DEVELOPMENT OF A LESSONS LEARNED MANAGEMENT PROCESS MODEL AND A WEB-BASED TOOL FOR CONSTRUCTION COMPANIES

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ABSTRACT

DEVELOPMENT OF A LESSONS LEARNED MANAGEMENT PROCESS MODEL AND A WEB-BASED TOOL FOR CONSTRUCTION COMPANIES

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Organizational memory formation and its effective utilization is a source of competitive advantage especially in project-based industries such as construction industry as it may eliminate potential problems in projects leading to higher profitability and less errors. However, project-based nature also poses challenges for establishing organizational memory as it is hard to capture knowledge of temporary project teams and transfer different types of knowledge between projects. This study presents a “Lessons Learned Management Process Model (LLMPM)” to capture experiences that may be acquired during project execution and disseminate this knowledge within the company to improve performance in future projects. A web based IT tool (LinCTool) that utilizes the proposed process model, has been developed in this study to capture, store and disseminate lessons learned. Expert review meetings with participants from both academy and the private sector have been carried out to develop LLMPM. Black-box testing method has been used to verify the LinCTool, and interviews have been conducted with four experts to test its usability. Results show that the proposed model and LinCTool have a potential to solve problems related with lessons capture and retrieval, and could be effectively used in medium to large size construction companies.

Keywords: Construction Industry, Lessons Learned Management, Organizational Learning, Process Model, Web Based Tool

ÖZ

İNŞAAT FİRMALARI İÇİN ÖĞRENİLEN DERS YÖNETİMİ SÜREÇ MODELİ VE WEB TABANLI ARAÇ GELİŞTİRİLMESİ

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Örgütsel hafıza geliştirilmesi ve bunun etkin bir şekilde kullanılmasının sağlanması özellikle inşaat sektörü gibi proje bazlı endüstrilerde, projelerde oluşabilecek potansiyel problemlerin ortadan kaldırılmasına yardımcı olarak daha yüksek karlılık ve daha az hatayla işlerin tamamlanmasına imkân sağlayabileceği için şirketlere rekabet avantajı sağlar. Bunun yanında, endüstrinin proje bazlı yapısı örgütsel hafızanın kurulması konusunda zorluklara neden olmaktadır. Bunun nedeni geçici olarak oluşturulan proje ekiplerinden bilginin yakalanmasının ve değişik bilgi türlerinin projeler arasında aktarılmasının güç olmasıdır. Bu çalışma, proje süresince edinilen deneyimlerin yakalanması ve yakalanan bu bilginin şirket içerisinde paylaşılarak diğer projelerde performansı arttıracak şekilde kullanılmasına olanak sağlayacak “Öğrenilen Ders Yönetimi Süreç Modeli” (ÖDYSM) sunmaktadır. Bu çalışmada, önerilen süreç modelini kullanarak bir şirketin öğrenilen derslerini yakalamak, depolamak ve şirket içinde paylaşılmasına olanak sağlayacak LinCTool olarak adlandırılan web tabanlı bir bilgi teknolojileri aracı geliştirilmiştir. ÖDYSM geliştirilmesi için akademiden ve özel sektörden uzmanların görüşlerinin alındığı toplantı düzenlenmiştir. LinCTool'u doğrulamak için kara kutu test yöntemi kullanılmış ve gerçek inşaat projelerinde LinCTool'un kullanılabilirliğini tespit etmek için 4 uzmanla görüşmeler yapılmıştır. Sonuçlar önerilen modelin ve LinCTool'un derslerin kaydedilmesi ve tekrar kullanılması ile ilgili problemleri çözme potansiyeline sahip ve orta-büyük ölçekli inşaat şirketlerinde etkili bir şekilde kullanılabileceğini göstermektedir.

Anahtar Kelimeler: İnşaat Sektörü, Öğrenilen Ders Yönetimi, Örgütsel Öğrenme, Süreç Modeli, Web Tabanlı Araç

Dedicated to my lovely niece Defne

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LIST OF ABBREVIATIONS

AAR	After Action Review
BI	Business Intelligence
BIM	Building Information Modeling
CAD	Computer-Aided Design
CAPRIKON	Capture and Reuse of Project Knowledge in Construction
CBR	Case-Based Reasoning
CLL	Corporate Lessons Learned
CLLD	Constructability Lessons Learned Database
CMAID	A Lessons Learned System in Construction Management Practices
COLA	Cross-Organizational Learning Approach
COML2	Constructability, Operability, and Maintainability Lessons Learned
COPPMAN	Construction Project Portfolio Management
DrChecks	Design Review Checking System
DTI	Department of Trade and Industry
EPC	Engineering, Procurement and Construction
ERP	Enterprise Resource Planning
ICT	Information and Communication Technology
IKIS	Interactive Knowledge-Intensive System
ISDN	Integrated Services Digital Network
IT	Information Technology
KM	Knowledge Management
KPfC	Knowledge Platform for Contractors
KyTC	Kentucky Transportation Cabinet
LinCTool	Learning in Construction Tool
LLG	Lessons-Learned Generator

LLMPM	Lessons-Learned Management Process Model
OKBank	Organizational Knowledge Bank
OLAP	On-Line Analytical Processing
OLM	Organizational Learning Mechanism
UK	United Kingdom
US	United States
PPR	Post-Project Review
SQL	Structured Query Language
SSL	Secure Sockets Layer
TÜBİTAK	The Scientific and Technological Research Council of Turkey

CHAPTER 1

INTRODUCTION

This chapter gives an introductory information about the study and presents the research background, objectives, scope, methodology, and outline of the thesis.

1.1. Research Background

Being a project-based industry, a unique product is developed through construction activities; therefore, construction industry significantly differs from manufacturing industry where a similar product is repetitively produced. Thus, the industry cannot reap the benefits of this kind of mass production and it becomes hard to reach an optimized production process within the construction industry. Construction industry is a project and knowledge based industry, and that makes construction companies to compete generally based on their service quality and extent of knowledge gained in the area. It is a widely accepted idea that, although vast amount of knowledge is gained during projects, companies can hardly manage and utilize accumulated knowledge in forthcoming projects. (Alashwal and Abdul-Rahman 2014; Fong 2005). The knowledge is generally lost by ending of the projects and companies cannot learn from their experiences. This situation leads similar problems to be encountered or prevents best practices to be repeated in the forthcoming projects Construction companies need to effectively use their resources within today's competitive environment, and this need makes learning and knowledge management issues critically important for the construction companies (Öztürk et al. 2016; Puddicombe 2006). Therefore, the companies need a system that would enable the sharing of knowledge between the employees and adoption of organizational learning principles within the company (Alashwal and Abdul-Rahman 2014; Fong 2005). Through organizational learning, companies may establish their own knowledge assets and with the use of this asset they may foster their performances and gain competitive advantage (Chinowsky et al. 2007; Love et al. 2015; Öztürk et al. 2016).

Learning is simply defined as share of knowledge obtained through transformation of experiences (Love et al. 2015). The learning effect is observed as a decrease in the time and effort required in repetitive works (Srour et al. 2016). Thus by enabling learning from projects, a knowledge created during the course of a project may be accumulated in the corporate memory and may stay alive for use in the forthcoming projects (Alashwal and Abdul-Rahman 2014; Öztürk et al. 2016). It is obvious that the individuals play crucial role in learning and their tacit knowledge should be the core concern within the companies. Companies learn through experiences and actions of individuals; they are the central bodies for acquirement, accumulation and dissemination of the knowledge within the companies (Fong 2005). Thus, learning in a company starts at the individual level and then, it is transferred to organizational level (Kiomjian et al. 2016; Love et al. 2015). Therefore, construction companies need establishment of a learning culture through individuals to have such kind of knowledge asset.

The importance of learning and knowledge management in the construction industry have been appreciated (Abu Bakar et al. 2016; Chan et al. 2005; Love et al. 2000; Vakola and Rezgui 2000; Yang et al. 2014); however, it is not easy to achieve the required level of competency due to the culture and characteristics of the industry (Ford et al. 2000; Kivrak et al. 2008; McLaughlin et al. 2008; Steiner 1998; Tan et al. 2010). First of all, the industry is project and knowledge based and they are both centered on individuals. Every project requires different expertise so individuals working for projects or companies considerably change and their knowledge is lost by their leaving the company (Chinowsky et al. 2007; Hwang 2014). To overcome this issue, share of knowledge could be made by codification of knowledge rather than by personalization. By this way, a permanent corporate memory can be established and different employees working for different projects can get the chance to reach the captured knowledge (Alashwal and Abdul-Rahman 2014; Fong 2005). Another industry specific obstacle is the unique nature of the construction projects. Even if the projects have the same design; the external factors such as ground conditions, project teams, etc. always make them different in terms of execution and construction (Alashwal and Abdul-Rahman 2014; Fong 2005). Projects differ in macro terms; namely in terms of site, context, client requirements, etc.; however, they are similar in micro terms as in structure of teams, processes, tools, skills, etc. (Kamara et al. 2003). Therefore, the knowledge gained through one project can be used in the other as long as the link between the two projects can be established. The users need to filter the relevant knowledge within the corporate memory (Chinowsky et al. 2007; Fong 2005). Thus, lessons learned in projects should be captured and reused in the forthcoming ones by using a manageable format to manipulate, and a mechanism to capture and disseminate the knowledge (Graham and Thomas 2007; Kamara et al. 2003). In addition to the stated obstacles, employees are reluctant to share their knowledge due to the thought of "knowledge is power" and unavailability of enough time (Fong 2005). Thus, a system that will support this sharing culture is required. Finally, knowledge in construction industry easily becomes obsolete and this may create knowledge noise to be accumulated (Fong 2005). Therefore, an evaluation mechanism is required for the knowledge to keep it up-to-date and useful.

Knowledge management strategies can be grouped under two categories. First strategy depends on the people interactions and company culture to manage knowledge within the company. Second approach uses IT-tools to manage knowledge. First strategy is named as "knowledge management techniques" and second one is "knowledge management tools" (Al-Ghassani et al. 2005). Dikmen et al. (2008) name these strategies as "personalization strategy" and "codification strategy" respectively by referring to main objectives of the strategies. These two strategies are complementary to each other, and in order to establish effective knowledge management system, both concept should be considered and integrated to the system (Alavi and Denford 2012). Fundamentals of people interaction and user involvement should be established in the knowledge management system; however, companies need the support of knowledge management tools to meet technical and social requirements as capture, categorization, and dissemination of knowledge (Alashwal and Abdul-Rahman 2014; Chinowsky et al. 2007). Tools and techniques have been underway for establishment of effective knowledge management in terms of company databases, intranets and such; however, efforts have not provided a best solution for capture and share of the knowledge yet (Hari et al. 2004; Kamara et al. 2003; Kivrak et al. 2008; McCarthy et al. 2000). Thus, use of an effective tool may lead construction companies in the long run to generate a learning culture and establish their own corporate memories as a valuable asset that would enable them to prevent mistakes, increase safety, decrease rework and improve their best practices.

1.2. Research Objectives

The aim of the study is to develop of a model for knowledge management that can handle lessons learned in construction projects effectively. With this perspective, deliverables of this study are a lessons learned management process model (LLMPM) and its computer application which is a web-based tool. Thus, the objectives of the study are structured as development of a lessons learned management process model and a tool that have the following features:

1. There have to be well-structured user responsibility definitions that would help to implement the model in a real company,
2. A simple lessons learned capture method has to be developed to record tacit and explicit knowledge without omitting any parts of the lessons
3. A well-organized information flow shall be defined to easily manage lessons learned within the company

4. A flexible tool has to be developed to support establishment of a company specific lessons learned management system
5. The tool has be online to ease accessibility of the users to lessons learned management system
6. A method has to be found to interact with other IT-solutions to be able to access necessary documents
7. A codification system has to be generated to ease entry of lessons learned to the database
8. A tagging system has to be developed for effective classification and retrieval of lessons learned,
9. Different retrieval methods shall be available to increase reachability of the related lessons learned
10. An evaluation system is necessary to manage the lessons learned and to eliminate the useless knowledge
11. A flexible tool that makes it possible to define different types of users provided in the developed model as well as adjustable to company specific requirements has to be developed.

1.3. Scope of the Study

The study is based on an extensive literature review on lessons learned and knowledge management strategies. Literature review findings form the basis to identify requirements of a lessons learned management process model focusing on capture and re-use of lessons learned during the course of construction projects. Model is aimed to facilitate the capture, share and reuse of the “lessons learned”. From this perspective, development of a “lessons learned” capture form has been included within scope of the study. A tag tree, which can capture these “lessons learned” information in a structured form, is also defined as necessary in such a system and it is part of the thesis scope. A second literature review process on papers, books on construction management, and available standards is held to identify the context of the taxonomy required for the tag tree that is necessary to record “lessons learned” information on each phases for different project types. The taxonomy is structured so that it can be responsive to management and construction processes of different types of projects that would be undertaken by a construction company.

Sharing the “lessons learned” information is the reason to capture it and sharing mechanism is the main part of the process model and the tool. Knowledge sharing mechanism relies on the “knowledge-pull” in the developed model, which means that development of “knowledge-push” type sharing mechanisms are not included within scope. Parallel with the defined scope, filtering mechanism has been developed with the useful information defined in the knowledge capture mechanism. Additionally, a questionnaire study is held between Turkish construction company professionals to develop project “similarity” calculation method that is considered as useful as knowledge sharing mechanism in such a system.

Defining user types and their roles in the system is included within the scope to facilitate knowledge re-use. Relations and user roles within the system are defined to successfully implement the model and tool functions. Finally, the functions defined in the process model has been operationalized by the tool. Technical details of the coding of the tool in the computer environment have been identified and the tool has been developed together with an IT company within the scope of the TUBITAK project.

Suitability of the model and the tool to the real projects has been validated by company professionals within this study. Four company professionals from three different construction companies that are listed in ENR 250 list, participated in the validation study.

1.4. Research Methodology

This research is a part of TUBİTAK funded research project that is aimed to develop a tool that would support construction companies in managing construction project portfolios. Construction Project Portfolio Management Tool (COPPMAN) is a computer program that works as a decision support system, which is capable of portfolio formation, portfolio analysis, and portfolio selection processes in construction companies, improved with abilities of dependency analysis between projects and use of past project data. Starting point of this research can be stated as meeting the COPPMAN requirements in terms of past project information. In this perspective, literature review on project portfolio management has been conducted and main requirements of the knowledge management are defined in order to support COPPMAN in the project selection step. Knowledge management requirements in the COPPMAN is not only limited with the lessons learned management; however, it is appreciated that, lessons learned management functions can be provided as a separate tool with the minimum information requirements and simplicity which is made possible to implement it easily in companies. In this perspective, lessons learned management process model is developed separately but also responding to COPPMAN needs. Functions of the LLMPM are defined by the researchers who work in the research project with the help of literature review. A questionnaire survey has been done to acquire necessary information in terms of defining project similarities. Another literature review has been conducted to create a taxonomy that is used as tag tree in the LLMPM. Following that; lessons learned management process model is created that would respond to the objectives identified in the light of the research background presented. LLMPM has been presented to experts through the evaluation meeting and some of the functions are improved in accordance with the feedbacks given by experts. A tool named as LinCTool (Learning in Construction Tool) is designed as a lessons learned management module within the body of a construction project portfolio management tool (COPPMAN). COPPMAN is the IT part of a decision support system. Past project’s cost and duration information, lessons learned from past projects, risk and strategic fit evaluations are used in the purpose of achieving this support role in the construction companies. With the help of entered parameters, COPPMAN tool proposes best portfolio options according to profitability, risk minimization and company strategies. Expected benefits of the COPPMAN can be stated as helping to the company executives about the project selection step by considering relation between projects within the portfolio with giving tangible information. Codification of the tool is carried out by a software developer company. The tool is developed by an iterative process together with the software company. Finally, LinCTool is developed as a separate, stand-alone tool that can be used by construction companies for lessons learned management. The tool is provided in an online platform through the web address of https://www.linctool.com to foster its usability for companies and accessibility to researchers as well. Access to web interface is done through SSL (Secure Sockets Layer) connection to increase information security.

Considering the evaluation of LinCTool, its verification studies are completed through a black-box testing. Stability and correctness of the LinCTool functions have been tested by controlling the outputs according to predefined inputs. Usability test for the web interface has been conducted within the evaluation of COPPMAN tool, and separate web interface usability test with the eye tracker is not conducted for LinCTool because of the time and resource limitation. In addition to limitations, since COPPMAN and LinCTool have similar web designs, COPPMAN results provide information about LinCTool also.

Besides these, a separate validation study that completely focused on suitability, usability and completeness of the LinCTool is made by actual use of the tool by company professionals. Steps of the research is given in the Figure 1.1 briefly and details will be explained in the forthcoming parts of this thesis.

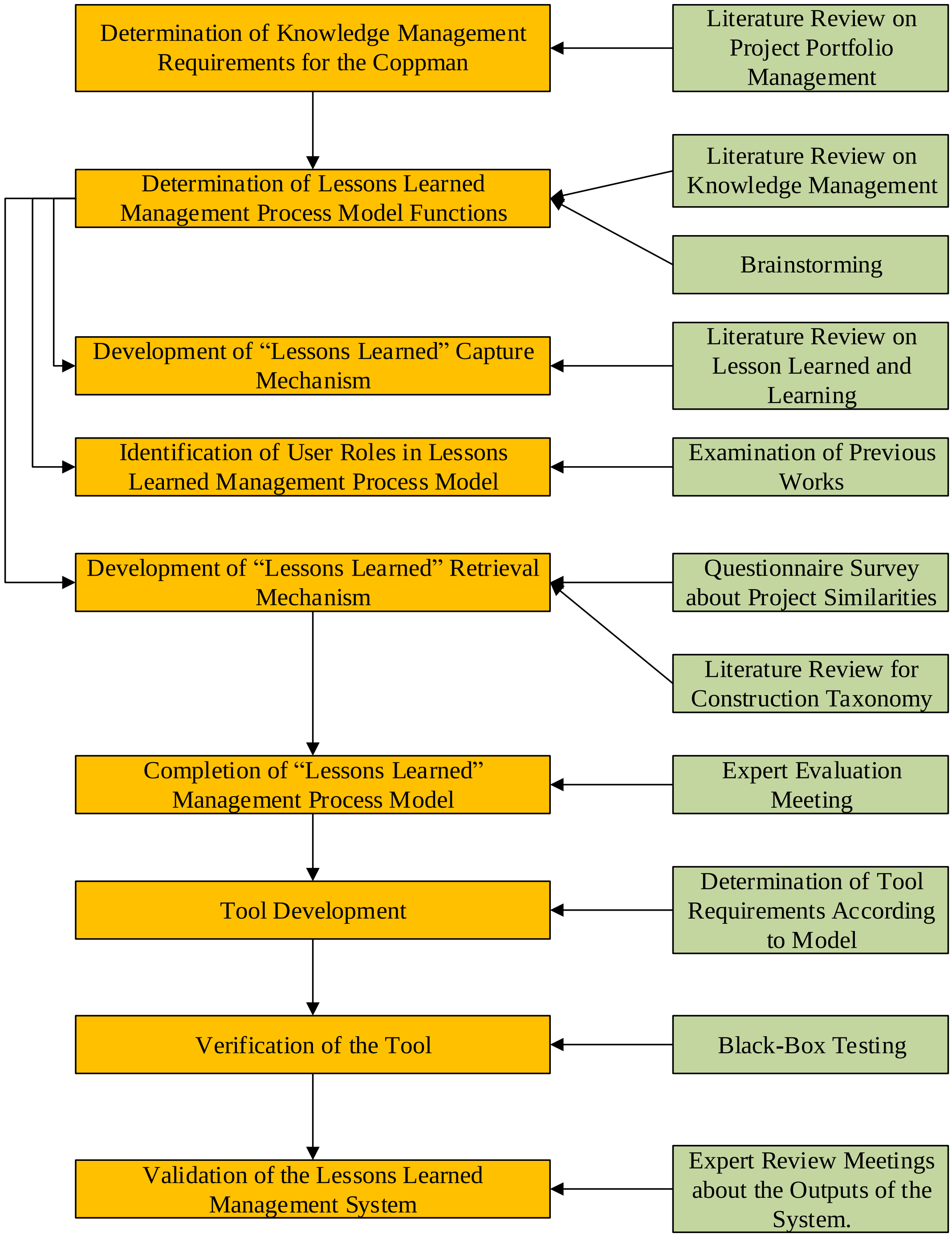


Figure 1.1: Steps of the Research

1.5. Organization of the Thesis

Chapter 2 presents the literature review on learning and knowledge management, which lays the foundations of the study. Chapter 3 presents a more specific literature review on lessons learned. Chapter 4 explains the details of the lessons learned management process model and its development. Chapter 5 introduces the tool by presenting its functions, process details and interfaces. Chapter 6 presents the methods followed for validation of the tool and its findings and finally; Chapter 7 concludes the study by discussing contributions and limitations of the study as well as recommendations for future work.

