر</td>
<td>أهمية كبيرة</td>
<td>5</td>
</tr>
<tr>
<td>نشاط يفضل نقطة تأثرة بدرجة كبيرة جدا، أهميته توضحها الممارسة</td>
<td>أهمية كبيرة جدا</td>
<td>7</td>
</tr>
<tr>
<td>الدليل على تفاصيل نشاط تأثرة بآخر يجعل أمانة درجة ممكنية من التأكيد لتصبح</td>
<td>أهمية قصوى</td>
<td>9</td>
</tr>
<tr>
<td>إذا كان النشاط س له إحدى القيم الصحيحة أعلاه عندما يكون النشاط ص حيترد يأخذ النشاط ص مقبول تلك القيمة حينما يقارب بالنشاط س</td>
<td>مقلوب القيم أعلاه</td>
<td>8, 6, 4, 2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>مقرب القيم أعلاه</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>1/5</td>
<td></td>
</tr>
<tr>
<td>1/7</td>
<td></td>
</tr>
<tr>
<td>1/9</td>
<td></td>
</tr>
</tbody>
</table>
Appendix F: AHP Workshop Form

Pairwise Comparison Criteria:

- Most influencing in distinguishing between knowledge cases.

1. CRITERIA GROUPS:

<table>
<thead>
<tr>
<th>Code</th>
<th>Group name</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1.</td>
<td>Project details</td>
</tr>
<tr>
<td>C2.</td>
<td>Building details</td>
</tr>
<tr>
<td>C3.</td>
<td>Case Indexing</td>
</tr>
<tr>
<td>C4.</td>
<td>Case details</td>
</tr>
<tr>
<td>C5.</td>
<td>Author details</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C1.</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Group name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1</td>
<td>Date</td>
</tr>
<tr>
<td>SC2</td>
<td>Client Name</td>
</tr>
<tr>
<td>SC3</td>
<td>Contractor Name</td>
</tr>
<tr>
<td>SC4</td>
<td>Address</td>
</tr>
<tr>
<td>SC5</td>
<td>Governorate</td>
</tr>
<tr>
<td>SC6</td>
<td>Project name</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>SC1</th>
<th>SC2</th>
<th>SC3</th>
<th>SC4</th>
<th>SC5</th>
<th>SC6</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. ATTRIBUTES: Group (C1.)
3. **ATTRIBUTES: Group (C)**

<table>
<thead>
<tr>
<th>Code</th>
<th>Attribute name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC7</td>
<td>Building type</td>
</tr>
<tr>
<td>SC8</td>
<td>Structure type</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>SC7</th>
<th>SC8</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SC8</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

4. **ATTRIBUTES: Group (C3)**

<table>
<thead>
<tr>
<th>Code</th>
<th>Attribute name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC9</td>
<td>Category</td>
</tr>
<tr>
<td>SC10</td>
<td>Section</td>
</tr>
<tr>
<td>SC11</td>
<td>Sub-Section</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>SC9</th>
<th>SC10</th>
<th>SC11</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC9</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC10</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SC11</td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
5. **ATTRIBUTES: Group (C4)**

<table>
<thead>
<tr>
<th>Code</th>
<th>Attribute name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC12</td>
<td>Topic</td>
</tr>
<tr>
<td>SC13</td>
<td>Issue/Problem</td>
</tr>
<tr>
<td>SC14</td>
<td>Reaction/Solution</td>
</tr>
<tr>
<td>SC15</td>
<td>Keywords</td>
</tr>
<tr>
<td>SC16</td>
<td>Element</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>SC12</th>
<th>SC13</th>
<th>SC14</th>
<th>SC15</th>
<th>SC16</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC12</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC13</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC14</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC15</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SC16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

6. **ATTRIBUTES: Group (C5)**

<table>
<thead>
<tr>
<th>Code</th>
<th>Attribute name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC17</td>
<td>Author’s Name</td>
</tr>
<tr>
<td>SC18</td>
<td>Author’s Position</td>
</tr>
<tr>
<td>SC19</td>
<td>Knowledge Interest</td>
</tr>
<tr>
<td>SC20</td>
<td>Phone</td>
</tr>
<tr>
<td>SC21</td>
<td>Email</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>SC17</th>
<th>SC18</th>
<th>SC19</th>
<th>SC20</th>
<th>SC21</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC17</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC18</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC19</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC20</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SC21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
Your participation is highly appreciated, thank you very much.