CHAPTER 2

ORGANIZATIONAL LEARNING AND KNOWLEDGE MANAGEMENT

In this chapter, the concept of “learning” is discussed by referring to an extensive literature survey. Literature review on two main topics as “Organizational Learning” and “Knowledge Management” is presented. The chapter starts with introduction to “Organizational Learning” and continues with “Knowledge” and its’ “Management”. Within this context; the knowledge with its definition, types and sources are presented first. After explaining what knowledge is, literature review on knowledge management is presented. Definition of knowledge management, why knowledge management is important for today’s world and processes of and strategies for knowledge management are introduced. Following presentation of knowledge management concept, its importance for the construction sector is discussed together with the types and sources of knowledge in the industry. Possible barriers for its effective implementation are discussed. The chapter is concluded with the literature review on the previous academic studies carried out regarding the construction industry.

2.1. Organizational Learning

The world is becoming more interconnected and the business is getting more complex and dynamic day by day. This situation makes the work to be handled more “learningful” and the organizations to be more learning focused (Senge 2006). Every company learns in a kind of way; however, the point with organizational learning is putting learning into strategy of the company and making it learning focused. Only with this strategy, a company can learn effectively. Organizations need to generate abilities to change and continuously restructure their business processes to survive. This ability to change and adaptation can be achieved by organizational learning (Opoku and Fortune 2010; Vakola and Rezgui 2000). Thus, organizational learning requires challenging the established norms with the focus on experience and the required systems, structures and actions to meet the changes. Simply, organizational learning is the "set of processes used to obtain and apply new knowledge, behavior, tools, and values" (Love et al. 2000). The definitions are generally focused "on the importance of acquiring, improving and transferring knowledge, facilitating and making use of individual learning and modifying behavior and practices to reflect the learning" (Love et al. 2000).

2.1.1. What is Organizational Learning?

Learning is in the nature of every humankind, every infant learns through its inquisitiveness. The most powerful learning originates by the direct experience. It is a trial and error process where someone takes an action and sees consequences of his/her action. Following that, they can repeat their action or take a new/different action. This constitutes the fundamentals of learning (Senge 2006). Individual learning can be defined in terms of personal skills and knowledge that are achieved through transformation of experiences into understandings (Hua and Chan 2013). Simply, learning is the "process of adjusting behavior in response to experience" (Opoku and Fortune 2010). So, the organizations can also learn since they are basically groups of people (Senge 2006). The behavior of an organization as a unique political combination, or an alliance, coalition, partnership, association etc. is rooted by various and conflicting experiences of people within the organization. Thus, behaviors are organized within an organization rather than people. Organizational rules (as standard operating procedures, routines, codes, programs, etc.) are the agreements to provide binding of these behaviors. These rules provide formation of the behaviors through affecting the interactions between the individuals that experience through the same organizational lens and draw lessons contributing to their learning. Thus, organizations learn through continuous change of experience of individuals to knowledge as organizational rules at the end of the processes of individual bargaining, compromising, or negotiating. These organizational rules constitute the organization's memory where the learnt organizational behavior is encoded and particular experiences are managed accordingly (Holmqvist 2003).

"Organizational learning" term was first referred by Cyert and March in their study in 1963 and has been an attractive field of research since then (Easterby-Smith and Lyles 2012; Holmqvist 2003). The idea behind organizational learning is that every individual has a mental model as a representation of his actions, thus by changing this model through learning, individuals and so organizations can change behavior to achieve better information processing and better decision making (Brandi and Elkjaer 2012). As Kululanga et al. (2001) define organizational learning in their study as "the systematic promotion of a learning culture within an organization such that employees at all levels, individually and collectively, continually increase their capacity to improve their level of performance". Thus organizational learning is mainly fostered by the change, more specifically through the strategic change (Chan et al. 2005).

Learning is the change in behavior, it means a positive change or more effective behavior (Spender 2008). Organizations need to focus on measuring this change as much as they consider development of learning capabilities to obtain benefits of organizational learning (Kululanga et al. 2001). However, sometimes it is difficult to measure learning since the organization may gain some cognitive resources that are not reflected to behavior (Fiol and Lyles 1985). Main indicator of learning for organizations are the "learning curves" as performance indicators that shows that unit cost of a production decreases with a decreasing rate as the organization continuous production for that specific product. Number of errors decreases as the experience is gained with the task (Argote 2013; Pentland 1995). In addition to learning curves that are based on number of direct labor hours spent per unit, different outcomes can be stated for measurement for organizational learning such as quality outcomes of complaints/defects per unit, number of late products per unit, etc. (Argote 2013). The actions that provide the organizations to do better what they are currently doing is structured under "adaptive learning" concept. There is also "generative learning" defined to meet the learning activities held for challenging and re-establishing the requirements and the ways undertaken for accomplishment of tasks (Chan et al. 2005).

An agreed definition of organizational learning is that it is "a change in the organization's knowledge that occurs as a function of experience" (Argote 2013). An organization gets experience as it performs its tasks and organizational learning occurs when this accumulated experience is converted to knowledge. Organization learning is the process of interpretation of experience by organizations and in the light of this, it is a means to improve organizational performance and to keep the organization adapted to its environment (Argote et al. 2012). Thus, "learning" is to be deemed as "organizational learning" as long as (Vakola and Rezgui 2000):

- it is performed to achieve organizational goals;
- it is shared or disseminated among members of the organizations; and
- learning outcomes (knowledge) are embedded in the systems, structures, and culture of the organizations.

Organizational learning is to be achieved by different methods. Between all, methods of training, programs, seminars, workshops, etc. constitute the "formal methods" for learning, whereas experience and mistakes can be deemed as "informal methods". The culture of the organization has a considerable impact on the level of organizational learning since it directs the creation, sharing and application of new knowledge and fostering of the learning focused values (Hua and Chan 2013). Organizational learning can occur at different levels as individual, group, organizational and inter-organizational. Individual learning is required for group and organizational learnings; however, it is not enough for organizational learning

(Argyris and Schon 1978; Love et al. 2000). Organizational learning is to be achieved when individual insights and skills are assimilated into organizational routines, practices and beliefs (Hua and Chan 2013). Thus, knowledge of the individuals need to be embedded in a non-human repository such as routines, structures, culture, and strategy and made available to use (e.g. transactive memory) to enable learning at higher levels (King et al. 2008; Love et al. 2000; Öztürk et al. 2016; Vera et al. 2012). Tools are required for easy acquisition, storage, and sharing of information, thus information technology and knowledge management systems are responsive means for increasing organizational learning (Argote 2013; Pentland 1995). Individuals can share their narratives on their practices through a discussion forum or a lessons learned database; and so their activities and views can be made explicit and thus the spatial, temporal, functional boundaries of their organizations can be overcome (Hayes 2012). Within this context, knowledge management practices enable use of the past as a means to structure the future (Spender 2008). Through an organizational memory, all the scattered information from different sources can be unified and knowledge of the past can be made alive in the current organizational activities as shared interpretations of the past. Simply, it is the map of organization's past (Argyris and Schon 1978; Casey 1997; Stein 1995). Thus, this valuable past knowledge becomes a strategic advantage/asset for the organization and can be used in making sense of the present by the organization (Easterby-Smith and Lyles 2012).

To summarize organizational learning concept, factors provided by Lipshitz et al. (2002) can be presented. The facets are identified and mapped in a conceptual model to introduce organizational learning concept to organizations. The facets, which are depicted in Figure 2.1, are as listed below:

- **Structural facet:** indicates what distinguishes the learning in the organizations and learning by the organizations. The facet refers to the organizational learning mechanisms (OLMs) that are either integrative where the person learns from his performance or non-integrative where the person learns from performance of others.

- **Cultural facet:** addresses the norms required for producing valid information and a commitment to corrective action. The norms are identified as follows:
  - transparency (revealing the thoughts and actions in order to receive feedback),
  - integrity (collecting and providing information regardless of implications, openness to failures and promotion of feedback),
  - issue orientation (focusing on relevance of information regardless of the social standing/rank of the recipient/source),
  - inquiry (persistence on investigation until establishing full understanding), and
  - accountability (responsibility for learning and implementation of lessons learnt).
- **Psychological facet:** is related with psychological safety that is required for making personnel willing to take the risks for learning; and also related with organizational commitment that is required for making personnel willing to share information and knowledge.
- **Policy facet:** identifies the formal and informal steps taken by senior management to foster organizational learning, and is related with organization's policies, rules, budgets, procedures, etc. Three main policies that are especially required for the facilitation of organizational learning are:
  - commitment to learning (e.g.; investments in education and training, installation of mechanisms and change in culture, experimentation and dissemination of information, recognition and reward systems, etc.),
  - tolerance for error (errors are not for punishment, they are to be valued as opportunities for learning), and
  - commitment to the workforce (e.g.; fair treatment of subordinates, employment security, etc.).
- **Contextual facet:** includes the external factors that are either indirectly controlled or not able to be controlled by the management. These factors can be listed as:

- error criticality (the immediacy and seriousness of the consequences of errors),
- environmental uncertainty (the rate of change and the level of competition in the environment),
- task structure (that has an effect on the feasibility of obtaining valid information and people's motivation to cooperate with colleagues),
- proximity to the organization's core mission (increases the likelihood that learning to be occurred within a particular task system), and
- leadership commitment and support (to establish successful change).

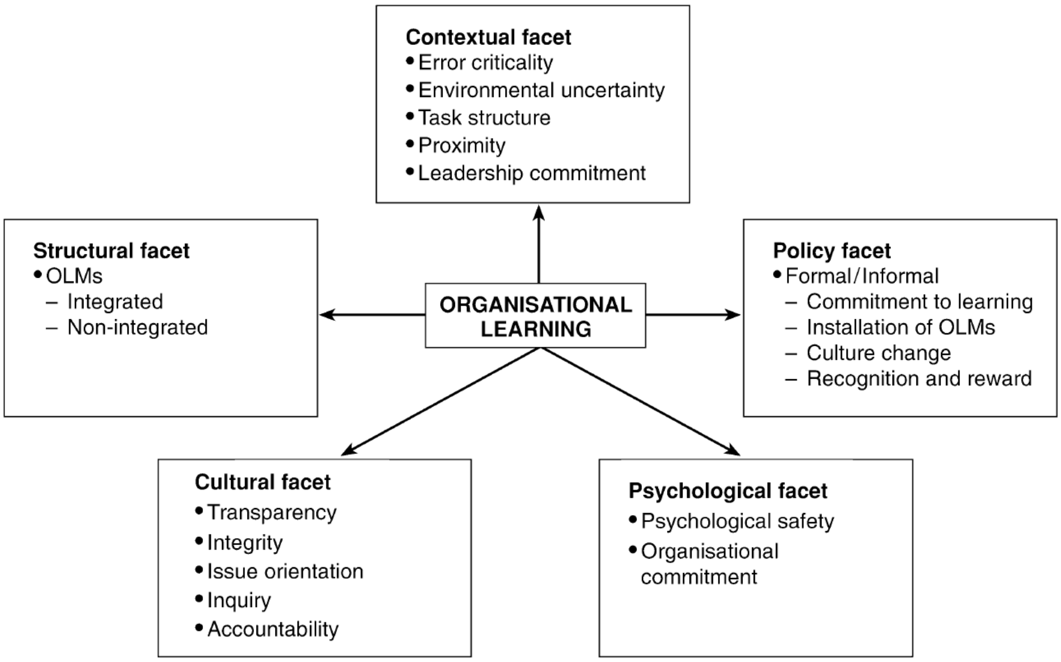


Figure 2.1: Multi-facet Model of Organizational Learning (Chan et al. 2005)

Besides, different perspectives have been put on organizational learning concept. Schilling and Kluge (2009) present different perspectives that have been presented on organizational learning within the body of the following table (Table 2.1). The study encapsulates the "learning" and "organization" concepts from a dual perspective. It handles the learning concept as "process (perceiving and processing information, i.e. experience) and result (modified knowledge or skill)" and the organization concept as "institutional (organization as a social system of members pursuing common goals) and instrumental (organization as a body of structures and rules that regulate human behavior in the workplace)".

Table 2.1: Summary of Perspectives on Organizational Learning (adapted from Schilling and Kluge 2009)

	Organization as "Social System"	**Organization as "Structures and Rules"**
Learning as "Process"	Collective process of learning: • Groups (building communities of practice) • Organizational development (changing the shared mental models of organizational members) • Information processing (acquiring, processing, and distributing shared organizational knowledge) • Organizational politics (preventing the acquisition, processing, and distribution of shared knowledge by micro-political activities)	Structured process of learning: • Information technology (distributing and storing information in social systems by IT-tools) • Knowledge management (planning, managing, and controlling of information and knowledge in social systems)
Learning as "Result"	Collective learning result: • Organizational culture (culture as a symbol and store of created, learned, and distributed material and immaterial artefacts)	Learning result by implemented structures and rules: • Strategic management (competitive advantages based on systems of scanning of and adapting to the environment) • Production management (rises in efficiency and productivity based on institutionalized systems of continuous improvement)

To summarize what organizational learning is or is not, the statements identified by Watkins and Marsick (1993) can be presented as follows (Love et al. 2000):

- "It is not just a collection of individuals who are learning."
- "It demonstrates organizational capacity for change."
- "It accelerates individual learning capacity but also redefines organizational structure, culture, job design, and assumptions about the way things are."
- "It involves widespread participation of employees – and often the client – in decision-making and information sharing."
- "It promotes systemic thinking and building or organizational memory."

Within the given concept of organizational learning, the literature focuses on two main streams as either the study of individual learning and its translation to actions for the benefit of the organization; or the study of investigation of behaviors that inhibit or disable individual learning. Therefore, the literature is mainly focused on individual process research or the organizational conditions for learning (Chan et al. 2005). From a different perspective, Dixon (1994) identifies the five main areas of organizational learning literature as:

- information acquisition,
- information distribution and interpretation,
- making meaning out of information,
- organizational memory, and
- retrieval of information.

Öztürk et al. (2016) summarize perspectives of researchers on organizational learning in four main groups. First group refers to dynamic environments where knowledge is to be circulated within the organization to increase the organizational performance by establishing a dynamic learning environment. Second constitutes project-based environments where learning in action is in concern. In project-based sectors, individuals and teams are active elements to learn as an organization within a strategic manner. The other group focuses on the learning process without considering the learning stocks in the organization. The final group considers the “unlearning” dimension of learning that has no significant effect on organizational performance. Unlearning is defined as the means for the organization to leave the unnecessary experiences and focus on experiences in a fresher environment (Holmqvist 2003).

2.1.2. Processes of Organizational Learning

Processes for organizational learning have been identified through several researches with different perspectives. However, as a summary to all, organizational learning processes can be grouped under two main processes as (Kululanga et al. 2001):

- creating or internalizing knowledge from the internal and external business environments, and
- applying the acquired knowledge to provide continuous performance improvement.

Since knowledge is the outcome of learning, organizational learning processes revolve around the “knowledge” concept. Learning is defined as ‘knowledge acquisition’ and it involves the processes where members share, generate, evaluate, and combine knowledge (Argote 2013). Organizational learning can also be presented through more detailed processes of three main interrelated processes as (Argote 2013; Senaratne and Malewana 2011)

- **Creating Knowledge:** when knowledge is obtained by the unit’s direct experience, “learning by doing/using”,
- **Transferring Knowledge:** when knowledge is developed from experience of another unit, “learning by reflecting, by discussing and confronting”, and
- **Retaining Knowledge:** when knowledge moves into the context of the organization, “learning by implementing, replicating and adapting codified knowledge”.

From a more social perspective, Schilling and Kluge (2009) have identified “social/psychological processes” related with organizational learning as;

- **Intuiting:** generating new perceptions and ideas from personal experience,
- **Interpreting:** individual presents his/her perceptions through words/actions to himself/herself/others,
- **Integrating:** a collective action at the group level with the achievement of a common understanding between the individuals/group, and
- **Institutionalizing:** implementation of the shared understanding within the systems, structures, procedures, rules and strategies of the organization; namely, transformation of the individual/group knowledge to organizational knowledge, so the knowledge can guide organizational actions without dependency to individuals/groups.

Sui et al. (2009) remark that implementation of Organizational Learning is a complex process since it requires joint consideration of strategic planning, operational processes, information technology, organizational culture, product design, R&D, manufacturing, marketing, etc. Establishing an organizational learning culture requires consideration of many variables as creating opportunities, promoting communication, establishing collaboration and teamwork, knowledge sharing, setting a collective vision, establishing connection with the environment, and providing leader support and reward system (Hua and Chan 2013). To be successfully implemented, Organizational Learning principles need to be effectively integrated into business processes or value chain of the organization. Therefore, the organization should improve the conditions establishing the (Sui et al. 2009):

- **Changes in organizational structure:** As the directive force for the mission, division, duties, level and decision-making power of an organization, the organizational structure needs to be designed not only according to the traditional factors as production, products, or work processes; but also considering the knowledge as the core resource. Organizational structure should be capable of the support and services required for organizational learning and knowledge innovation (Sui et al. 2009).
- **Cultural and incentive policies:** The culture of the organization forms the views on learning and the learning capacity of the organization. It can be established through; clear expression of the value and the objectives, including learning and innovation at the core of the annual organizational plan, encouraging the members of the organization to share their thoughts in the daily activities, and organizing meetings to discuss organizational values. Additionally, an incentive mechanism that would foster implementation of organizational learning is required. It needs to provide good mechanism to establish knowledge sharing environment, encouraging to do experiments, putting a premium on the conduct of knowledge sharing of the employees within an appraisal system, evaluating different perspectives, considering the needs of the employees within the incentive system and putting emphasis on

interpersonal relationships and team spirit (Sui et al. 2009). Offering incentives is a successful strategy for motivating individuals to invest in organizational knowledge. These incentive solutions can be as follows (Foss and Mahnke 2012):

  - high-powered incentives (e.g. making employees more of residual claimants);
  - promotion rules;
  - conferring access to critical resources; and
  - making credible commitments.

- **Organizational learning tools and platforms:** Establishing a strong application and management of technology is crucial for organizational learning as its role in business management. The organization should ensure an internal network to improve the knowledge exchange with the use of information technology as foundation that would also act as an electronic performance support system with the database or the knowledge base to collect, process, store, and transmit the knowledge within the organization (Sui et al. 2009).

Sui et al. (2009) also claim that implementation of learning could not be achieved with the solutions specific to project management. They assert that a management model where the manager focuses on coordination and promotion of members of the organizations to solve their problems rather than only controlling and solving problems. They classify the processes for implementation of organizational learning as:

- **Prototype:** is the development of an experimental system according to the needs of the users to determine the beneficial organizational learning examples and methods.
- **Expansion:** is the process where organization undertakes appropriate measures to ensure that learning outcomes are strengthened and the organizational learning is established through expanding experiences with organizational learning. It includes decision on choosing the implementation

scope and representative demonstration of projects to increase returns, and also ways to identify and eliminate the failures. The organization can also consider the balanced score card to evaluate four prospects as finance, internal business, customer, innovation and learning; to set targets; and to analyze the investment income that organizational learning brought.

- **Institutionalization:** is the process required for integration of organizational learning into the value chain and business processes of the organization. The process consists of systematic externalization of knowledge through the exclusive processes, patents, solutions, brands or business models; quantification of knowledge through formulas; and internalization of knowledge as the know-how in business process or teams. Knowledge is also handled to be repeated or used in diverse ways as franchising, joining in the chain, original equipment manufacturer, etc. Within this process learning is linked to the work through the systems, structures and processes. Typical requirements of this process are as follows:
  - learning as a part of the organizational operation system has to be the shared responsibility of all the members of the organization;
  - learning has to be something that members are willing to do, not have to do;
  - the organization should establish a feedback mechanism of organizational performance to enable members to correct the organizational behavior; and
  - self-management should be achieved to provide the team members to learn from each other and improve their work continually.

2.1.3. Factors that Affect Organizational Learning

Every organization learns differently so every organization has its own learning style and the learning capability; there is no single theory, model, or mode of learning.

Within this context, the characteristics of “learning and organizations” can be presented as follows (Dibella 2012):

- All organizations learn: all organizations have the learning ability.
- Source of learning: organizations include social interactions and so does the learning.
- Learning is rooted in culture: learning is affected by the culture of the organization
- Organizations are differentiated structures: organizations consist of different units with different behaviors and forms for interaction.
- Learning styles: differ for each organization may also differ for units of an organization.
- Managerial focal point: managers need to learn how their organizations learn and direct strategic actions for the organization accordingly.

Learning is basically defined as the conversion of experience into knowledge. According to Glynn et al. (1994) this conversion is affected by interaction of the experience with the context of the organization and its environment as it is depicted in Figure 2.2 (Argote 2013).

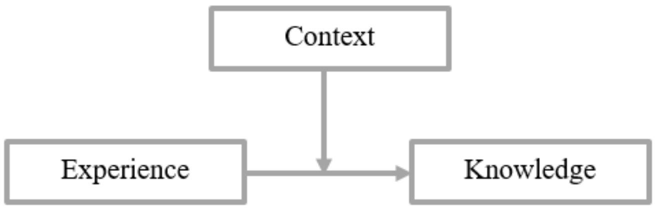


Figure 2.2: A framework for Analyzing Organizational Learning (Argote et al. 2012)

- **Organizational Context**: includes characteristics of the organization, such as its structure, culture, technology, identity, memory system, goals, incentives, and strategy. Relationships with other organizations through alliances, joint ventures, and memberships in associations are also included within this context. The organizational context can be further divided into two as “active context” that is able to take action (as organization’s members and tools that interact with the organizational tasks) and the “latent context” as the others that are not able to take action (such as; factors that affect organization’s tasks and tools, members’ abilities, motivations, and opportunities (e.g.; selection methods, training programs, performance feedback, rewards, job design, organizational culture/structure/absorptive capacity, social network, etc.)). Thus this active context as members, tools and tasks, and the networks between these elements constitute the primary mechanisms that the organizational learning occurs within organizations (Arrow et al. 2000).

- **Environmental Context:** includes elements outside the boundaries of the organization such as competitors, clients, suppliers, trade associations, regulators, educational establishments, and governments. The environment can also vary along many dimensions, such as volatility, uncertainty, interconnectedness, and munificence. Load of orders for products or requests for services can also be included within this context (Argote et al. 2012).

Additionally, Argote et al. (2012) categorize the context that affects the organizational learning within three main groups as:

- **National context:** different languages, different physical resources, and different legal rules and policy regulations;
- **Technical context:** as the extent of uncertainty around a problem, the amount and complexity of information, the architecture (or modularity) of a technology or design, the equipment and tools used in production, and the type of technology used to store or transfer the requisite knowledge; and
- **Social context:** as the similarity of the contexts, characteristics of members such as their social identity and experience working together, characteristics of relationships among members such as transactive memory systems (who knows what), leadership, and the organization’s structure, culture, and practices.

Rulke et al. (2000) identify learning channels that affect knowledge obtained as follows:

- purposive (learning through deliberate attempts to transfer knowledge through company newsletters, formal training programs, and the like),
- relational (learning from personal contacts both inside and outside the firm), and
- external arm's length (learning from trade association publications and newsletters).

According to this interaction, main drivers of organizational learning are organizational elements as members, tools and tasks, and the networks between these elements (Argote 2013):

- Member-member network: is the organization's social network
- Task-task / Tool-tool network: depicts interrelationships within tasks/tools
- Member-task network: depicts division of labor, member assignments to tasks
- Member-tool network: maps the members with the tools they use
- Task-tool network: maps the tasks with the tools used
- Member-task-tool network: maps the members with the tasks performed and the tools used

Individual members (Argyris and Schon 1978; Walsh and Ungson 1991), tools (Kane et al. 2005), and task sequences/routines (Darr et al. 1995) can be the knowledge repositories in an organization. Therefore, exchange of these elements between different units can be a mechanism for knowledge transfer across these units. Thus, organizations mainly learn through these elements and so from their products and services (Argote 2013; Mansfield 1985).

The type of the organizational experience also has an effect in development of organizational learning. The significant types of an experience are as follows: direct/indirect experience, novelty of experience, success/failure experience, ambiguity of experience, spatial location of experience, timing of experience, rareness of experience, simulation of experience, heterogeneity of experience, pace of experience (Argote 2013).

2.1.4. Styles of Organizational Learning

According to Argyris and Schon (1978), to achieve organizational learning, its members should act as learning agents of the organization. They should detect and correct the errors in respond to changes in internal and external environments of the organization and should make these results be embedded in the organization's memory (Argyris and Schon 1978). However, these processes as acquisition of knowledge and transformation of knowledge to action are affected by the learning style of the organization. Argyris and Schon (1978) proposed that organizations mainly display the following learning styles:

- **Single-loop learning:** Members within an organization detect and correct errors in respond to changes in internal and external environments of the organization. The success is mainly centered on effectiveness since focus is on meeting best the existing goals and objectives, and keeping the organizational performance within the stated norms (Argyris and Schon 1978; Love et al. 2000; Vakola and Rezgui 2000). It is related with detection and correction of the errors to provide the expected outcomes without changing the performance requirements (Wong et al. 2009).
- **Double-loop learning:** Differently from single-loop learning, incompatible organizational norms are questioned and changed by assigning new priorities or weightings to them, or completely restructuring the norms with the associated strategies and assumptions, thus making them more effectively realizable (Argyris and Schon 1978; Love et al. 2000; Vakola and Rezgui 2000). It is related with the improvements obtained as a result of this change by detecting the underlying causes of the problems and making reforms in the

processes. Therefore, double-loop learning requires “doing the right things” rather than “doing things right” as in single-loop learning (Wong et al. 2009).

- **Deutero learning:** With deutero learning, members of the organization learn about organizational learning through the interactions between organizations behavior and its ability to learn (Argyris and Schon 1978; Love et al. 2000). It provides achievement of a system that enables continuous learning and so, it is the one that is more fructuous in performance improvement (Wong et al. 2009).

2.1.5. Organizational Learning and Knowledge Management

The term of “Organizational Learning” has been in debate since 1960s, whereas advent of “Knowledge Management” concept is considerably new since it has been in concern since mid-1990s (Alavi and Denford 2012; Easterby-Smith and Lyles 2012; Walker 2016). Works of Peter Senge first published in 1990 (Senge 2006) as “Learning Organization” and Nonaka and Takeuchi (1995) with “knowledge-creating company”, the advances in information technologies, and the internet have all contributed to the development of knowledge management tools (Vakola and Rezgui 2000; Vera et al. 2012). Following the consideration of strategic value of organizational knowledge by organizational learning; attempts to facilitate acquisition, sharing, storage, retrieval, and utilization of knowledge processes with the help of IT such as databases, electronic video conferencing, etc. laid the foundations of knowledge management issue (Easterby-Smith and Lyles 2012). Additionally, factors of globalization of the economy and markets, volatility of business and competitive environments, a trend toward knowledge-intensive products and services, and rapid progress in information technologies created the focus on knowledge management (Alavi and Denford 2012).

“Organizational Learning” and “Knowledge Management” concepts have some considerations in common since they are dependent variables through the issue of “learning as knowledge processes”; however, this section mainly handles the differences between these two concepts (Vera et al. 2012). First, it is required to state the differences between “knowledge” and the “learning” concepts. “Knowledge” is the content/outcome that the organization has, it is an “asset” or a “stock”, whereas “learning” is the “process” that the content/knowledge is acquired, or the knowledge changes/flows, or the knowledge is maintained/developed. It is the study between “what is learned” and the “process of learning” (Easterby-Smith and Lyles 2012; Teece and Al-Aali 2012; Vera et al. 2012). Therefore; organizations can learn and the organizational knowledge can be stored (Easterby-Smith and Lyles 2012; Salk and Simonin 2012). These are the main focuses of “organizational learning” and “knowledge management” concepts respectively. Knowledge management mainly focuses on what knowledge is, defining knowledge typologies, and contrasting explicit and tacit knowledge and technical and social mechanisms to support them. However, organizational learning considers processes and interrelationships between learning at the individual/group or organizational level, system/infrastructure for alignment between strategy, structure, culture, procedures and system, and learning from outside/inside the firm (Vera et al. 2012). Thus, organizational learning is related with the management of creation of organizational knowledge, whereas knowledge management is more related with the optimization of the process. Learning is to be achieved at organizational level through the processes and structures that may help members create new knowledge with the aim of improving themselves and the organization continuously (Love et al. 2000). Knowledge management is required to identify the knowledge assets of an organization; to collect, store and optimize them; and to deliver the outcome to the locations where it can be transformed to a value (Spender 2008). Main contribution of the knowledge management processes is in the conversion of individual knowledge to organizational knowledge. As a summary, learning cannot be achieved without knowledge (Love et al. 2000). Knowledge management strategies are required to maximize organizational learning. Therefore, knowledge management is the subset of organizational learning principles as it provides the means to manage the knowledge as the main outcome (Chan et al. 2005). The following figure (Figure 2.3) depicts the role of knowledge management in achieving improved organizational performance through improved processes and outcomes of learning (King 2009).

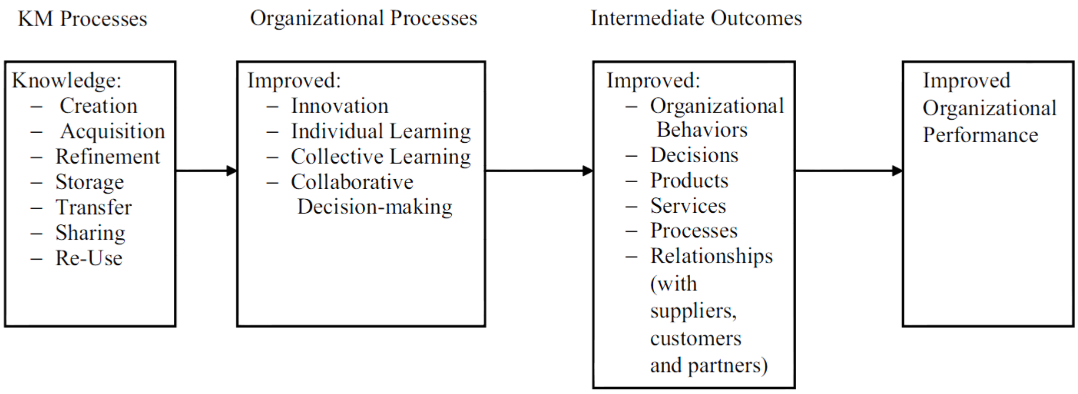


Figure 2.3: Role of Knowledge Management and Organizational Learning in Organizational Performance (King 2009)

2.1.6. Organizational Learning and Strategic Management

As it is mostly cited in the literature, creation of knowledge is the most important element for competitive advantage, since knowledge is appreciated as the key resource (Foss and Mahnke 2012; Nonaka and Takeuchi 1995). Strategic management should be more focused on intangible assets and knowledge rather than tangible assets that are easily imitable or substitutable and far from being sources of competitive advantage (Bierly and Hämäläinen 1995). Technical and organizational know-how constitute the knowledge assets of the organizations as competencies that identify the competitive position of the organizations (Teece and Al-Aali 2012). Knowledge of organization in markets, internationalization, marketing activities, research and development, design, procurement and logistics, production and manufacturing processes, human resource management practices, finance and accounting, and strategy is the main source of competitive advantage (Salk and Simonin 2012). Additionally, ability of learning faster than the competitors is stated as the only competitive advantage of the companies of the future (DeGeus 1988; Vera et al. 2012). Organizational learning requires a continual process of evolvement of the knowledge accumulated by individuals, groups, and the organization. This notion constitutes the basis of strategy formulation and implementation processes of an organization. Organizational learning is simply defined as a system/infrastructure, which is used for alignment of organization level knowledge storehouses as strategy, structure, systems, culture, and procedures (Vera et al. 2012). It is the main capability and driver in accomplishment of the continual improvement that is also driver of all other capabilities and competencies (Bierly and Hämäläinen 1995; Opoku and Fortune 2010).

Value of a resource is not stable; it may change with time. Teece et al. (1997) state that besides organizational resources, "dynamic capabilities" of an organization as its capability to create, integrate, and reconfigure new resources through strategic routines also create the competitive advantage of the organization. Dynamic capabilities are required to maintain effective organizational learning, and these capabilities can be increased through organizational learning (Teece and Al-Aali 2012). Since they are related with change, they are related with learning (change in cognition/behavior), and they are also related with knowledge as they work on routines and resources (the most valuable, rare, hard-to-imitate resources) (Vera et al. 2012). Thus, it is obvious that these capabilities also have a link with knowledge management strategies when they are extended to capacities (Teece 2007; Teece and Al-Aali 2012):

- to sense and shape opportunities and threats (building new knowledge),
- to seize opportunities to capture value, and
- to maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets (transforming the organization to adapt new business models and the competitive environment).

With a more knowledge management centered view "absorptive capacity" of an organization can be defined as "a set of organizational routines and processes, by which firms acquire, assimilate, transform, and exploit knowledge to produce a dynamic organizational capability" (Senaratne and Malewana 2011; Vera et al. 2012; Zahra and George 2002). Within this perspective, organizations should always be responsive to changes in their environment and consider how to evolve, transform and renew themselves (Vera et al. 2012). As stated by Buckler (1996), learning capacity of an organization should be higher than the change exposed by the environment to sustain as a successful organization (Love et al. 2000) Thus, organizations need to identify their capabilities first, and then they can take strategic actions (Dibella 2012).

Organizational learning should be main concern and task of strategic management studies since it may lead the required organizational capabilities that would create a sustainable competitive advantage. From the strategic management perspective, organizational learning can be divided into two as "external" and "internal". External learning keeps the focus on four strategic domain of organizational environment as customers, competitors, networks, and institutions. Whereas, internal learning is mainly related with individual, intra-functional, inter-functional, and multilevel learning that improves the internal efficiency of the organization. Thus, organizational learning is the conversion of domain specific knowledge to shared organizational knowledge. In addition, this shared knowledge defines the limits of the strategic capability and the competitive advantage of the organization (Bierly and Hämäläinen 1995).

Categorization provided by Mintzberg (1990) for schools of strategy research also includes "learning school" as strategy making is an emergent process. Within this scope, strategy is characterized as a decision making and learning process (Bierly and Hämäläinen 1995).

2.1.7. Benefits and Barriers of Organizational Learning

Within the extent of the principles for organizational learning, organizations may obtain improvements in many fields in the organization with the gained experience.

Following table (Table 2.2) presents the factors that contribute to learning (Argote 2013). Gains in structuring knowledge as the ways of managers to structure or organize the operations effectively and the operating knowledge as the ways of production workers to perform effectively are held together (Argote 2013; Skilton and Dooley 2002).

Table 2.2: Contributions of Changes in Experience through Learning

Factors	Source
Productivity gains through changes in the task and technology within the organization: "routinization of tasks, learning by management that leads to more efficient production control, learning by engineers who redesign the equipment and improve routing and material handling, and learning by suppliers who are able to provide a speedier and more reliable flow of material"	(Joskow and Rozanski 1979)
Experience gains lead to: "firms learn to make methods more productive, to design layout and work flow more efficiently, to coax more production out of machinery, to develop specialized new processes and product design modifications that improve manufacturability, and to institute better management control"	(Porter 1979)
Facilitator factors for organizational learning: "individual learning, better selecting and training of new members, improved methods, better equipment and substitution of materials and/or capital for labor, incentives, and leadership"	(Hayes and Wheelwright 1984)
Determinants of organizational learning curves at manufacturing plants: "increased proficiency of individual workers; improvements in the organization's technology, tooling, and layout; improvements in its structure, organization, and methods of coordination; and better understanding of who in the organization is good at what"	(Argote 1993)
Utilization of organizational memory: "affected the new product development process by influencing both the interpretation of new information and the performance of new routines, improvement in the short-term financial performance of new products by higher organizational memory levels, increase in both the performance and creativity of new products by greater memory dispersion"	(Moorman and Miner 1997)

Argote (2013) classifies the presented factors affecting learning in three as follows:

- "improvements in the performance of individual employees, including direct production workers, managers, and technical support staff";
- "improvements in the organization's structure and routines"; and
- "improvements in the organization's technology".

Differently from the factors affecting organizational learning, studies focusing on effects of the organizational learning also indicate the possible changes with adoption of organizational learning principles. Lin and Kuo (2007) identify significant and direct effect of “Organizational Learning” and “Knowledge Management Capability” on “Organizational Performance” within the study carried out on financial training centers in Taiwan. Similarly, Liao and Wu (2009) investigate the relations between “Organizational Learning”, “Knowledge Management” and “Organizational Innovation” by the study made with manufacturers and financial firms in Taiwan. It is found that “Knowledge Management” directly and positively affects “Organizational Learning” and “Organizational Learning” directly and positively affects “Organizational Innovation”, whereas “Knowledge Management” indirectly affects “Organizational Innovation”. Thus, the study indicates that “Organizational Learning” has a critical effect between “Knowledge Management” and “Organizational Innovation” as an enabling process where “Knowledge Management” is the input and “Organizational Innovation” is the output. In another study, Rose et al. (2009) handle public service managers in Malaysia and focus on the effects of organizational learning on the work environment. They find out that “Organizational Learning” is positively related to “Organizational Commitment”, “Job Satisfaction”, and “Work Performance”. Therefore, these studies reinforce the opinion that organizational learning assists behavioral change, improves efficiency and effectiveness of the workforce and helps for achievement of organizational goals and objectives Given the possible benefits of organizational learning, it seems essential to adopt this culture within the organization. However, there may be some barriers to getting benefits of organizational learning due to poor systems and behaviors of the organization. The barriers may be rooted at the levels within and between organizations or individual/group processes/behaviors (Fischbacher-Smith and Fischbacher-Smith 2012). Barriers of organizational learning are presented in Table 2.3.

Besides these presented barriers; Schilling and Kluge (2009) have identified a comprehensive list of barriers for organizational learning at the “actional-personal”, “structural-organizational”, and “societal-environmental” levels separately for four different processes of organizational learning as "intuiting", "interpreting", "integrating", and "institutionalizing".

Table 2.3: Barriers of Organizational Learning

Barriers	Source
• Individual level barriers: incomprehensible language by management; insufficient levels of competence/proficiencies; inability to think, talk, see the same thing as management does; difficulties in telling the truth to managers/own group; and employees do not want to take part in the firm's decision making • Organizational structures creating hierarchy or divisions • Managerial actions creating problems of sharing information and coordinating people for co-operation	(Steiner 1998)
• Dominance of a single (engineering culture: focus on technology instead of people) culture and lack of balance among cultures • Lack of organizational learning infrastructures and development process experimentation • Poor ability of organization to share and utilize the knowledge obtained	(Ford et al. 2000)
• Cross category barriers: Existing resources for knowledge operation (money, time, technology, skills, data transfer), Need of rewards (individuals rewarded for sharing/creating knowledge), Culture (knowledge strategy: dominantly either push or pull culture, KM aspects are unnoted, IT systems not available) • Technology barriers: Available technology (when not able to provide a single knowledge solution), Legacy systems (when not able to provide knowledge transfer, not using a standard approach) • Organizational barriers: Knowledge strategy implementation, Causal ambiguity, Poor targeting of knowledge, Cost management of knowledge transfer, Resistance to share of proprietary knowledge, Distance (geographical, culture, language, legal and linguistic differences), Unproven knowledge (Is knowledge rated as being of value?), Organizational context, Information not perceived as reliable, Lack of motivation (knowledge as power syndrome) • People barriers: Internal resistance (protect interests of organization/business unit), Self Interest (expose knowledge to competition), Lack of trust (as an effect on the level of information shared), Risk (fear of penalty, losing profit), Fear of exploitation (wish of something in return), Lack of motivation (not invented here syndrome), Fear of contamination (fear of up-market brand organizations getting together with down-market brands), Lack of retentive capacity (ability to routinize to use new knowledge), Lack of absorptive capacity (ability to identify and apply new knowledge)	(McLaughlin et al. 2008)

2.1.8. The Learning Organization

The ability of learning faster than the competitors may be the only sustainable competitive advantage of a company (DeGeus 1988; Senge 2006). This requires the learning notion together with the ability to change to be at the core of the organizational strategy (Dibella 2012). Systematic problem solving, experimentation, learning from their own experiences and from others, and transferring knowledge are the main capabilities that learning organizations have built (Garvin 1993).

"Organizational learning" is an academic term that is used for description and quantification of learning activities. It mainly refers to studies of learning processes of organizations, whereas "Learning Organization" refers to the ideal organization that is able to learn effectively. Thus "organizational learning" studies search the ways of reaching to "Learning Organizations" by the use of processes structured with management practices and training (Easterby-Smith and Lyles 2012; Love et al. 2000).

The term was first coined in the late 1980s; however, work of Peter Senge which first published in 1990 (Senge 2006) provided an international awareness of the term (Easterby-Smith and Lyles 2012). Senge (2006) defines a "Learning Organization" as "a place where people are continually discovering how they create their reality and how they can change it". Survival for a learning organization is not enough; it has to continually expand its capacity to create its future by adapting "survival/adaptive learning". The learning organization is considered as the one that is able to survive in the long run as the term is deemed to be synonym to the "long term success" (Dibella 2012). So, "learning" for a "Learning Organization" should not only mean as "acquiring more information" it should be more "expanding the ability of the organization to produce the results that it truly envisages" (Senge 2006).