مشاركتكم محل تقدير كبير ، شكرًا جزيلا.
Appendix G – Example of AHP results calculations

The first step to obtain Eigen vector of weights is by summing the values of each column in Table 8-8. The summing result is:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C1.</td>
<td>1</td>
<td>0.301</td>
<td>0.462</td>
<td>0.325</td>
<td>5.575</td>
</tr>
<tr>
<td>C2.</td>
<td>3.318</td>
<td>1</td>
<td>1.426</td>
<td>0.360</td>
<td>6.126</td>
</tr>
<tr>
<td>C3.</td>
<td>2.163</td>
<td>0.701</td>
<td>1</td>
<td>0.373</td>
<td>4.61</td>
</tr>
<tr>
<td>C4.</td>
<td>3.078</td>
<td>2.776</td>
<td>2.683</td>
<td>1</td>
<td>7.26</td>
</tr>
<tr>
<td>C5.</td>
<td>0.179</td>
<td>0.163</td>
<td>0.217</td>
<td>0.138</td>
<td>1</td>
</tr>
<tr>
<td>Sum</td>
<td>9.738</td>
<td>4.941</td>
<td>5.788</td>
<td>2.196</td>
<td>24.571</td>
</tr>
</tbody>
</table>

The second step involves dividing each score in the matrix with the sum of its column. The result is:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C1.</td>
<td>0.103</td>
<td>0.061</td>
<td>0.080</td>
<td>0.148</td>
<td>0.227</td>
</tr>
<tr>
<td>C2.</td>
<td>0.341</td>
<td>0.202</td>
<td>0.246</td>
<td>0.164</td>
<td>0.249</td>
</tr>
<tr>
<td>C3.</td>
<td>0.222</td>
<td>0.142</td>
<td>0.173</td>
<td>0.170</td>
<td>0.188</td>
</tr>
<tr>
<td>C4.</td>
<td>0.316</td>
<td>0.562</td>
<td>0.464</td>
<td>0.455</td>
<td>0.295</td>
</tr>
<tr>
<td>C5.</td>
<td>0.018</td>
<td>0.033</td>
<td>0.037</td>
<td>0.063</td>
<td>0.041</td>
</tr>
<tr>
<td>Sum</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The following step comprises of calculating the normalised Eigen vector through obtaining the average across the rows. The result is:
The following step is calculating Consistency Index (CI) judgements. This is done by employing formulas illustrated in section 8.7.2.2. Therefore, the following is performed to calculate the maximal Eigen value $\lambda_{\text{max}}$ to lead to obtaining the Consistency Index (CI). Coyle (2004) illustrated the steps of calculating $\lambda_{\text{max}}$. For this study $\lambda_{\text{max}}$ is obtained through the following steps:

1. Summation of products between judgments and Eigen vector, leading to a new vector. The calculations between first row of judgments is:

\[(1 \times 0.124) + (0.301 \times 0.241) + (0.462 \times 0.179) + (0.325 \times 0.418) + (5.575 \times 0.038) = 0.629\]

The remaining four rows are (1.292, 0.949, 2.226, and 0.196).

2. Dividing each value of (0.629, 1.292, 0.949, 2.226, and 0.196) by the corresponding Eigen vector (0.124, 0.241, 0.179, 0.418, and 0.038). This gives 0.629/0.124 = 5.073. values of the other values are (5.372, 5.303, 5.320, and 5.104).

3. Calculating the mean of the above values gives:

\[(5.073+5.372+5.303+5.320+5.104)/5 = 5.24. \text{ Therefore, the value of } \lambda_{\text{max}} = 5.232\]
4. CI is calculated from 
\[ \text{CI} = \frac{\lambda_{\text{max}} - n}{n-1} \]

Since \( n = \) number of criteria (5). Consequently, \( \text{CI} = \frac{5.235 - 5}{5 - 1} = 0.0593 \)

5. The final step is calculating Consistency Ratio (CR).

\[ CR = \frac{CI}{RI} \]

Where: \( RI = \) Random consistency index.

\( RI \) is obtained from the following table provided in Saaty (Saaty, 1987).

Table 0-1: Random consistency index (RI) (Saaty, 1987).

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

As a result, \( CR = \frac{0.0593}{1.12} = 0.0529 = 5\% \)

Therefore, according to Saaty (Saaty, 1987), the consistency for judgments depicted in Table 8-10 (5\%) is accepted since it is less than the limit of 10\%. 
Appendix H – Workshop for Usability Testing to Evaluate KMoBM System

Plan of the workshop:

• Workshop demonstration
The demonstration of the workshop will consist of research aim and objectives, the process of BM, where the capturing and retrieving of knowledge can take place in the BM process. The demonstration will then show the aim of the KMoBM system, main parts of the system and how it links the BIM and CBR. Next, a series of tasks will take place to evaluate the usability of the KMoBM prototype. Following each task, participants are asked to answer several questions to rate the system.

• Tasks
The scenarios of tasks are based on real-life activities to be carried out by professionals when using the system. The system prototype has three major parts: browsing, retrieving and retaining. The browse section includes three categories: legal, technical and administrative and each category has several sections and sub-sections. The retrieve section is based on the CBR retrieval for knowledge cases stored in database. The third section has the role of retaining cases in knowledge base. This section includes two functions: case retaining though BIM and manual case retaining.