Senge (2006) defines "Learning Organization" as an organization that "truly learns" by continuously enhancing their capacities to realize their aspirations. He identifies the requirement of five disciplines as "Systems Thinking", "Personal Mastery", "Mental Models", "Building Shared Vision", and "Team Learning". "Systems Thinking" is the main discipline between all since it is the one that integrates all disciplines to fit into coherent body of theory and practice. It makes all the disciplines to realize their potential. "Personal Mastery" promotes the personal motivation to continually analyze and learn what our actions causes what in our world. "Mental Models" provide analysis of the problems in our current ways of seeing the world.

"Building Shared Vision" helps to focus on the long term all together. Lastly, "Team Learning" improves the skills of groups of people to look for the wider picture rather than by looking in individual perspectives.

- **Systems Thinking:** this discipline underlines that organizations are also systems since they are bounded by interrelated actions whose effects may be observed years later. Accordingly, methodologies developed with this discipline focuses on identification of the cause and effect patterns clearly and changing them effectively (Senge 2006).
- **Personal Mastery:** is the discipline that focuses on continual clarifying and deepening the personal vision, focusing on personal energy, developing patience and so learning to see the reality objectively. It is deemed as spiritual foundation of the learning organization since commitment and capacity of an organization for learning is limited according to its members. Individual learning does not guarantee organizational learning; however, organizations cannot learn unless the individuals learn, since they are the active force of organizations (Argyris and Schon 1978; Love et al. 2000). If the individuals in an organization are not sufficiently motivated for growth and development there would be no growth, no increase in productivity or no development for that organization (Senge 2006).
- **Mental Models:** are the assumptions, generalizations, pictures and images that all influence our understanding of the world and taking action (Senge 2006).
- **Building Shared Vision:** is the discipline of focusing on a shared vision of the intended future. It fosters the focus and energy required for learning by providing the excitement of accomplishment of the vision determined (Senge 2006).
- **Team Learning:** is the discipline that promotes the ability of the members to achieve "thinking together". It is the vital discipline since teams are the fundamental learning units in an organization (Senge 2006). Because organizations may know more than sum of individuals working in; at least

they may know more through working as a team (Easterby-Smith and Lyles 2012).

2.1.9. Organizational Learning in Construction Industry

Traditional organizational structures and policies are not suitable to face the challenges of today and have become inadequate to meet the requirements of dynamic environment (Love et al. 2000). With the key role in sustainability and prosperity of organizations, organizational learning has gained importance in the construction management literature as well (Chan et al. 2005). Construction professionals have responded to this requirement with the search of ways to establish a learning culture within the organizations where every individual can contribute to decision making and keep up with the change (Love et al. 2000). Adoption of organizational learning in the construction industry is crucial to provide a change and improvement in the current situation whilst the major weaknesses of the industry are reported (Egan 1998; Latham 1994) as poor performance and under-capitalization. Thus, industry needs to search new ways for increasing efficiency of existing processes and managing the organization through changes in their processes and working practices (Love et al. 2000; Vakola and Rezgui 2000). By adopting learning practices, construction contractors may reverse the industry specific situation of slow adaptation to the changing environment. As a result, continuous improvement and innovation may be established in the industry (Kululanga et al. 1999; Opoku and Fortune 2010). Enhancement of the knowledge continuously, improvement of the processes and human resource development constitute the main focus of the learning organizations (Chinowsky et al. 2007). Continuous improvement is stated as the main driver of maintaining competitive advantage for contracting organizations within the construction industry (Wong et al. 2009). Additionally, Chinowsky et al. (2007) identify the issues that bring the need of organizational learning principles as drivers for motivation in adopting learning organization culture as follows:

- **Performance:** educated workforce is expected to be more efficient,
- **Aging Workforce:** since the knowledge mainly resides with individuals in the construction industry, the loss of knowledge through retirement of the personnel is an issue in the industry,
- **Distributed Workforce – Globalization:** elimination of the geographic boundaries may require specific knowledge related with the local conditions, therefore establishment of learning principles or an organizational knowledge base may serve for this purpose,
- **"Better" Solutions:** Establishment of the learning culture may improve the solutions to the problems by finding and generating new solutions,
- **Evolution (Growth) of the Organization:** continuous growth in profits and performance is to be established by focus on evolution, thus the learning organization is to prepare itself for future and its success through cycling of new knowledge.

The efforts have been put are beneficial as an introduction to "learning"; however, they do not meet the actual requirements of the learning organization in the industry (Chinowsky et al. 2007).A roadmap that would define the way to becoming a learning organization in the construction industry has not been constructed yet (Love et al. 2000). The learning organization is expected to be "skilled at creating, acquiring, sharing, and applying knowledge, and embracing change and innovation at all levels, resulting in optimum performance and maximum competitive advantage" (Construction Industry Institute 2006). Mechanisms should be established that would enable sharing of the knowledge within organization, lead to continuous improvement, and continue to operate efficiently and effectively while responding to the needs of changing environment (Love et al. 2000). Thus, construction organizations need to change the reactive learning mechanisms to proactive learning mechanisms where every individual focusses continuous obtainment and dissemination of knowledge. The cultural and behavioral change should be at the core within the focus of learning organization culture to stay competitive (Chinowsky et al. 2007; Love et al. 2000). A learning organization culture specifically requires continuous learning and personal advancement at all levels and in every project and business process (Chinowsky et al. 2007; Opoku and Fortune 2010). Learning should be channeled to the business undertaken at all levels in an instructional way of relationship with the environment (Love et al. 2000). Chinowsky et al. (2007) identify entities of a learning organization that enables interaction of learning at different levels as:

- **Organization:** as all levels of management and staff personnel, learning organization requires establishment of learning culture from top executives to all the staff,
- **Community:** as communities of practice that are working as a group in similar technical activities,
- **Individual:** as the main element of organizations that searches for and disseminates knowledge within the organization.

Further, they state characteristics of a learning organization as (Chinowsky et al. 2007):

- **Leadership:** as ability of leading the organization to a learning organization through setting vision, creating proactive learning environment, empowering learning at all levels, allowing or encouraging risk, and building the culture;
- **Processes and infrastructure:** management processes and the technical infrastructure are required to respond the needs for implementation of learning;
- **Communication:** between the communities and the individuals is required to establish the share of knowledge;
- **Education:** as fostering the education opportunities within the organization;
- **Culture:** as development of the culture required for continuous support and promotion of learning.

Construction organizations generally stated as incapable of solving problems, grasping unanticipated opportunities, and adapting to dynamic business environment. They are also inflexible and slow in responding to escalating and changing needs of customers. As a result of this, recent studies that focus on continuous improvement have been raised within the industry; however, the performance of the industry has been generally stated as unsatisfactory according to the conducted industry review studies. Therefore, organizational learning can serve as a means for organizations in establishment of the behavioral change required to fill the gap between the expected performance and the actual performance. Simply, it constitutes the processes that provide the change in knowledge obtained through past actions to behaviors, tools, and strategies for improving future actions (Wong et al. 2009). Construction activities are held mainly on-site and due to this, they are error prone activities. Moreover, these errors are very costly since they are the costs for rectification, disruption, and delays. To overcome this, every organization need to learn from their mistakes and improve their performance accordingly, so learning should be the core competency of the organizations in the construction industry (Wong et al. 2009).Organizational learning is important for construction companies since it can provide construction companies shifts in direction as in changes listed below (Kululanga et al. 2001):

- **From a doing to thinking workforce:** establishment of a thinking workforce that contributes to improvement by questioning, rather than simply performing obsolete processes;
- **From reactive to proactive readiness to change:** focusing on the future of the companies and creating an organizational learning culture to handle the requirements of change;
- **From loss to competitive advantage:** construction companies should aim innovation through development of practices, services and products that would be attractive for clients; as a result, they can achieve survival of the companies; and
- **From status quo to continuous improvement:** continuous improvement of construction business processes can be achieved through organizational learning principles.

Garvin (1993) identifies the functions that the construction organizations should achieve to be successful in learning as (Love et al. 2000):

- Systematic problem solving,
- Experimentation with new approaches,
- Learning from their own experience and past history,
- Learning from the experiences and best practices of others, and
- Transferring knowledge quickly and efficiently throughout the organization.

Construction companies may not establish strategies to learn effectively; however, if they can accomplish their strategies related with experience they can also achieve different forms of learning as (Kululanga et al. 2001):

- **Integrated organizational learning:** when change occurs in both cognition and behavior of the company, for example awareness of the construction company in an issue results in improved behavior/processes.
- **Transitional organizational learning:** when learning occurs in respond to challenges in the business environment, more specifically in forms of:
    - **Forced organizational learning:** as a result of internal or external threat (e.g.; governmental legislation),
    - **Experimental organizational learning:** trials carried out to respond challenges of the business environment,
    - **Blocked organizational learning:** occurs when construction company understands how to respond to the change; however, it is not able to take action due to some reason (e.g.; unavailability of resources),
    - **Anticipatory organizational learning:** occurs when construction company is under the pressure of change (e.g.; Russian business environment that led resistance of the firms to embrace western business values).

Construction companies may learn through different channels and different mechanisms. As a summary, the identified learning mechanisms in the construction industry by Kululanga et al. (1999)can be presented as follows:

- **Learning mechanisms based on collaborative arrangements:** where companies may learn competencies of each other while staying as separate companies (e.g.; corporate mentoring, partnering, alliancing, consortia, etc.)
- **Learning mechanisms based on non-collaborative arrangements:** work arrangements between companies (e.g.; acquisition and mergers)
- **Learning mechanisms based on networks:** any network that may provide transfer of knowledge (e.g.; Construction Industry Institute, Construction Information Technology, Institute of Civil Engineers, etc.)
- **Learning mechanisms based on in-house research schemes, team learning, reviews, benchmarking, shows, and exhibitions:** research and review efforts to increase generation and acquirement of new knowledge (e.g.; learning through teams/groups, reviews from failures/successes, internal/external benchmarking, environmental scanning, etc.)
- **Learning through individual employees:** new competencies and processes/functions by employee improvement (e.g.; staff training, seminars, attracting/inviting/contacting staff from other organizations, etc.)

Besides the stated drivers, channels, mechanisms; dimensions as enabler factors are also important measures for learning in the industry and need to be taken into consideration. Kululanga et al. (2001) present dimensions that contribute to organizational learning of construction companies as an instrument to measure and monitor the organizational learning of the companies. They identified dimensions and related measures that are addressing improvements through:

- continuous learning of employee,
- use of teams (team learning for improvement efforts),
- internal-learning within a company through sharing of knowledge,
- lessons from past experiences,
- integrating learning with work through collaborative and non-collaborative work arrangements,
- investigations within the firm or by arrangement with others,

- learning from others,
- continuous renewal of business processes, and
- seeking new developments in the business environment.

As a summary, learning in construction is stated to be difficult due to unique characteristics of the industry. It is a project based industry where all the projects are unique, and the projects are undertaken by temporary teams put together to work for that unique product. Therefore, the learning and feedback loops are generally broken by relocation of the teams. Additionally, teams are also consisting of different members who differ in backgrounds and cultures. This situation makes construction projects differing in both permanent and project-based settings (Senaratne and Malewana 2011; Styhre et al. 2004). Chinowsky et al. (2007) identify barriers in the industry for implementation of a learning organization culture as lack of:

- support from senior executives,
- support from employees,
- time and money,
- value measurement, and
- knowledge sharing infrastructure.

In addition to these stated difficulties and barriers Barlow and Jashapara (1998) also mention the following difficulties specific to construction partnering projects as one of the most important mechanisms for achievement of organizational learning (Chan et al. 2005):

- the tensions and conflicts between clients and suppliers;
- the ability to codify knowledge according to the duration of the partnering relationship (is it a long-term relation or not);
- the way for the knowledge retaining and distribution; and
- internal political and cultural environments that affect communication structures.

2.2. Knowledge

As the main outcome of organizational learning, knowledge is alleged to be the main source of the sustainable competitive advantage and economic growth. It is uniquely structured and embedded in an organization through the effects of organizational climate and culture. Organizations' knowledge should be managed, stored, traded and applied as a tangible asset; however, it is difficult since it is actually organization's intellectual capital (Spender 2008). This makes knowledge and its management central to organizational learning. In order to understand what is knowledge management and why it is important, "knowledge" term should be clarified first. Knowledge definition, knowledge types and knowledge sources, which are all important to develop successful knowledge management strategies are explained in general in order to provide easiness to understand knowledge management concept, its importance and strategies. The following section handles the knowledge management details.

2.2.1. Definition of Knowledge

In knowledge management literature, there are mainly two different approaches used in order to describe knowledge. One of the approaches uses data and information concepts and the relation between them. However, the other approach does not use data and information concepts for definition of knowledge. In the first approach, superiority is constructed between data, information and knowledge (Tan et al. 2010). Data can be described as objective facts, raw facts or un-interpreted material without categorization (Davenport and Prusak 2000; Nonaka and Takeuchi 1995; Spender 2008). When data is interpreted and structured within a context, it becomes information (Green et al. 2004). Definition implies that, information is the organized form of data, it is data with meaning and the meaning is the lens that is put over the data (Spender 2008). In addition, there is a relation between knowledge and information similar to data and information. Knowledge is “actionable information” that can be used for making decisions (Kanter 1999; O’Dell and Grayson 1998) Thus, knowledge can be defined as interpreted form of information, namely the contextualized information (Nonaka and Takeuchi 1995; Spender 2008). Knowledge includes know-how and this makes it the “production process” rather than the “raw material” namely the data (Shelbourn et al. 2006). If these terms are explained with an example, “200 km/hr” is data and it is meaningless without any additional explanation. When data is provided as the “car speed is 200 km/hr”, the data translates into information of the car is very fast. Additionally, knowledge is being aware by an experience that officers would penalize the driver for this car speed. Data, information and knowledge are located on a graph of order/structure and human agency as in Figure 2.4 by Choo (2006). In reality, differences between knowledge, information and data are not clear as described here (Davenport and Prusak 2000). Bhatt (2001) argues that one person’s knowledge can be information to others. This is related with the knowledge base of individuals. Orange et al. (2000) corroborate the importance of individual in knowledge concept by defining knowledge as learning outcome, which is related to person. Second approach does not use comparison between knowledge, data and information to define knowledge. By this way, there is no need to making clear distinction between knowledge and information. Comprehensive definition of knowledge provided by Davenport and Prusak (2000) is “a fluid mix of framed experience, values, contextual information, expert insight, and grounded intuition that provides an environment and framework for evaluating and incorporating new experiences and information”. According to Rennie (1999) knowledge is related with the ‘know-what (declarative knowledge accumulated in minds), know-how (procedural knowledge accumulated in bodies) and know-who’ (Argote 2013; Vera et al. 2012).

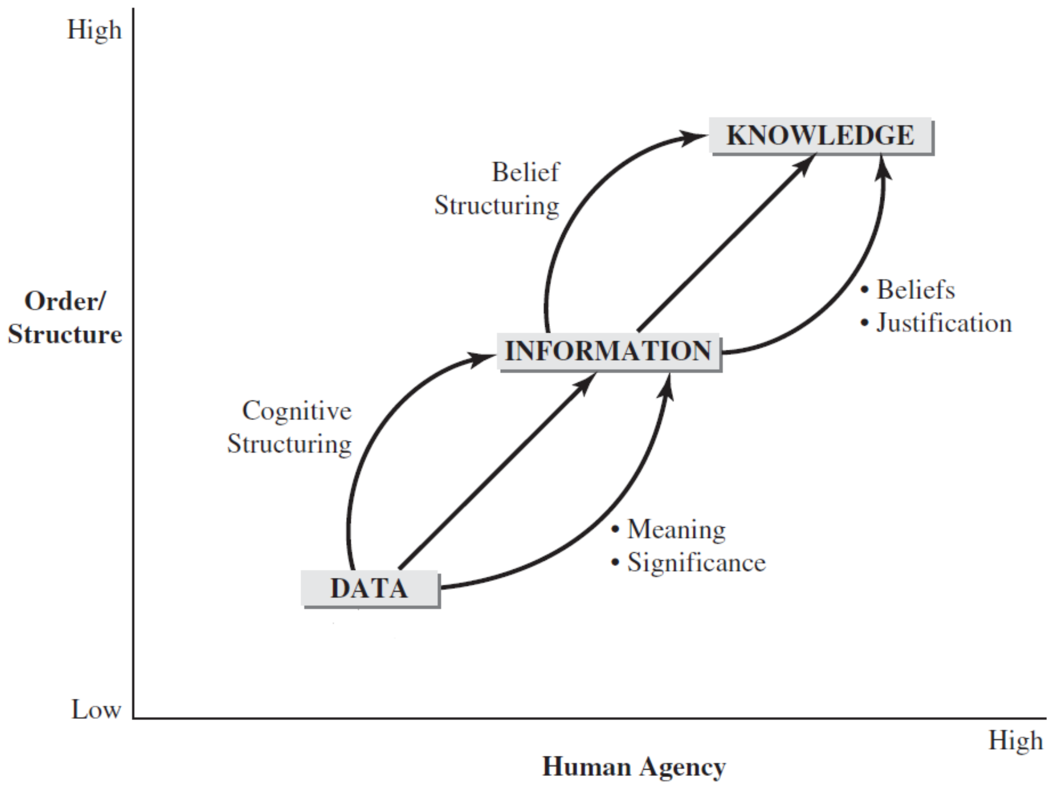


Figure 2.4: Data, Information, and Knowledge (Choo 2006)

2.2.2. Types of Knowledge

Identifying characteristics of knowledge helps to understand the flow, transfer, storage and lack of knowledge (Salk and Simonin 2012). Knowledge is mainly categorized according to its difficulty in articulation as "explicit knowledge" and "tacit knowledge" in the literature (Argote 2013). Tacit knowledge was first proposed by Polanyi (1967) to simply represent the most critical part of knowledge as personal/individual knowledge (Kivrak et al. 2008). This term have become a widely accepted characterization by various authors and knowledge is qualified as being "explicit" or "tacit" (El-Diraby and Zhang 2006; Green et al. 2004; Kivrak et al. 2008; Nonaka and Takeuchi 1995; Ozorhon et al. 2005).

Explicit knowledge is the easily documented type of knowledge, which can be expressed in formal language, can be captured in sentences, drawings, or writings by linguistic and symbolic representations (Hwang 2014; Nonaka et al. 2006; Senaratne and Malewana 2011). Since its nature is suitable for codification in words and numbers, explicit knowledge can be stored in either paper or electronic format and this makes explicit knowledge easy to share between individuals (Carrillo 2004; Carrillo and Chinowsky 2006; Kivrak et al. 2008).

On the other hand, tacit knowledge is hard to document and so difficult to articulate because of its contextual nature (Argote 2013; Carrillo and Chinowsky 2006; Hwang 2014). According to definition of Polanyi (1967), tacit knowledge is personal and context specific, so it is related with senses, movement skills, physical experiences, intuition or implicit rules of thumb (Nonaka et al. 2006). Sharing, copying and managing tacit knowledge is hard, because it is stored in people's heads and gained by experiences (Kivrak et al. 2008). Sharing tacit knowledge is to be achieved by successful interaction of the "knowledge holders" with "knowledge seekers", so organizational culture is determinative in achievement of the tacit knowledge sharing (Hwang 2014). According to (Ozorhon et al. 2005)"tacit knowledge is hidden in the beliefs, perceptions, norms and actions of individuals". This definition explains that why documentation and sharing of tacit knowledge is hard. In order to store tacit knowledge, it should be converted to explicit knowledge (Yıldız 2012). Also, people centered solutions are proposed as the another way to share tacit knowledge (Green et al. 2004) such as face-to-face contact, communities of practice, lessons learned, etc (Carrillo and Chinowsky 2006).

Nonaka and Takeuchi (1995) present four basic modes of knowledge creation as conversions of tacit knowledge and explicit knowledge (Mintzberg et al. 1998; Snell and Hong 2012; Tsoukas 2012):

- **Socialization:** is the conversion from tacit knowledge to tacit knowledge. It is the process of sharing tacit knowledge through observation, imitation, and practice, often without the use of wording/language (e.g.; the case where the apprentice learns from his master, share of insights through demonstration, role modeling).

- **Externalization:** is the conversion from tacit knowledge to explicit knowledge often through use of metaphors and analysis. These processes include articulation through concepts, models, hypotheses, metaphors, and analogies (e.g.; narratives for lessons learned).
- **Combination:** is the conversion from explicit knowledge to explicit knowledge through combinations of different explicit knowledge sources (formalized knowledge is shared, merged, modified and integrated).
- **Internalization:** is the conversion from explicit knowledge to tacit knowledge. Within this process, explicit knowledge is taken back to the tacit form when the people internalize it as in 'learning by doing' (e.g.; embodiment of newly-agreed routines, employing new process technologies (Hua and Chan 2013)). Therefore, knowledge needs to be first articulated, and then absorbed/internalized by the individuals involved.

Difficulties with articulation of tacit knowledge should not preclude the discussion of skilled performances in the works involved. Attention should be given to these even if they cannot be converted to explicit. Social interactions have the potential to help individuals to re-structure their knowledge and behaviors. At least one can achieve a better view of the tasks held through reminding himself how he does things and obtain some distinctions and features that he was not able to notice before. Manifestation or display of the tacit knowledge is possible if it is not possible to capture/convert it, new knowledge can also occur through remark of the tacit knowledge through dialogical interaction. Therefore, the need is creation of new ways for talking, fresh forms for interacting, and novel ways for distinguishing and connecting (Tsoukas 2012).

Tacit knowledge is vital for the companies to obtain competitive advantage since it constitutes the knowledge of individuals that is very hard to be replicated by the competitors and so provides unique competencies (Easterby-Smith and Lyles 2012; Paranagamage et al. 2012). However, there are some different arguments on conversion of tacit knowledge to explicit. Some researchers strictly argue that tacit knowledge cannot be turned to explicit, they assert that it can only be manifested/displayed and communicated and remarked by this way (Tsoukas 2012). Besides, some of them state that it is very difficult since it requires both identification of the change and willingness to share the change where sometimes it may also include non-reflectional characteristics (Snell and Hong 2012). There may be a residual part of tacit knowledge that may not converted to explicit; however, this should not preclude the effort for the conversion since tacit knowledge mainly differs in characteristics. The example provided in study of Nonaka (1991) where an engineer observes a bread-maker and transfers this tacit knowledge to explicit by a bread-making machine (Matsushita's bread-making machine). Therefore, it should be considered that tacit knowledge can be transferred to explicit; however, there may be still some tacit knowledge that may not be transferred to others. A conducted study (Berry and Broadbent 1984) shows that an individual may gain experience in a recurring task; however, he may not be able to articulate the change in his knowledge. This study also shows that one was not able to transfer the tacit knowledge to others, but he was able to transfer his knowledge to a similar task he held. This thought supports the circulation of individuals within different tasks or contexts of organizations to share tacit knowledge, but there is still the risk of knowledge of the individual may got lost so it should be stored in social systems at least by a group. Learning of a team/group as building blocks of an organization is more important and stable than individuals. Transfer of knowledge through team members is easier with groups/teams since they generally handle face-to-face meetings and share more information due to shared objectives (Argote 2013). Different strategies should be handled to store individual knowledge in organizational structures and routines or in technologies such as information systems and knowledge networks. However, if the knowledge of the individual is highly tacit and difficult to share at all, then strategy of creating contracts or incentives that may keep the individual within the company can be followed (Argote 2013).

Traditional knowledge management systems as document repositories may help transfer of tacit knowledge to explicit knowledge only at the level of indication of who knows what and only address the connections to be established for transfer of the tacit knowledge. However, today's knowledge management systems also have the capability to achieve this networking ability within the system through online communities, discussion groups, blogs and forums with the advances of Web 2.0 technologies (Zammuto et al. 2007). Advances of these technologies only apply according to the capability of the knowledge management system established in the company (Argote 2013).

2.2.3. Sources of Knowledge

In social science perspective, knowledge sources can be classified as perception, introspection, memory, reason and testimony. "Perception" is about our five senses and these are sight, touch, hearing, smelling and tasting. These perceptual faculties are accepted as knowledge sources. "Introspection" is about capacity to understand which cannot be achieved by perception. Introspection reveals how the world appears to us in our perceptual experiences. Another source of knowledge is "memory" and it is the capacity to retain knowledge acquired in the past. "Reason" is the source of knowledge, which is used for justification of some beliefs. In this source, knowledge does not depend on any experience. Last knowledge source is "testimony" and it uses someone's sayings as knowledge source (Steup 2014). These are general definitions provided within social sciences perspective for defining knowledge source and presented from a very broad perspective; however, they constitute the basics of knowledge sources.

From organizational perspective; Levitt and March (1988) state that knowledge is embedded in routines and standard operating procedures, rules, products and processes, technologies and equipment, layout and structures, and culture and norms of an organization. In parallel with these sources, Walsh and Ungson (1991) mention individual employees, the organization's culture, its standard operating procedures and practices, roles and organizational structures, and the physical structure of the workplace as sources. In the same vein, Starbuck (1992) addresses individuals, physical capital (including hardware and software), organization's routines, and its culture as sources of organizational knowledge. As a summary, most of the researches are underlining common organizational knowledge sources as:

- individuals (including managers, technical support staff, and direct production workers);
- the organization's technology (including its layout, hardware, and software);
- the organization's structure, routines, and methods of coordination; and
- the organization's culture (Argote 2013).

Organizations not only learn from their own direct experiences but also learn from experiences of other organizations. This can either be by moving people, technology, and routines of the organization to the recipient organization or by modifying the people (by training), technology, and routines of the recipient organization. "Benchmarking", mechanisms to transfer "best practices" or "lessons learned" are the basic means to transfer knowledge between organizations (Argote 2013). Establishing a superordinate relationship for an organization such as a franchise, chain, or network has also considerable effect in transfer of knowledge. Other potential sources of knowledge transfer through organizations can be achieved by investigating the behavior of organizational entities establishing inter-organizational arrangements such as; cooperative relationships, strategic alliances, joint ventures, transplants, interlocking boards of directorates, consortia, business groups, and multinationals (Argote 2013; Holmqvist 2003). External environment namely suppliers and consultants, product or competitor's product, customers, patent applications, scientific and trade publications, face-to-face meetings, conferences and other organizations are also main sources of knowledge (Argote 2013).

2.3. Knowledge Management

Organizational learning is to be defined as "the process of improving actions through better knowledge and understanding" (Fiol and Lyles 1985). Organizational knowledge is obtained through manageable processes of organizational learning, mainly through the processes of knowledge management. Thus organizational learning and the knowledge management are complementary to each other (King et al. 2008; Spender 2008). This part of the study explains what is knowledge management and why it is important. In the literature, definition of "knowledge management" is provided by various authors and organizations, and some of them are given in the next section. Importance of knowledge management for today's conditions and main driver forces are also explained. In the last part of this section, proposed steps for knowledge management and strategies are presented with explanations of different perspectives.

2.3.1. What is Knowledge Management?

Knowledge management simply considers the ways of measuring, disseminating, storing and leveraging knowledge mostly with the help of information technology to foster the organizational performance (Easterby-Smith and Lyles 2012). As Hearn et al. (2002) state, knowledge management requires providing "the right information to the right people at the right time" (Hwang 2014). It is a complicated process that has socio-cultural, organizational, behavioral, and technical dimensions. It involves behavioral strategies (e.g. organizational learning), information-based approaches (e.g. best practices), and technologies (e.g. data mining and knowledge repositories). So, knowledge management systems mainly support coding and sharing documents in repositories, development of knowledge directories, and creation of knowledge networks (Alavi and Denford 2012). Girard (2017), investigates the knowledge management definition in detail and concludes with a summary definition based on this review as "*the process of creating, sharing, using and managing the knowledge and information of an organization*". Within the context of this study (Girard 2017), frequency analysis of 100 definitions is made and the following word cloud is obtained (Figure 2.5), where most important words are obtained as "knowledge, organization, process, information, use, share, create and manage".

Figure 2.5: Word Cloud of "Knowledge Management" Definitions (Girard 2017)

Knowledge management has several dimensions and perspectives that have a link with each other through knowledge management. The following figure represents a model which presents the extent of knowledge management and its links within these multifaceted dimensions (Jashapara 2011).

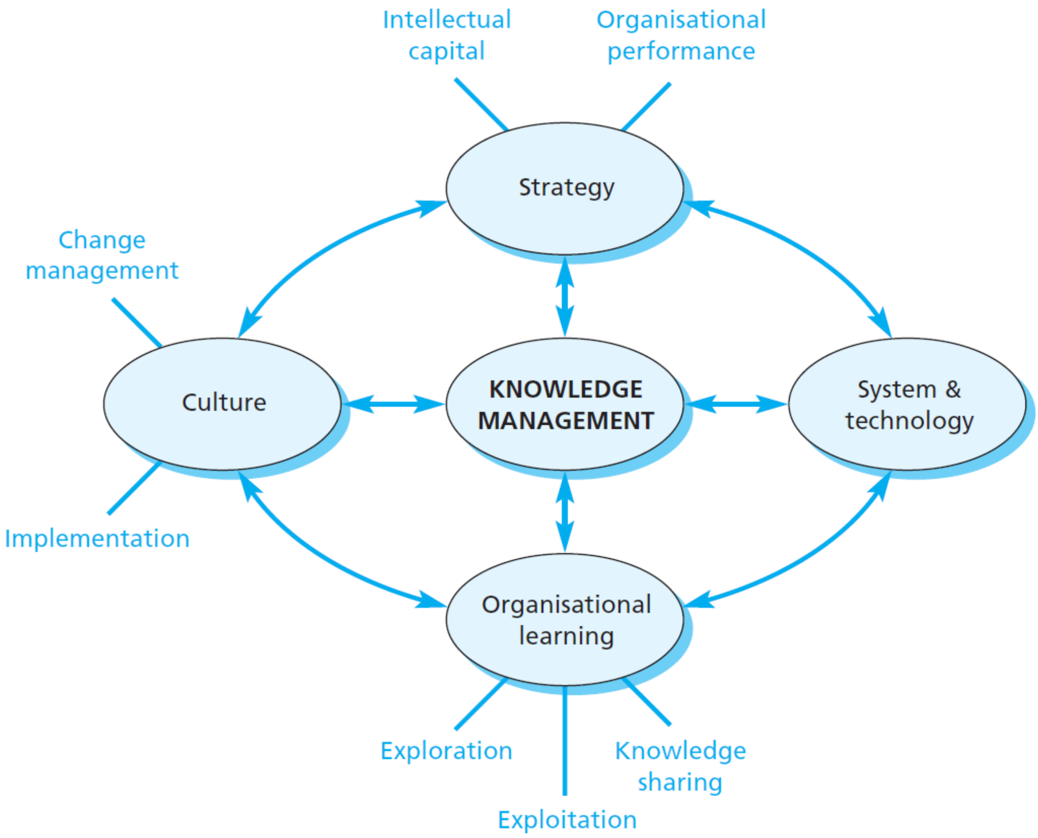


Figure 2.6: Dimensions of Knowledge Management (Jashapara 2011)

Knowledge management is defined by (KPMG 2000) as "*systematic and organized attempt to use knowledge within an organization to improve performance*". According to Davenport and Prusak (2000) "*knowledge management is the process of creating value from an organization's intangible assets*". Similarly, (Webb 1998) defines it as "*the identification, optimization, and active management of intellectual assets to create value, increase productivity and gain and sustain competitive advantage*". The common idea behind these definitions is using the knowledge acquired in sector by locating it into a systematic process in order to improve performance and gain advantage. Process includes 'creating, securing, capturing, coordinating, combining, retrieving, and distributing' knowledge (Tserng and Lin 2005). A comprehensive definition is provided by Dalkir (2011) as "*Knowledge management is the deliberate and systematic coordination of an organization's people, technology, processes, and organizational structure in order to add value* *through reuse and innovation. This is achieved through the promotion of creating, sharing, and applying knowledge as well as through the feeding of valuable lessons learned and best practices into corporate memory in order to foster continued organizational learning.*". Examples from other definitions of knowledge management from different resources are given in Table 2.4. Generally, they underline two dimensions as "processes of identifying and managing validated facts with the support of technology" and "social dimension as the role of people, group dynamics, social and cultural factors, and networks" (Vera et al. 2012). Thus knowledge management is to be based on either database systems, intranets, and other distributed systems that allow members to reach the data whenever it is required, or on social networks as the traditional one-to-one transfer of knowledge (Chinowsky et al. 2007).

Table 2.4: Knowledge Management Definitions

Definition	Source
"the ability of an organization to manage, store, value, and distribute knowledge"	(Liebowitz and Wilcox 1997)
"the explicit control and management of knowledge within an organization aimed at achieving the company's objectives"	(Van der Spek and Spijkervet 1997)
"draws from existing resources that your organization may already have in place – good information systems management, organizational change management, and human resources management practices"	(Davenport and Prusak 2000)
"is a set of processes to create, store, transfer, and apply knowledge in the organization"	(Laudon and Laudon 2014)
"the formal management of knowledge for facilitating creation, access, and reuse of knowledge, typically using advanced technology"	(O'Leary 1998)
"a conscious strategy of getting the right knowledge to the right people at the right time and helping people share and put information into action in ways that strive to improve organizational performance"	(O'Dell and Grayson 1998)
"the process of creating, capturing, and using knowledge to enhance organizational performance"	(Bassi 1997)
"any process or practice of creating, acquiring, capturing, consolidating, sharing, disseminating, and reusing knowledge to enhance learning and performance in organizations"	(Scarborough et al. 1999)
"a system that supports the creating, archiving, and sharing of valued information, expertise, and insight within and across communities of people and organizations with similar interests and needs"	(Rosenberg 2001)
"'the management processes (including planning, organizing, implementing, controlling and evaluating) of creating, capturing, transferring, sharing, retrieving, and storing of data, information, knowledge experiences, and skills by using appropriate information and network technology, with the endorsement of total involvement in organizational learning to enable knowledge acquisition throughout the processes"	(Zou and Lim 2002)

Table 2.4: Knowledge Management Definitions (continued)

Definition	Source
"a process that must take account of the mechanisms and structures needed to handle knowledge while, at the same time, paying regard to the processes and players influencing the knowledge one is seeking to manage"	(Christensen 2003)
"is made up of both the collect function (data and information dimensions) and connect function (knowledge and wisdom function)"	(April and Izadi 2004)
"the effective learning processes associated with exploration, exploitation and sharing of human knowledge (tacit and explicit) that use appropriate technology and cultural environments to enhance an organization's intellectual capital and performance"	(Jashapara 2011)
"the systematic process and strategy for finding, capturing, organizing, distilling and presenting data, information and knowledge for a specific purpose and to serve a specific organization or community"	(King 2005)
"developing searchable document repositories to support the digital capture, storage, retrieval, and distribution of an organization's explicitly documented knowledge"	(Sambamurthy and Subramani 2005)
"the planning, organizing, motivating, and controlling of people, processes and systems in the organization to ensure that its knowledge-related assets are improved and effectively employed"	(King 2009)
In management science: "the active management of knowledge in an organization by using systematic processes" In human resource management: "a necessary endeavor to transport knowledge from those who have it to those who needs it"	(Tellioglu 2012)

2.3.2. Importance of Knowledge Management

Knowledge becomes more and more important because the key element of today's economy is "knowledge" (Anumba et al. 2005). According to Department of Trade and Industry (DTI) (1998), production and use of knowledge have significant role for wealth creation in knowledge driven economies (Carrillo 2004). Competitive advantage of organizations is closely related with the knowledge that is in its employees' head and capability of using this knowledge to achieve business objectives (Tan et al. 2007). Therefore, today's global economic conditions require knowledge rich organizations to survive. Wiig (2000) defines driving forces for knowledge management in three categories. According to his research, external, internal and ongoing developments are the three main categories for driving forces of knowledge management. Driving forces that are mentioned by Wiig (2000) with further classification are listed below;

1. External Driving Forces
    - Globalization of business and international competition
    - Sophisticated customers
    - Sophisticated competitors
    - Sophisticated Suppliers
2. Internal Driving Forces
    - Bottlenecks in enterprise effectiveness
    - Increased technological capabilities
    - Understanding of human cognitive functions
3. Ongoing Developments
    - Economics of Ideas
    - Information Management and Technology
    - Cognitive Science
    - Shifts in Bottlenecks
    - Customization Requirements for Sophisticated Customers
    - Sophisticated Competitors
    - Globalization

In addition to driving forces, expected improvements with knowledge management are determined by Mertins et al. (2001) (Carrillo 2004). These are cost/time reduction, increase in productivity, process improvement, facilitation of information exchange, customer satisfaction, process transparency, increase in quality and staff satisfaction. In addition to that, research conducted by KPMG (2000) among 453 organizations in UK, Europe and US shows similar results. One of the surveys conducted in this research presents expected benefits of knowledge management together with their expectation rates. First three expectations are determined as “better decision making”, “better customer handling” and “faster response to key business issues”. Full list of the expectations is provided in Table 2.5.

Table 2.5: Expected Benefits of Knowledge Management (KPMG 2000)

Benefit	Expectation rate
Better decision making	86%
Better customer handling	83%
Faster response to key business issues	83%
Improved employee skills	80%
Improved productivity	78%
Increased profits	76%
Sharing best practice	75%
Reduced costs	73%
New ways of working	71%
Increased market share	68%
Create additional business opportunities	66%
Improved new product development	60%
Staff attraction / retention	45%
Increased share price	28%

Therefore, knowledge management can be deemed as a means to increase profit, decrease costs, decrease time of production and design, ensure customer and staff satisfaction, improve competitive advantage and help market leadership (KPMG 2000).

2.3.3. Knowledge Management Processes

Knowledge management processes are generally grouped by four main steps as "knowledge capture", "knowledge sharing", "knowledge reuse" and "knowledge maintenance" (Tan et al. 2010). Beside these main steps, various authors use different categorizations. As an early classification, Huber (1991) presents four high-level processes as "knowledge acquisition", "information distribution", "information interpretation", and "organizational memory" (Pentland 1995). Holzner and Marx (1979) identify knowledge processes required for an effective learning process as:

- **construction:** implies new material to knowledge stock,

- **organization:** as setting relations between the bodies of knowledge, classification or integration,
- **storage:** for possibility of memory or application,
- **distribution:** of knowledge to the points where it is needed/to be applied, and
- **application:** of knowledge for possibility of performance improvement (Pentland 1995).

Davenport and Prusak (2000) define steps as “knowledge generation”, “knowledge codification and coordination”, and “knowledge transfer”. According to Bhatt (2001) steps are as follows; “creation”, “validation”, “presentation”, “distribution” and “application”. Another definition of knowledge management processes is done by Mertins et al. (2001) and includes main steps of “create”, “store”, “distribute” and “apply”. In addition to these “capturing”, “storing”, “reusing” and “sharing” of knowledge are the processes proposed by Kivrak et al. (2008). Alavi and Leidner (2001) present the knowledge management framework through processes of “creation”, “storage and retrieval”, “transfer” and “application” (Alavi and Denford 2012). Works done by different authors uses different terms for categorization; however, all of them mention about the same main steps ultimately. As mentioned before the main steps can be summarized as “capturing”, “sharing”, “reuse” and “maintenance”. The main difference between these categorizations is only the level of detail (Tan et al. 2010).

Knowledge Capture: In the literature, sub-processes for knowledge capture are identified. (Bhatt 2001) identifies these as “creating”, “presenting” and “validating”. “Planning”, “creating”, “integrating”, “organizing”, and “assessing” are the processes that are defined by (Rollett 2003). According to (Tan et al. 2007) these sub processes are “identifying”, “locating”, “representing”, “storing” and “validating”.

Knowledge creation simply refers to development of a new organizational know-how and capability. It can either be generated within the organization or be acquired from its external resources. Information technologies have the potential to support access to existing knowledge sources and foster the collaborative interactions among individuals, and so contribute to knowledge creation process (Alavi and Denford 2012). The organizational knowledge creation process consists of main five steps as occurring in continual cycles (Tsoukas 2012):

- the sharing of tacit knowledge among the members of a team;
- the creation of concepts whereby a team articulates its commonly shared mental model;
- the justification of concepts in terms of the overall organizational purposes and objectives;
- the building of an archetype which is a tangible manifestation of the justified concept; and
- the cross-leveling of knowledge, whereby a new cycle of knowledge creation may be achieved elsewhere (or even outside of the organization.)

Identification and location of knowledge are related with the investigation of knowledge types and finding out where knowledge is created to handle (Kamara et al. 2003).

Knowledge storage and retrieval processes are generally supported with creation of an organizational memory and various means to access its content. Two types of organizational memories can be established as “internal memory” that includes tacit knowledge as individual’s skills and organizational culture, and “external memory” that consists of mainly explicit knowledge such as formal policies and procedure, manuals and computer files (Alavi and Denford 2012).

Most of the time organizations do not actually know what they know. This is because of weakness of the systems had to locate and transmit different types of knowledge (Alavi and Denford 2012). Thus indexing, organizing and structuring of knowledge (Rollett 2003) in order to facilitate access and reuse of knowledge are the main purposes of representing and storing knowledge (Tan et al. 2007).

In order to be sure before distributing captured knowledge, it should be verified in terms of correctness and accuracy (Tan et al. 2010). Importance and reusability of captured knowledge should also be investigated in order to decrease risk of knowledge overload (Kamara et al. 2003). These processes are named as validating knowledge by (Tan et al. 2010).