Therefore, the part of system evaluation during the workshop has three tasks. Each of which has been planned to test a single area of the system. The tasks are organised in a way to show participants the capturing and retrieving lifecycle of knowledge cases. Therefore, it was decided that the tasks would be organised as follows: retaining cases, retrieving cases and browsing for cases.
### Usability testing to evaluate KMoBM system

#### Personal information

<table>
<thead>
<tr>
<th>معلومات شخصية</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Name:</strong> ………………………………………………………………………………………………………….</td>
</tr>
<tr>
<td><strong>2. Position:</strong> ……………………………………………………………………………………………………</td>
</tr>
<tr>
<td><strong>3. Years of experience:</strong> …………………………………………………………………………………………..</td>
</tr>
<tr>
<td><strong>4. Computer usage at work:</strong> ……………………………………………………………….. (Hours/week)</td>
</tr>
</tbody>
</table>

#### Details of the organisation

<table>
<thead>
<tr>
<th>معلومات عن المؤسسة التي تعمل بها</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Organisation:</strong> …………………………………………………………………………………………………</td>
</tr>
<tr>
<td><strong>2. Sector / Department:</strong> …………………………………………………………………………………………</td>
</tr>
</tbody>
</table>
| **3. Number of employees working in the maintenance sector:**  
  - 0-49  
  - 50-249  
  - More than 250  
  - More than 250 |
| **4. Number of maintenance branches:** …………………………………………………………………………………….. |

(Geographically)
**Part 1: Usability testing for the KMoBM system**

### Task 1: Process of knowledge case retaining

#### 1. Manually:
- **a.** To add a realistic case and its details.

#### 2. Through BIM:
- **a.** Due to licencing restrictions, only one machine has the Revit software. Therefore this part of the task is demonstrated to through a projector. This part includes assigning element properties (the knowledge case fields), exporting the file through IFC format and uploading the file to the system.

#### Process of Knowledge Case Retaining:

Please rate the KMoBM system in terms of the following:

<table>
<thead>
<tr>
<th>Process of Knowledge Case Retaining</th>
<th>[ ]</th>
<th>[ ]</th>
<th>[ ]</th>
<th>[ ]</th>
<th>[ ]</th>
<th>[ ]</th>
</tr>
</thead>
</table>
| The ease of case retaining (Through BIM). | 5   | 4   | 3   | 2   | 1   | KMoBM��統
| The ease of case retaining (manually). |     |     |     |     |     | 1. 1
| The ease of knowledge capturing as soon as it has been recognised. |     |     |     |     |     | 2. 2
| The comprehensiveness of details of knowledge cases to be retained. |     |     |     |     |     | 3. 3
| The comprehensiveness of details of knowledge cases to be retained. |     |     |     |     |     | 4. 4

How can this section be improved?

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**Appendix H: Workshop for Usability Testing to Evaluate KMoBM System**
### Task 2: Process of knowledge case retrieving

<table>
<thead>
<tr>
<th>Arabic</th>
<th>إن الالات العامل لأستيراج حالات المعرفة</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. In this task, a problem is described in the CBR box that is related to the case that has been retained in the previous task.</td>
<td>1. في هذا الجزء سيتم إدخال شرح لمشكلة في خانة ال CBR و تكون متعلقة لحالة المعرفة التي تم حفظها في الجزء السابق.</td>
</tr>
<tr>
<td>2. In this task, case attributes are briefly explained of how the weight of attributes can affect distinguishing between knowledge cases.</td>
<td>2. في هذا الجزء سيتم تقدير شرح موجز لمدى تأثير تقل الخصائص في التمييز بين حالات المعرفة.</td>
</tr>
</tbody>
</table>

### Process of Knowledge Case Retrieving:

<table>
<thead>
<tr>
<th>Arabic</th>
<th>إن الالات العامل لأستيراج حالات المعرفة:</th>
</tr>
</thead>
</table>

Please rate the KMoBM system in terms of the following:

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Very poor 1</th>
<th>Neutral 3</th>
<th>Excellent 5</th>
</tr>
</thead>
</table>

1. The process for knowledge case retrieving using CBR.
2. Presentation and organisation of knowledge details.

How can this section be improved?

<table>
<thead>
<tr>
<th>Arabic</th>
<th>كيف يمكن تحسين هذا القسم؟</th>
</tr>
</thead>
</table>
Appendix H: Workshop for Usability Testing to Evaluate KMoBM System

Task 3: Process of knowledge case browsing

1. To examine the taxonomy of knowledge.
2. To navigate for a saved case in the system.

Process of Knowledge Case Browsing:

Please rate the KMoBM system in terms of the following:

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Very poor</th>
<th>Neutral</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

1. Taxonomy of categories, sections and subsections for knowledge base.
2. The ease of locating a desired knowledge case.
3. The ease of locating a desired professional’s details.

How can this section be improved?
Appendix H: Workshop for Usability Testing to Evaluate KMoBM System

Overall rating of KMoBM system:

<table>
<thead>
<tr>
<th>KMoBM:</th>
<th>KMoBM</th>
</tr>
</thead>
</table>

Please rate the overall KMoBM system in terms of the following:

<table>
<thead>
<tr>
<th>Ranking</th>
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<th>Neutral</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

1. Ease of use.
2. Organisation of the KMoBM system.
3. Efficiency in reducing additional workload.
4. Expected improvement of knowledge sharing between employees.
5. Expected improvement of communication between employees.
6. Expected level of reuse of captured knowledge in same or another project.

What are main strengths of the system?

What are main weaknesses of the system?
Your participation is highly appreciated, thank you very much.