In knowledge management process, live capturing of knowledge plays important role. Live means that capturing knowledge while project is being executed, rather than capturing after completion through project meetings (Kamara et al. 2003). Research conducted by (Robinson et al. 2004a) shows that 76% of construction organizations and 70% of client organizations believe that live capture of knowledge is crucial. Live capture of project knowledge also prevents knowledge loss due to the time lapse between creation of knowledge and capturing knowledge. Human brain may not store everything and there is probability of forgetting some events or remembering them incorrectly. This probability increases when time lapse between creation and capture of knowledge increases (Tan et al. 2007).

Knowledge Sharing: Sharing of knowledge is about facilitating knowledge access by the right person when it is needed. Rollett (2003) defines two ways to share knowledge as "knowledge pull" and "knowledge push". According to his definition, if knowledge transfer is done by "knowledge seeker", it named as "knowledge pull". This passive knowledge transfer can be repository creation to provide an area to user for knowledge search (Markus 2001). By typing keywords users can retrieve necessary information from the knowledge repositories. On the other hand, in "knowledge push" method, "knowledge receiver" does not seek for knowledge (Rollett 2003). Creating an electronic alert system to inform the related people when a new knowledge is captured and stored is an example of knowledge pushing (Markus 2001). Knowledge sharing also refers to the knowledge emerging through interaction and dialogues between individuals that more constitutes the social context of the term (Alavi and Denford 2012). Knowledge exchange can be characterized through three modes as:

- exchange of knowledge between individuals;
- exchange between individuals and knowledge repositories (e.g. downloading a report from a document repository); and

- exchange among existing knowledge repositories (e.g. using RSS feeds to transfer pre-specified knowledge items among existing knowledge repositories) (Alavi and Denford 2012).

Information technology applications needs to be designed in order to meet the needs of the specific knowledge exchange mode. Network models for transfer of knowledge are required for exchange of knowledge between individuals through digital links; however, stock models are required for electronic transfer of knowledge through repositories (Alavi and Denford 2012).

Knowledge Reuse: This part of knowledge management is crucial for success of knowledge management system, because this is the main objective of knowledge management as using gained knowledge in the past to improve organizational abilities. According to Majchrzak et al. (2004) innovation can be achieved by searching, evaluating and selecting the best reusable idea (Tan et al. 2007) so that knowledge capturing is a beneficial process only when it is used (McGee 2004). Application of knowledge is required as use of knowledge in processes of decision making, problem solving, and coordination among individuals/groups in an organization. Because knowledge itself does not mean an organizational value unless it is used in taking effective actions (Alavi and Denford 2012). For example, a person may have explicit knowledge about the parts of a bike and a tacit knowledge of how to keep balance on the bike; however, he may only practice his knowing by riding the bike, namely by putting the knowledge into action (Vera et al. 2012). Similarly, libraries or encyclopedias are the repositories of knowledge; however, the knowledge in these repositories can only be recognized or internalized as long as they are read (Salk and Simonin 2012).

Knowledge Maintenance: Due to changing environment, recently obtained knowledge may be more valuable than the knowledge acquired previously. Old experience may be no more valid according to today's conditions. Thus, maintenance of knowledge to eliminate the outdated knowledge is required (Pentland 1995). According to Rollett (2003) knowledge maintenance tasks includes "reviewing", “correcting and updating”, “refining”, “preserving” and “removing”. Review of stored knowledge provides chance to make knowledge management system be updated and thus to increase the quality of system. Value of knowledge depends on the time and it may be useless over time because of the development of new tools, technologies, processes and procedures (Bhatt 2001). Reviewing of repository should also include reviewing of the structure in order to be sure that categories are still valid for current time and the captured knowledge is stored at right categories. In case of finding any error by reviewing, it should be corrected and updated. During the review process, refining of knowledge may be needed other than correcting. This also increases usability of knowledge by extracting unnecessary information. Some valuable information should be preserved against loss of this knowledge. On the other hand, some knowledge may become outdated and according to Rollett (2003) and they can lead to “unnecessary baggage, incurring costs through storage and administration, and more importantly, distracting the attention of employees without contributing to organizational goals” so that this type of outdated knowledge should be deleted from the system (Rollett 2003).

In the light of the provided different categorizations, the following knowledge management cycle model provided by King et al. (2008) can be presented to summarize the processes of knowledge within the links of parallel paths from occurrence of knowledge to its contribution to organizational performance (Figure 2.7). Within this model, knowledge “creation” refers to the development of new knowledge through the modes of knowledge creation provided by Nonaka and Takeuchi (1995), whereas “acquisition” is more related with the search mechanisms of valuable knowledge outside the organization. Knowledge “refinement” refers to explication and arrangement of knowledge to enable its “storage” in organizational memory. Following codification of knowledge, “transfer” implies communication of the knowledge on purpose from a sender to the known receiver; however, “sharing” indicates the less-focused dissemination of knowledge through a repository to the people that are most probably unknown to the contributor. Following this dissemination process, once “utilization” of knowledge is achieved it has the potential to contribute to the “organizational performance” (King et al. 2008).

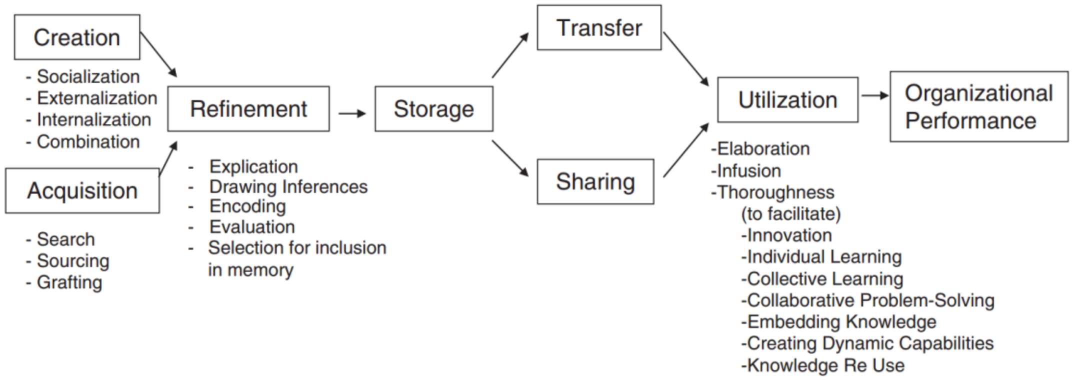


Figure 2.7: Knowledge Management Cycle Model (King et al. 2008)

Within the context of the presented knowledge processes, there may be need of supportive tools to effectively go through these processes. Jashapara (2011) presents knowledge management tools as facilitators of these processes as follows:

- **Organizing knowledge:** ontology and taxonomy;
- **Capturing knowledge:** cognitive mapping tools, information-retrieval tools, search engines, agent technology, personalization;
- **Evaluating knowledge:** case-based reasoning (CBR), online analytical processing (OLAP), knowledge discovery in databases- data mining (expert systems, decision trees, rule induction, genetic algorithms and genetic programming, neural networks and backpropagation, associative memories, clustering techniques), machine based learning;
- **Sharing knowledge:** internet, intranets and extranets, security of intranets, text-based conferencing, groupware tools, videoconferencing, skills directories: expertise yellow pages, e-learning; and
- **Storing and presenting knowledge:** Data warehouses and visualization.

2.3.4. Knowledge Management Strategies

Knowledge management strategies can be divided into two categories as “knowledge management techniques” and “knowledge management technologies”. Knowledge management techniques refers to non-IT tools that are more related with the human resource management. On the other hand, knowledge management technologies refer to IT-tools which are based on developing system to manage knowledge with the help of information technologies (Al-Ghassani et al. 2005). These technologies emerged to facilitate knowledge management in terms of articulation, storage, transfer, creation, and retrieval of knowledge (Alavi and Denford 2012; Hayes 2012). Thus, these technologies effect organizational learning by effecting richness of the available information (Pentland 1995).

In order to achieve organizational goals, brainstorming, knowledge communities, face to face meetings, post project reviews, trainings, mentoring, etc. are used as knowledge management techniques (Al-Ghassani et al. 2005). These techniques provide networks to capture and share lessons learned on previous projects (Carrillo and Chinowsky 2006). On the other hand; techniques are not enough to develop successful knowledge management and knowledge management technologies should also be used to guarantee that captured knowledge will stay within the company. Dikmen et al. (2008) also provide similar approach to categorization of knowledge management. They name it as “personalization strategy” that knowledge sharing relates with personal interaction and “codification strategy” that uses a system to codify and store knowledge in a database. Valuable knowledge should be stored to make knowledge accessible and usable by the others, even when people leaves company. Individuals were the primary source of organizational memory in the early 1800s. Following the organizations efforts in capturing of knowledge of the individuals through written records, manuals on rules and procedures, and reporting systems for transmission of information; embodiment of the organizational memory shifted from dominance of individuals to embodiment in records, rules, and procedures in the late 1800s and early 1900s (Argote 2013; Argyris and Schon 1978).

From this perspective, information technologies have a great potential and importance in effective knowledge management (Egbu and Botterill 2002). With the advances in responding the needs of communication and information sharing in knowledge management, information technologies (mainly intranets, groupware, databases, knowledge warehouses, and web-based/data sharing software) constitute the basics of majority of the knowledge management studies in the literature (Argote et al. 2012; Hayes 2012). Alavi and Tiwana (2006) summarize the use of information technologies according to the knowledge processes as follows (Alavi and Denford 2012):

- **Knowledge Creation:** e-learning, collaboration support systems;
- **Knowledge Storage and Retrieval:** data warehousing and data mining, repositories;
- **Knowledge Transfer:** communication support systems, enterprise information portals;
- **Knowledge Application:** expert systems, decision support systems.

Information technologies can also be divided into two as “integrative applications” and “interactive applications”. Integrative applications refer to structured databases to store and retrieve past project information, expert finders, electronic bulletin boards through to best practice reports, and working papers. Interactive dimension is achieved through applications with email, desktop conferencing, discussion forums, lessons learned databases, and groupware and intranet platforms where knowledge can be shared without consideration of physical location (Argote et al. 2012; Hayes 2012). New trend with interactive platforms is adoption of Web 2.0 technologies to enhance collaboration and knowledge share within the organization. These technologies are including use of wikis, blogs, social networking and instant messaging, the ability to link out to other pages, and the categorization of data by users through tagging that are also user-friendly systems that users have familiarity with (Alavi and Denford 2012; Hayes 2012; McAfee 2006). Tools and techniques used in knowledge management are not alternatives to each other and they should be used together to achieve effective knowledge management systems. Additionally, effective knowledge management systems also include social elements as well as technological elements in their combination (Alavi and Denford 2012). Therefore, high and low technology elements as ranging from fostering conversation between individuals to establishing internet-based communication systems are to be used in combination to enhance knowledge sharing (Hua and Chan 2013). In the light of these, an ideal knowledge management system should provide ease of use, value and quality of knowledge, system accessibility, and user involvement (Alavi and Denford 2012).

2.4. Knowledge Management in Construction Industry

In construction sector, knowledge management is simply defined as reusing of past projects' knowledge in future projects (Lin et al. 2006). Facilitation of reuse of captured tacit and explicit knowledge during the project execution in order to help decision makers is the main objective of knowledge management in the industry (Yıldız 2012). In construction industry, knowledge management consists of two stages as at "project level" and at "firm level" (Kamara et al. 2003). On the other hand main source of knowledge in construction industry is projects because knowledge generations occur during project execution (Tan et al. 2007). Managing project knowledge effectively, provides corporate level advantages such as choosing the right projects and winning bids as well as carrying out projects successfully (Kivrak et al. 2008). Construction industry is a part of global economy and like other sectors, knowledge management is a key for gaining competitive advantage by reducing project time and cost, and improving quality (Hwang 2014; Shelbourn et al. 2006). However, necessary mechanisms to capture and reuse tacit and explicit project knowledge in other projects have not been adequately addressed yet for construction sector (Kivrak et al. 2008; Tan et al. 2007). The established systems in the industry have been poor to transform the individual knowledge to organizational knowledge (Opoku and Fortune 2010). Information technologies have great potential to facilitate information understanding and sharing effectively, and it may provide enhancement of construction knowledge. However, the work has done so far is not enough for an effective solution (Hari et al. 2004; Kivrak et al. 2008; Shelbourn et al. 2006; Wetherill et al. 2002).

2.4.1. Importance of Knowledge Management for Construction Industry

Construction projects have unique requirements that are executed by various temporary organizations (Hwang 2014; Kamara et al. 2002b). This makes construction industry a knowledge intensive sector because of its characteristics of multidisciplinary teams with different notions of value, unstable nature, heavy reliance on previous experience, conflicting objectives, unique projects, tight schedules, limited budgets, etc. (Cushman 1999; Graham and Thomas 2007; Hwang 2014; Kivrak et al. 2008; Shelbourn et al. 2006; Wetherill et al. 2002). In addition to these characteristics, globalization of construction market, increased competition and demands, requirement of new technologies and highly skilled workforce make knowledge management critical (El-Diraby and Zhang 2006; Graham and Thomas 2007; Hari et al. 2004). According to Carrillo (2004) in order to survive at low profit and high competition conditions, effective knowledge management provides benefits. Examples for these benefits are decreasing project time and cost, quality improvements and as a result of these companies gain competitive advantages (Shelbourn et al. 2006; Yang et al. 2014). Effective knowledge management is appreciated as the main driver of innovation and improved business performance in the industry (Abu Bakar et al. 2016; Kamara et al. 2002a; Yusof et al. 2012). If knowledge obtained from past projects can be used in future projects, it can prevent re-invention of the wheel, facilitate innovation, and lead increased agility, efficiency, flexibility, quality, learning, better decision making, better teamwork, and supply chain integration, improved project performance, higher client satisfaction, and organizational growth (Hari et al. 2004; Kamara et al. 2003; Ly et al. 2005). According to Kamara et al. (2002b) main driving forces for knowledge management in construction sector are handling high staff turn overs, minimizing waste, keeping up with sectoral changes and managing supply chain. Survey conducted by Robinson et al. (2001), among UK engineering and construction firms, shows similar results about driver forces such as continuous improvement, sharing valuable tacit knowledge, disseminating best practices, responding to customers quickly, reducing rework, and developing new products and services (Carrillo and Chinowsky 2006). Similarly, (Kivrak et al. 2008) conduct a study on Turkish construction contractors and identify main drivers for adopting knowledge management strategies in the order of their importance as; "reduce rework", "respond to clients quickly", "encourage continuous improvement", "sharing tacit knowledge", "disseminate best practice", and "develop new products and services". According to Cooper et al. (2002), past project performance and records are the key factors to increase management performance in future projects and they have to be managed properly (Yıldız 2012). Additionally, Latham Report (Latham 1994) underlies that lack of coordination between the partners as one of the effects on performance of UK construction industry and puts emphasis on use of IT for facilitating the process of sharing information and knowledge between the parties. Moreover, the report asserts that establishment of an organizational memory would respond to the needs specific to constraints in the sector. Knowledge management has the potential to provide benefits as (Vakola and Rezgui 2000):

- improvement in working conditions, health and safety;
- methods and tools to foster learning from experience;
- better quality of the end-product; and
- protecting the environment and natural resources.

All of these benefits may result in empowerment of the employee through achievement of organizational learning with the help of corporate information and knowledge bases that includes the "lessons learned" of the company (Rezgui 2001; Vakola and Rezgui 2000). Yang et al. (2014) mention that knowledge management system, where technological and cultural supports are both taken, has considerable benefits such as improving the abilities of organizations to be flexible and to respond more quickly to changing market conditions, to be more innovative, and to improve decision making and productivity. Integration of information management system may provide potential benefits as those derived from calculating and printing tasks, record-keeping tasks, record-searching tasks, system restructuring capabilities, analyzing and simulating capabilities and process and resource control tasks. They also present measurable benefits of knowledge management system application in an engineering consulting firm in Taiwan. They quantify benefits and report considerable savings in data retrieval, time savings in data collection, staff-hour savings in proposal preparation and savings in cost per project. Kim (2014) investigates the effect of knowledge management on organizational success in the construction industry through project performance and identifies the positive effect of knowledge management on organizational success. Yusof et al. (2012) note that several studies present that there is a positive relationship between the efficiency and effectiveness of knowledge management within a company and its success and growth. Abu Bakar et al. (2016) reveal in their study that knowledge processes (mainly "knowledge conversion") have a significant and positive relationship with growth performance of construction companies. The results are parallel with the expected benefits of the knowledge management as competitive advantage, performance, firm competitiveness, economic performance, and innovativeness (Abu Bakar et al. 2016).

Managing knowledge is also highly important for companies that executes international projects. Because knowledge in construction industry also means the ability to understand the market, assess the client's requirements, and translate these conceptions into products and services by effectively utilizing organizational resources (Abu Bakar et al. 2016). Eriksson et al. (1997) state that, in international projects, decisions and actions are closely related with the local institutions and capturing and managing this knowledge can help company to successfully complete projects by providing necessary knowledge and minimizing 'liability of foreignness' (Yıldız 2012).

It is obvious that, knowledge is critical for construction companies for success and maximization of value through enhancing competencies, confidence effectiveness, and sustainability; and project knowledge should be captured regardless of the type of project, type of construction, project phases and type of information source (Cushman 1999; Green et al. 2004; Hari et al. 2004; Kamara et al. 2003; Kivrak et al. 2008; Shelbourn et al. 2006; Wetherill et al. 2002). On the other hand, knowledge capture and learning from project are important as well as difficult because of time, resource constraints and temporary teams in construction projects. Therefore, loss of knowledge is a common issue in construction sector (Tan et al. 2007). The knowledge types, sources and the barriers to knowledge management in the industry are explained in the following sections.

2.4.2. Types of Knowledge in the Construction Industry

Overall knowledge in the construction domain can be grouped under three categories as (Rezgui 2001):

- **Domain Knowledge:** constitutes the information that is available to all companies in the industry and can easily be stored in databases (e.g.; administrative information as zoning regulations/planning permissions, standards, technical rules, product databases, etc.)
- **Organizational Knowledge:** the company specific information that constitutes the intellectual capital of the organization. It is embedded both formally in company records and informally through the skilled processes of the organization (e.g.; knowledge about the personal skills, project experience of the employees and cross-organizational knowledge as knowledge acquired through business relationships with other partners including clients, architects, engineering companies, contractors, etc.)
- **Project Knowledge:** is the potential usable knowledge (e.g.; as solutions to technical problems, for avoiding repeated mistakes, etc.) that the company obtains through projects and interaction with other companies (e.g.; project

records, the recorded and unrecorded memory of processes, problems and solutions)

When knowledge in the industry is considered specific to being explicit or tacit, most of the knowledge required for success is appreciated to be tacit (Abu Bakar et al. 2016). Documented material in paper/electronic format such as; standard operating procedures, best practice guides (Carrillo and Chinowsky 2006), specifications, design codes (Kivrak et al. 2008), project information, drawings, cost reports, risk analysis results and other information which can be collected, stored and archived (Abu Bakar et al. 2016; Zhang et al. 2009) are examples for explicit knowledge (Yıldız 2012). Whereas, abstract sources such as; experience, expertise, know-how of construction professionals, company culture, and lessons learned gained from projects are the examples for tacit knowledge in the construction sector (Abu Bakar et al. 2016; Carrillo and Chinowsky 2006; Yıldız 2012)

2.4.3. Sources of Knowledge in the Construction Industry

Kivrak et al. (2008) conducted a survey to determine the knowledge sources and their importance particularly for the construction sector. Participants of this survey were professionals working in large scale construction contractor companies and they were asked to give rates between “1” to “5” to determine priorities of knowledge sources in construction sector. Complete result of this survey is given in Table 2.6. According to the results, top three sources of knowledge can be listed as “colleagues”, “company’s experience” and “personal experience”. Common point between these three sources is that all of them depend on experience. Therefore, it is obvious that main knowledge source is the experience that is gathered during execution of projects. This argument is supported by the least three important knowledge sources of “internet”, “knowledge brokers external to firm” and “external events” which are not related with projects.

Table 2.6: Knowledge Sources in Construction (Kivrak et al. 2008)

Rank	Knowledge Source	Average Point
1	Colleagues	4.25
2	Company's experience	3.75
3	Personal experience	3.66
4	Company documentation	3.33
5	Current project documentation	3.25
6	Project team meetings	3.25
7	Intranet	2.25
8	Personal library	2.25
9	Clients	1.00
10	Internet	0.83
11	Knowledge brokers external to firm	0.25
12	External events (e.g. conferences, seminars)	0.17

Reusability of knowledge is important consideration in knowledge management. According to (Tan et al. 2010), nine knowledge source categories can be used to determine "reusable project knowledge". In order to determine "reusable project knowledge", they identify five main points. These can be summarized as;

- **Adaptability:** Reusable project knowledge should be adaptable to new application which may not be same with the origin.
- **Transferring capability:** Reusable project knowledge may be transferred for reuse to other sectors.
- **Reuse capability:** Knowledge may be used in other departments of company as well as the in same or similar projects.
- **Origin of need:** Necessity may depend on circumstances that are repeated regularly.
- **Benefit to improvement:** Knowledge may interoperate with the previous company and industry knowledge to help innovation and improve best practices.

According to these five characteristics (Tan et al. 2010) define the "nine knowledge sources" of projects as;

- **“Process knowledge”:** This source is about knowledge about execution of the project. According to their definition this source mainly contains tacit knowledge.
- **“Knowledge about clients”:** This covers experience of client specific requirements and this source may be explicit with the help of form of a standard procedure but can also be tacit.
- **“Costing knowledge”:** This source is related with the cost of project and it can be explicit or tacit according to whether it is captured and stored in a software or paper or not.
- **“Knowledge about legal and statuary requirements”:** This knowledge source comes from regulations, codes of practice and experiences related with these regulations and codes. Some part of this source can be easily accepted as explicit; however, experiences may remain tacit or be transferred to explicit.
- **“Knowledge about reusable details”:** Specifications and method of statements are examples for this source and these can be accepted as explicit knowledge.
- **“Knowledge of best practices and lessons learned”:** Failures and best practices that are acquired during the execution of project are the sources of knowledge and these sources can be explicit if they are captured and stored in some form.
- **“Knowledge of performance of suppliers”:** This source is about performance of project stakeholders and it is explicit so that can be easily stored in databases.
- **“Knowledge of who knows what”:** This is also accepted as source of knowledge that is acquired from project knowledge. This is used to improve accessibility of needed tacit knowledge by locating who knows what. This source can be accepted as explicit knowledge with the help of developed organizations’ staff structure.

- **"Other types of knowledge":** This source composed of sector specific knowledge such as knowledge about competitors, risk management knowledge and project management knowledge. Depending on the approach, these can be labelled as explicit or tacit knowledge.

Tan et al. (2010) also identify possible emergence time of knowledge sources according to project stages and it is given in Table 2.7. This is important because, knowledge creation time is important for developing a strategy to capture and store and to reuse when it is needed.

To develop a successful knowledge management strategy, knowledge sources have to be identified with their nature as tacit or explicit and time of creation and should be taken into consideration in development of strategies.

Table 2.7: Knowledge Sources with Creation Time according to Project Phases (adapted from Tan et al. 2010)

	Phase of Project			
Knowledge Sources	**Pre-project**	**Pre - Construction**	**Construction**	**Post – Construction**
1. Process Knowledge				
• Briefing	•	•		
• Design	•	•		
• Tendering and estimating	•	•		
• Planning		•		
• Construction and buildability			•	
• Operation and maintenance			•	•
2. Knowledge about client				
• Clients' requirements	•	•		
• Client organizations' internal procedures	•	•	•	
• Background knowledge about clients' business	•	•		
3. Costing knowledge				
• Cost of alternative forms of construction			•	
• Whole life cost of a facility			•	•
4. Knowledge of legal and statuary requirements				
• Health and safety			•	•
• Changes in regulatory requirements	•	•	•	•
• Contract	•	•	•	•

Table 2.7: Knowledge Sources with Creation Time according to Project Phases (adapted from Tan et al. 2010) (continued)

	Phase of Project			
Knowledge Sources	**Pre-project**	**Pre - Construction**	**Construction**	**Post – Construction**
5. Knowledge of reusable details				
• Standard design details	•	•	•	
• Specifications	•	•	•	
• Method of statements	•	•	•	
6. Knowledge of best practices and lessons learned	•	•	•	•
7. Knowledge of performance of suppliers			•	•
8. Knowledge of who knows what				•
9. Other types of knowledge				
• Risk management	•	•		•
• Team working	•	•	•	•
• Project management	•	•	•	•

2.4.4. Barriers to Knowledge Management in Construction Industry

Knowledge management is very crucial to be successful in modern economy but implementation may not be straightforward. Especially, construction industry as a project based industry have some limitations and barriers to implement knowledge management successfully (Kivrak et al. 2008). It is obvious that knowledge management is not a new concept for construction industry; organizations are partly successful at managing knowledge with the help of experienced staff. New consideration about knowledge management is that putting it into a structured form (Carrillo 2004). Tools and techniques have been underway for establishment of effective knowledge management; however, efforts have not provided a best solution for capture and dissemination of knowledge yet (Hari et al. 2004; Kamara et al. 2003; Kivrak et al. 2008; Ly et al. 2005; Shelbourn et al. 2006; Wetherill et al. 2002). Construction companies are accepted as successful about collecting and storing explicit knowledge, whereas they are not good enough to retrieve and share this knowledge. On the other hand, explicit knowledge does not cover all the knowledge that is used by construction industry. Tacit knowledge, which is acquired during execution of projects, is more important in terms of providing competitiveness and sustainability of organizations. Converting this valuable tacit knowledge to explicit knowledge to take full advantage needs some effort; however, there are some problems to achieve this transformation (Hwang 2014; Kivrak et al. 2008). KPMG (2000) report states that 'lack of time to share knowledge', 'failure to use knowledge effectively' and 'difficulty of capturing tacit knowledge' are the main problems about knowledge management. Tan et al. (2010) also identify main barriers for management of construction knowledge. 'Lack of standard work processes', 'not enough time', organizational culture', not enough money', 'employee resistance', and 'poor information technology infrastructure' are stated as the main barriers. Importance of these barriers are determined by Kivrak et al. (2008) in a survey conducted among eight large scale Turkish construction contractors. Result of this survey is given in Figure 2.8.

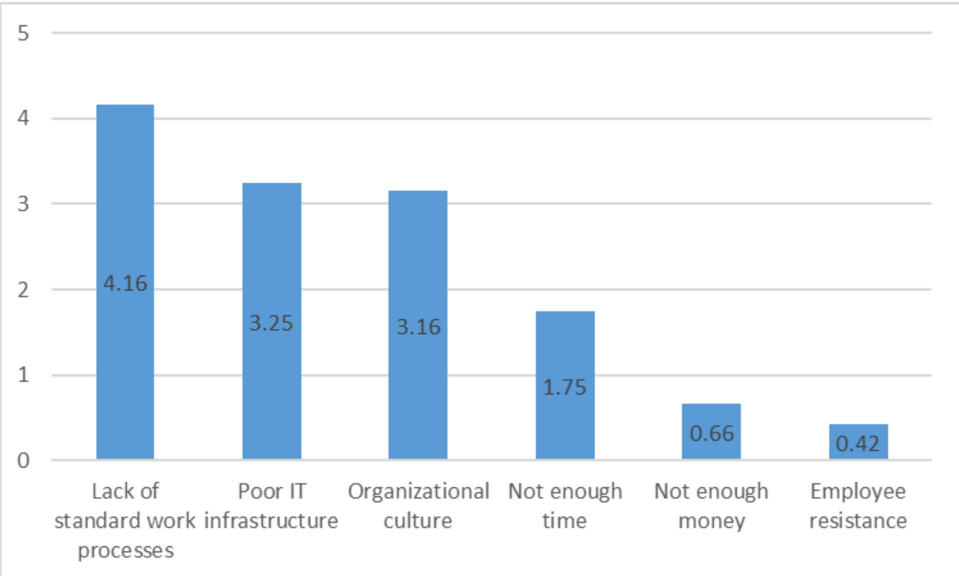


Figure 2.8: Knowledge Management Barriers with Importance (Kivrak et al. 2008)

Senior manager support for knowledge management processes is also seen important. Successful knowledge management process is time consuming and needs some organizational changes. Therefore, it may not be successful and beneficial as much as it is expected without senior manager support (Tan et al. 2010).

Post project evaluation is used at most for capture of project knowledge in the construction industry. This system enables capture of knowledge; however, it is not very effective due to lost personnel, insufficient time, and loss of important insight due to time lapse. These problems are emerging for post project evaluation because construction is a project based industry and team members are leaving the projects to take part in other projects following the handover of their responsibilities (Abu Bakar et al. 2016; Hwang 2014; Kamara et al. 2003; Kivrak et al. 2008; Opoku and Fortune 2010; Wetherill et al. 2002). Even if post project evaluations are done with right people, there is a problem associated with the human nature. Most of the time, people do not want to share their failures and mistakes (Yıldız 2012). Good practice sharing is also limited because according to (Carrillo and Chinowsky 2006) "knowledge is power" and team members may not want to share this valuable resource with others.

(Rezgui 2001) summarizes the reasons behind poor handling of knowledge management in the industry as follows:

- **Dependency to individual knowledge:** Most of the construction knowledge resides in the minds of the individuals,
- **Complexity of project data:** The intent behind decisions is often not recorded or documented, considerable effort is required to manage the project-related data such as ad hoc messages, phone calls, memos, conversations, etc.
- **No cooperation between the knowledge creator and user:** people that are to be collecting and archiving project data may not be aware of the specific requirements of the people that will use it,

- **Post-project evaluations/Relocating personnel:** the data is usually captured at the end of construction rather than at the time it is observed, so knowledge is lost with the left personnel,
- **Unorganized lessons learned:** excessive details with the lessons learned create problems to compile and disseminate the valuable knowledge to where it is needed,
- **Hidden meaning in project data:** Most of the historical reports of projects are unsuccessful in presenting the meaning assigned by the original authors, the historical data should be sound in representation of data context to be used with minimum (or no) consultation,
- **Reluctance to change:** Potential benefits that may accrue from adoption of new approaches in knowledge management are intended by the organizations; however, the necessary changes in individual roles and organizational processes are generally resisted.

From another perspective, Egbu (2004) presents the barriers to the success of knowledge sharing in construction organizations as follows (Zin and Egbu 2009):

- Incoherent knowledge vision/lack of ownership of the knowledge vision,
- No appreciation/lack of appreciation of knowledge as an important asset,
- Lack of an information-sharing culture and climate,
- Lack of/or inappropriate methods/tools for measuring and valuing knowledge,
- Lack of/inadequate standardized processes,
- Rigid/inflexible organizational structures,
- Time constraints and pressure on key staff/knowledge "experts",
- Fear of the use and application of IT tools for KM (Technophobia),
- The "knowledge is power syndrome" and failure to see the "law of increasing returns" associated with knowledge creation – shared knowledge stays with the giver while enriching the receiver, and
- Lack of a clear purpose and shared language and meaning of KM.

In a further study Zin and Egbu (2009) classifies the key issues affecting knowledge management initiatives in the industry as; finance, culture, technology and people.

Successful knowledge management can be achieved with developing necessary tools with the support of organizational culture and necessary resources. Practicality of methods and inexpensiveness of solutions may also be required to make the companies be able to adopt these solutions.

Similarly, Yang et al. (2014) mention the barriers that construction organizations may encounter during knowledge management implementation as; the lack of standard processes, insufficient time, poor organizational culture, insufficient funding, employee resistance, and poor IT infrastructure.

Therefore, successful knowledge management can be achieved with developing necessary tools with the support of organizational culture and necessary resources. Practicality of methods and inexpensiveness of solutions may also be required to make the companies be able to adopt these solutions (Graham and Thomas 2007; Hari et al. 2004; Ly et al. 2005; Shelbourn et al. 2006; Wetherill et al. 2002). The failure of the industry lies in the lack of these mechanisms, processes that provide a formal structure/strategic framework for capturing of knowledge that used in construction processes (Cushman 1999; Dikmen et al. 2008; El-Diraby and Zhang 2006; Ly et al. 2005; Shelbourn et al. 2006; Vakola and Rezgui 2000). Thus, a successful mechanism that would overcome most of the barriers for effective management of knowledge is required in the industry. In consideration of these barriers, Lin and Lin (2006) summarize the critical success factors for effective knowledge management in the industry as follows:

- Establishment of a reward strategy and mechanism,
- Development of a knowledge management department in the organization,
- Evaluation and monitoring of knowledge management process,
- Clear definition of objectives and rules,
- Mutual trust among parties,
- Mechanism to approve activities for contribution to knowledge,

- Friendly and functional system to exchange and reuse knowledge,
- Willingness to share knowledge,
- Ability to generate innovative ideas, and
- Top management support.

Similarly, Kamara et al. (2002b) state that effective knowledge management system should include both organic and mechanic measures. The following arguments need to be taken into consideration in development of a knowledge management tool/system:

- Readiness of the organization for knowledge management needs to be assessed to identify the structures, policies, resistors and enablers that would affect knowledge management implementation in the organization.
- Knowledge management strategies need to be linked with business problems so the system should direct the organization in selecting the right strategies.
- Technologies need to be integrated with business processes across corporate and project organizations through use of tools such as enterprise resource planning (ERP) and business intelligence (BI) tools.

Cost-effective methodologies and tools for the 'live' capture of project knowledge need to be generated for effective use of project knowledge and thus enabling effective management of knowledge.

2.4.5. Review of Previous Work in the Construction Industry

Knowledge management activities within construction industry can be grouped as "technical enablers" implying the "information and communication technology (ICT)" and also as "social enablers" consisting of "organizational structure" and "organizational culture. Different endeavors have been undertaken in the industry to meet the specific requirements of knowledge processes as (Kale and Karaman 2011):

- Knowledge acquisition (searching, collaborating, creating);

- Knowledge conversion (organizing, storing, integrating, combining);
- Knowledge application (retrieving, sharing); and
- Knowledge protection (securing).

Knowledge management in the construction literature has been revolved as follows. The traditional focus has been (Arriagada D. and Alarcón C. 2014):

1. firstly on constructability: quality and productivity: as functional, space and sequential coordination strategies between different specialties;
2. secondly on learning strategy: improvement of products and processes by simplifying the processes and eliminating errors and so increasing productivity; and
3. thirdly on innovation: adoption of new materials, processes, and technologies, using the strategy of imitation, adaptation, and invention.

Whereas, recent focus in the industry has been shifted to (Arriagada D. and Alarcón C. 2014):

1. technology: as adoption of ICT;
2. people: as different actors in the production process; and
3. process: as various activities, flows, and production sequences.

Even knowledge management is an attractive topic in the literature, adoption of the knowledge management systems by company professional is very low. They are reluctant to invest in these technologies; however, increasing demands in the industry forces the companies to establish knowledge management strategies (Belay et al. 2016). Most of the studies in construction industry are informal and people centered and lacking formal strategies (Abu Bakar et al. 2016). As it is stated earlier in the study; endeavors undertaken for management of knowledge in the industry mainly occurs at two levels, as “project level” and “firm level”. Standard operating procedures, best practice guides, and codes of practice are used at the firm level; however, project based industry needs more knowledge of the projects being executed (Kamara et al. 2003). Post project evaluation is a mostly used strategy for capture of project knowledge in construction industry. This system enables capture of knowledge; however, it is not very effective due to factors such as; lost personnel, insufficient time, loss of important insight due to time lapse. These evaluations would also be limited in dissemination of knowledge since they have been handled by previous personnel (Kamara et al. 2003; Kivrak et al. 2008; Wetherill et al. 2002). Besides these, framework agreements are used; however, these may lead vulnerability due to high staff turnover rates in the industry (Kamara et al. 2003). Directory of expertise and intranets provide agility, reduce the cost and increase value and quality; helpdesks and websites also bring some benefits; however, these technologies raise some confidentiality and copyright issues (Patel et al. 2000). Use of information technology in forms of ISDN (Integrated Services Digital Network) networking, CAD (Computer-Aided Design), workflow management tools, other groupware applications for collaborative working, project management applications and office tools are wide in use, where large firms in the construction sector also prefer to invest in intranets, or (project) extranets (Kamara et al. 2003; Shelbourn et al. 2006). In addition to these, current practice is adoption of BIM (Building Information Modeling) in knowledge management processes. Abilities of BIM as capturing of information in a digital format, easy updating and transferring, and visualization have the potential to promote possibility of capture and dissemination of knowledge (Deshpande et al. 2014; Ho et al. 2013).

Studies held in construction management literature show that large construction companies have used different approaches such as formal scheduled annual meetings, impromptu telephone calls, formal documents like checklists, recommendations, and manuals with the ultimate aim of sharing explicit and tacit knowledge. However, the studies also show that implementation of knowledge management in small to medium sized construction companies are very limited (Hwang 2014). Following studies summarize the identified construction company solutions according to knowledge processes in studies on United Kingdom, Turkey and Hong Kong respectively and some more classification studies as presented in Table 2.8 (Bigliardi et al. 2014).

Table 2.8: Examples for Knowledge Management Solutions

Adopted Knowledge Management Solutions
United Kingdom (Carrillo et al. 2002) • creation of knowledge: discipline-specific and include computer-aided design (CAD) systems, analysis systems, estimating systems, etc. • processing knowledge: word processors, spreadsheets, desktop publishing systems, databases, etc. • sharing of knowledge: intranets and other groupware systems such as videoconferencing, document management systems, bulletin boards, shared databases, electronic mail systems, etc. • capture and codification of knowledge: tools generally based on the concept of "artificial intelligence" and effective decision support systems (DSS)
Turkey (Kivrak et al. 2008) (in the order of importance) • capturing knowledge: colleagues, company's experience, personal experience, company documentation, current project documentation, project team meetings, intranet, personal library, clients, Internet, knowledge brokers external to the firm and external events (e.g. conferences, seminars, etc.) • storing knowledge: reports, the folder, computer files, personal archives, own head, minutes of meetings, video tape, Internet and email • reusing and sharing knowledge: on-the-job training, intranet, meetings, face-to-face interactions, e-mail, as well as traditional techniques such as face-to-face conversations, meetings, phone calls and teleconferencing and informal chatting and storytelling
Hong Kong (Fong and Choi 2009) • knowledge acquisition: external sources as specific staff in the workplace and internal sources as job rotation, reduction of valuable knowledge into writing at staff departures and experience evaluations at project conclusion • knowledge creation: exploration of alternative solutions for the assignments in the workplace, motivation to spell out work-related suggestions, developing new knowledge from existing knowledge, identifying the best practice for future use • knowledge storage: paper and electronic means, the organization's routines/procedures, the human brain with firms' documentation and personal reference files for explicit knowledge, and electronic databases, written documentation and remaining with individuals for tacit/implicit knowledge • knowledge transfer: mentoring, expert input into specific projects, daily interaction, electronic means and documentation • knowledge distribution: electronic means and documentation • knowledge use: knowledge/experience learned from previous projects • knowledge maintenance: use of databases/libraries
Classification of ICT tools in the industry (Bigliardi et al. 2010) • knowledge creation: CAD, virtual reality, investment workstation; • knowledge capturing and codification: expert systems, neural nets, fuzzy logic, genetic algorithms, intelligent agents; • knowledge distribution: word processing, imaging and web publishing, electronics calendars and personal information management; • knowledge sharing: groupware, computer-supported cooperative work, intranet and portals; • knowledge use: e-meetings, group DSS, collaboration suite, e-mail and broadcast software; • knowledge protection: virtual protection network and firewall; and • knowledge search and acquisition: browser, data warehouses and database index systems.

Table 2.8: Examples for Knowledge Management Solutions (continued)

Adopted Knowledge Management Solutions
Classification of technical knowledge management enablers in the industry (Kale and Karaman 2011) • knowledge acquisition: internet, intranet, knowledge work systems, knowledge discovery tools, concept/mind mapping, electronic community of practices, and data mining; • knowledge conversion: corporate and project databases, knowledge entries, artificial intelligence, expert systems, and indexing/searching system; • knowledge application: intranet, internet, knowledge sharing boards, newsgroup and web-based discussions, enterprise information portal, groupware, and decision support systems; and • knowledge protection: firewall system and information security system for tracking and restricting access.
Classification of social knowledge management enablers in the industry (Kale and Karaman 2011) • knowledge acquisition: formal training, post project reviews, questionnaire surveys, knowledge audit collaboration with clients, subcontractors, and supplies, and performance monitoring; • knowledge conversion: procedures, rules and processes, document management system, formal incentive system, group problem solving and decision making, and standardization process; • knowledge application: memoranda and letters, technical support, on-the-job training, internal newsletters and circulars, technical forums, communities of practice, mentoring, and storytelling; and • knowledge protection: employee conduct rules, formal rules, and procedures for protecting knowledge.

As a summary, research focus on knowledge management in the industry can be classified into three areas as (Hwang 2014):

- the ecology of knowledge management (focusing on the technology and the culture for knowledge acquisition and sharing),
- the development of knowledge management system (mainly essential requirements of knowledge management technologies and their effectiveness), and
- the development of knowledge community (investigating the impact of collaboration in overcoming the barriers in knowledge management).

In a more technology focused view, Rezgui (2001) investigates the work held in information and knowledge management area in the construction management literature and evaluates the following technology solutions:

- **Document management systems:** are the mostly used systems; however, there have been limitations in the reuse of the knowledge and lessons stored within these documents since they are generally unstructured, poorly organized, handled as “black-boxes”, and lack integration and inter-working between the available systems.
- **Product data technology:** are the standards that normalize product information as a valuable basis for data exchange and sharing; however, they generally do not address interoperability issues between product components.
- **Groupware systems:** are the systems that can enhance teamwork and minimize bureaucracy through system components such as; workflow (task scheduling), multimedia document management, email, conferencing and shared scheduling of appointments. Although there have been some related technologies, construction professionals have been reluctant to formally adopt these solutions.
- **Advanced information management systems:** are the solutions provided to support information management in a distributed object environment together with advances in information versioning, change notification and recording of intent behind decisions.
- **Decision support systems:** include various knowledge-based systems and case-based reasoning prototypes/systems that have been successful in specialized domain problems, while remain poor in facing the complex variety of sources of knowledge and the formats and media in which they are stored.
- **Data warehousing solutions:** have been described and presented as a potential solution for knowledge management in the construction industry. They have been standing out with the advances in information and communication technologies as improvements in relational database systems and middleware products enabling database connectivity across heterogeneous platforms. These solutions provide advances in separation of “informational processing” (decision making based on stable historical data)

and "operational processing" (running business in real time with current data). These solutions can organize data from different operational systems in a centralized repository. They can increase the quality and consistency of data by cleansing and transformation before using in decision-support applications. The process is depicted in Figure 2.9. (where OLAP stands for "On-Line Analytical Processing" that are the tools for accessing and analyzing decision-support information from a data warehouse and presents a set of graphical tools within an end-user interface to provide multi-dimensional view of the information base)

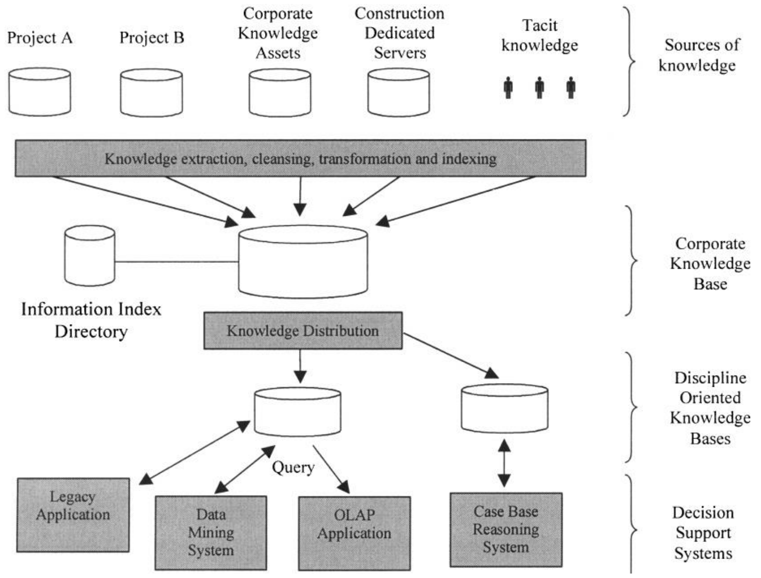


Figure 2.9: Overview of the Knowledge-Management Process Using a Data-Warehousing Solution (Rezgui 2001)

However, the stated technologies are criticized by having some of the following characteristics as; homogeneity (being fixed and not open, lack of support for legacy), high entry level (expensive solutions), lack of scalability (limited growth path in terms of hardware and software), application-centric and lacking support for business processes (need to organize the company around the adopted solution).

Similarly, Kamara et al. (2002b) summarize their observations on UK construction organizations in terms of their knowledge management processes as follows:

- there is no formal way of capturing and reusing knowledge accumulated by individuals although there is strong reliance on this knowledge,
- preferring long-standing (framework) agreements with suppliers to preserve continuity (and the reuse and transfer of knowledge),
- capture of lessons learnt and best practice in operational procedures to establish a repository of process and technical knowledge (usually through post-project reviews (PPR)),
- transfer/relocation of people in different activities to transfer and/or acquire knowledge,
- utilizing formal/informal feedback between providers and users of knowledge for transferring learning/best practice and validating knowledge (e.g., site visits by office-based staff),
- reliance on informal networks and collaboration, and ‘know-who’ to locate the knowledge,
- obstacles in dissemination of knowledge as reliance on departmental / divisional heads,
- for information sharing and communication use of appropriate IT tools (such as GroupWare, Intranets).

In accordance with the information provided, notable studies that are held in construction industry can be introduced as in Table 2.9.

Table 2.9: Knowledge Management Studies in Construction

Knowledge Management Studies	Source
KnowBiz: establishing the link between knowledge management and business performance in construction firms	(Carrillo and Anumba 2000)
KLICON: role of IT in capturing and managing knowledge for organizational learning on construction projects	(McCarthy et al. 2000; Patel et al. 2000)
A study on a project memory capture system for design evolution capture, visualization and reuse in support of multi-disciplinary collaborative teamwork	(Reiner and Fruchter 2000)
A study on retrieval of explicit project knowledge from heterogeneous documents	(Scherer and Reul 2000)
C-SanD: provide mechanisms for ensuring knowledge pertaining to sustainability where it is captured and distributed in a structured manner	(C-SanD 2001) cited in (Tan et al. 2010)

Table 2.9: Knowledge Management Studies in Construction (continued)

Knowledge Management Studies	Source
CLEVER: a framework assists construction firms in selecting an appropriate strategy for the transfer of knowledge that is appropriate for their organizational and cultural contexts	(Kamara et al. 2002a)
e-COGNOS: an open model-based infrastructure and a set of tools that promote consistent knowledge management within collaborative construction environments	(Wetherill et al. 2002)
A study on investigation of the process of knowledge capture within an organization	(Hari et al. 2004)
IMPaKT: A framework for facilitating knowledge management implementation in construction companies	(Robinson et al. 2004b)
A study on investigation of how construction project managers manage their knowledge	(Ly et al. 2005)
A framework to model the organizational memory formation process for construction companies	(Ozorhon et al. 2005)
STEPS: a mechanism entitled as "start-up–takeoff–expansion–progressive–sustainability" to measure maturity of knowledge management practices of large construction organizations	(Robinson et al. 2005)
A taxonomy and a prototypical ontology for building construction are presented with a framework for agent-based system to capture and document knowledge of the organization as a corporate memory	(El-Diraby and Zhang 2006)
A conceptual framework to formalize the knowledge-capturing process within construction companies and a Web-based system, KPfC, that facilitates knowledge capture and reuse	(Kivrak et al. 2008)
A study that aims expansion of BIM to Building Knowledge Model (BKM) and presents a software environment that links TEKLA-Structures, RECALL and TalkingPaper	(Fruchter et al. 2009)
KVAM: model (knowledge value-adding model) for quantitative performance measurement of communities of practice within a knowledge management system in an architectural/engineering company	(Yu et al. 2009)
A study of visual representation of tacit knowledge in a computer game and its effects on knowledge acquisition and retention	(Kang and Jain 2011)
A study on importance-performance analysis of knowledge management practices	(Kale and Karaman 2012)
BIMKSM: a BIM-based knowledge sharing management system that enables visualization of knowledge in the BIM environment	(Ho et al. 2013)

2.5. Concluding Remarks

"Organizational learning" and "knowledge management" concepts and the relation between them are tried to be explained by the literature review that is given in this chapter. As mentioned before, aim is providing sustainable competitive advantage to companies. This can be possible by creating a "learning organization", and "organizational learning" and "knowledge management" are the main processes in order to achieve this goal. “Organizational learning” studies are tried to find a way to develop a learning culture with in a company, which provides ability to learn from experiences of third parties or learn through the knowledge transfer as well as learn from their own experiences. Learning is a process that related with acquiring, maintaining, and developing the knowledge. Parallel with this relation, “knowledge management” is related with defining and managing organizational knowledge in an effective way in order to learn as an organization. Managing the knowledge is also important for decreasing knowledge loss. On the other hand, knowledge sources are various in construction projects and all of them may be needed special methods to manage effectively. For example, “knowledge of who knows what” can be managed with the help of organizational staff structure charts in relatively easy way. On the other hand, best practices and failures which are experienced in the past are also considered as important source of knowledge in project based industries such as construction industry. These constitutes for the “lessons learned” concept and according to Garvin (1993) learning from past experiences is the one of the important point for construction companies in order to be a “learning organization”. Figure 2.10 shows the relation between the explained concepts.

As given in the Table 2.9, works are done to find a way to managing knowledge in construction sector. All of them have similar objectives, which is managing company knowledge, but they have different approach because of the focusing on different knowledge sources. In this study, aim is defined as developing a model for managing lessons learned in the construction projects, so in order to understand what is “Lessons learned”, concept is investigated in detail and the findings are given at the following section.

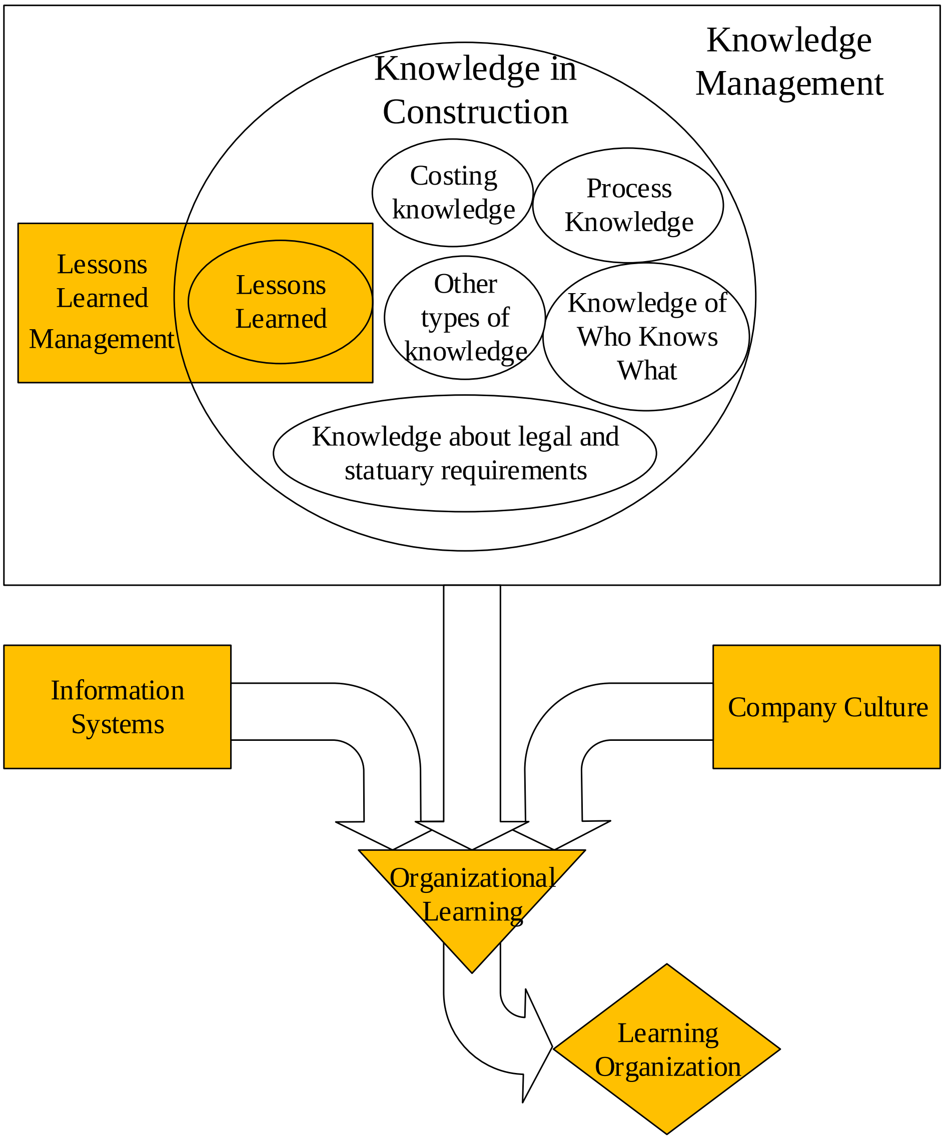


Figure 2.10: Relation between "organizational learning", "knowledge management" and "lessons learned"

CHAPTER 3

LESSONS LEARNED

"Learning" in construction management literature is mostly referred as the source of "competitive advantage" and "improved productivity" in the industry. Thus, the organizations need to establish their learning capabilities to secure their challenge for the industry. "Learning capability" of an organization is defined as "the ability of the organization to learn the lessons of its experience and to pass those lessons across boundaries and time" (Styhre et al. 2004). This capability constitutes the total of the mechanisms established by the organization to achieve continuous learning throughout the organization. Without such kind of capability, organization would be 're-inventing the wheel' rather than achieving change and improvement (Styhre et al. 2004). Therefore, within the context of organizational learning, main focus should be continuous testing of experience and its transformation into knowledge that would be available to the whole organization and would be related with their mission (Hua and Chan 2013). Assessment of effectiveness of past actions and their effects on future actions is required for organizational learning together with evolvement of insights and associations. Garvin (1993). identifies "learning from past experience/history through feedback" as one of the major activities that a construction organization should achieve to become a learning organization (Love et al. 2000). Since the construction industry is a project-based industry, learning from projects by the active learning actors as individuals and teams in a strategic context is essential (Öztürk et al. 2016). Koskinen (2012) asserts that project-based organizations learn from their members/teams as they solve project-based problems. During course of different projects, organizations can accumulate the knowledge of projects in an organizational stock that would serve as common practices to be used in the organization (Öztürk et al. 2016). The findings of the study of Fong and Choi (2009) also show the importance of lessons learned from projects. In the study, experience learned from previous projects are found to be the most important means for knowledge-use among company professionals in Hong Kong. Since projects are unique, there is no standard set of practices applicable to all projects; however, these unique properties are those creating the value by improving the procedures, processes, and technologies within the organization. The unique problems and solutions to these problems within each project constitute the tacit knowledge kept by individuals. Due to nature of construction projects as changes in locations and changes in individuals, this knowledge needs to be converted to organizational knowledge (Zin and Egbu 2009). Thus, project reviews and analysis of the lessons learned are successful mechanisms for organizational learning in construction industry (Opoku and Fortune 2010).

Learning is one of the main drivers in improvement of organizational performance (Öztürk et al. 2016). Evaluation/feedback is crucial for management cycles, it constitutes the link between organizational performance and change in the organizational knowledge (Kartam 1996; Vakola and Rezgui 2000). Reviews have the potential to provide application of lessons to similar work, at least help prevention of same mistakes of the past (Arditi et al. 2010; Kululanga et al. 1999). Performance records act as source of feedback as they address the lessons to be learned (Wong et al. 2009). Thus, evaluation and dissemination of "lessons learned" are crucial processes for every organization in order to achieve success. "Lessons learned" constitute the fundamentals of individual learning within the context of informal learning methods (Hua and Chan 2013). A case study with the Turkish architectural design firms in scope held by Öztürk et al. (2016) reveals that individual learning positively effects learning at the project level, and both contribute to learning at the organizational level. Additionally, the study indicates that learning at the organizational level has a direct effect in organizational performance while learning at individual and project levels have an indirect effect. Therefore, organizations have to learn from their past experiences, effectively use the “lessons learned”, and share this knowledge within the organization to achieve the organizational learning; and so succeed in changing and adapting to the continuously changing market conditions, and also obtain increased performance (Love et al. 2000; Opoku and Fortune 2010; Vakola and Rezgui 2000). Thus, knowledge is to be created while the organizations perform their business processes. The ways to store the knowledge and to make it available to others who may find it beneficial to use in their problems constitute the main focus of knowledge management. Therefore, implementation of lessons learned capture systems also constitutes a part in focus of knowledge management (Chinowsky et al. 2007). As a result of this focus, knowledge bases are structured as means to enable a corporate memory culture that further supports organizational learning (Vakola and Rezgui 2000). Within this context, libraries are constructed through the lessons learned by individuals while execution of different projects. Following that, the lessons are categorized and conveyed to the personnel through different means such as corporate intranets, database systems, etc. and by this way a reactive form of learning has been established (Chinowsky et al. 2007). In this chapter, lessons learned and lessons learned systems are examined in detail. As mentioned before, lessons learned are the important part of knowledge management applications so that in order to clarify this importance, definition of lessons learned term is given and its place in the knowledge management is described as a separate chapter. Possible benefits of storing and retrieving lessons learned for the construction sector and current situation within the construction industry are given in the following sections of this chapter.

3.1. Definition of Lessons Learned

According to simple definition done by Carrillo et al. (2013), “Lessons learned are the intellectual assets used to create value based on past experience.” This refined definition can be expanded as “a good work practice or innovative approach that is captured and shared to promote repeat application, or an adverse work practice or experience that is captured and shared to avoid recurrence" (Harrison 2002). According to Stewart (1997), originating point of lessons learned term is determining right and wrong parts of an event with the help of guidelines, tips, or checklists, but it is evolved during the time and according to Weber et al. (2001), it is still evolving. One of the broader definitions of lessons learned is provided by Arditi et al. (2010) and it covers all experimental knowledge which can be used to avoid failures and improve efficiency by applying the past experience knowledge called as 'knowledge artefacts' to a task, decision or process. Other definitions stated by various authors are given in Table 3.1. Different definitions are provided by various authors and organizations according to their purpose such as; minimizing waste, providing better work safety, and ensuring learning to live; however, main point is helping organizations to achieve their goals (Weber et al. 2001).

Table 3.1: Definition of Lessons Learned

Definition	Source
"a catchall phrase describing what has been learned from experience"	(Juran 1992)
"procedures developed to 'work around' shortfalls in doctrine, organization, equipment, training and education, and facilities and support"	(U.S. Marine Corps 1994) cited in (Fong and Yip 2006)
"validated knowledge and experience derived from observations and historical study of military training, exercises, and combat operations"	(U.S. Army 1997) cited in (Fong and Yip 2006)
"the knowledge gained from experience, successful or otherwise, for the purpose of improving future performance" Examples: "a lesson learned that is incorporated into a work process"; "a tip to enhance future performance"; "a solution to a problem or a preventative action"; "a lesson that is incorporated into a policy or a guideline"; or "an adverse situation to avoid".	(Construction Industry Institute 1998) cited in (Caldas et al. 2009)
"A lesson learned is a knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. Successes are also considered sources of lessons learned. A lesson must be significant in that it has a real or assumed impact on operations; valid in that is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or eliminates the potential for failures and mishaps, or reinforces a positive result"	(Secchi et al. 1999)
"the learning gained from the process of performing the project"	(PMI 2000a)

Table 3.1: Definition of Lessons Learned (continued)

Definition	Source
"A lesson learned is a recorded experience of value; a conclusion drawn from analysis of feedback information on past and/or current programs, policies, systems and processes. Lessons may show successes or innovative techniques, or they may show deficiencies or problems to be avoided. A lesson may be: 1. An informal policy or procedure. 2. Something you want to repeat. 3. A solution to a problem, or a corrective action. 4. How to avoid repeating an error. 5. Something you never want to do (again)."	U.S. Air Force cited in (Weber et al. 2001)
"the outcome of after action review (AAR)" AAR: "a discussion of a project or an activity that enables the individuals involved to learn for themselves what happened, why it happened, what needs improvement and what lessons can be learned from the experience" It is related with four leading questions: "1. What did we set out to do? 2. What actually happened? 3. Why did it happen? 4. What are we going to do next time?"	(Carrillo 2005)
"A knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. Successes are also considered a source of lessons learned. A lesson must be significant in that it has a real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or eliminates the potential for failures and mishaps, or reinforces a positive result."	European Space Agency, 2006 cited in (Caldas et al. 2009)

3.2. Knowledge Management and Lessons Learned

Knowledge assets of an organization determine the competitive position of the organization. These assets are embedded in the routines and the patterns that the organizations have structured through solutions of particular problems. Thus, firm specific knowledge as process know-how and knowledge processed by group of skilled employees constitute the intangible assets of the firm that are difficult/impossible to imitate. These competencies are generally created through repetitively performed activities within organizational processes/routines; so they cannot be bought, they have to be built (Teece and Al-Aali 2012; Vakola and Rezgui 2000). Thus, as a kind of these assets, lessons learned constitute the crucial part of knowledge management systems and organizational learning (Caldas et al. 2009; Carrillo 2005). Kivrak et al. (2008) identify duties of lessons learned practices as main drivers of knowledge management in the industry as “reduce rework”, “sharing tacit knowledge”, and “disseminate best practice”. Given the importance of “lessons learned” in knowledge management and organizational learning issues, consideration of lessons learned in the practices should be main concern of individuals in the industry. At least, an individual needs to check the occurred activity and extract a lesson learned to gain insight from an experience or benefit from knowledge management (Caldas et al. 2009). A lesson learned program is appreciated as the “vital element” of knowledge management practices of organizations. Together with the other knowledge management programs such as; training, mentoring, communities of practice, and work processes, lessons learned has critical role in knowledge management as it is depicted in Figure 3.1.

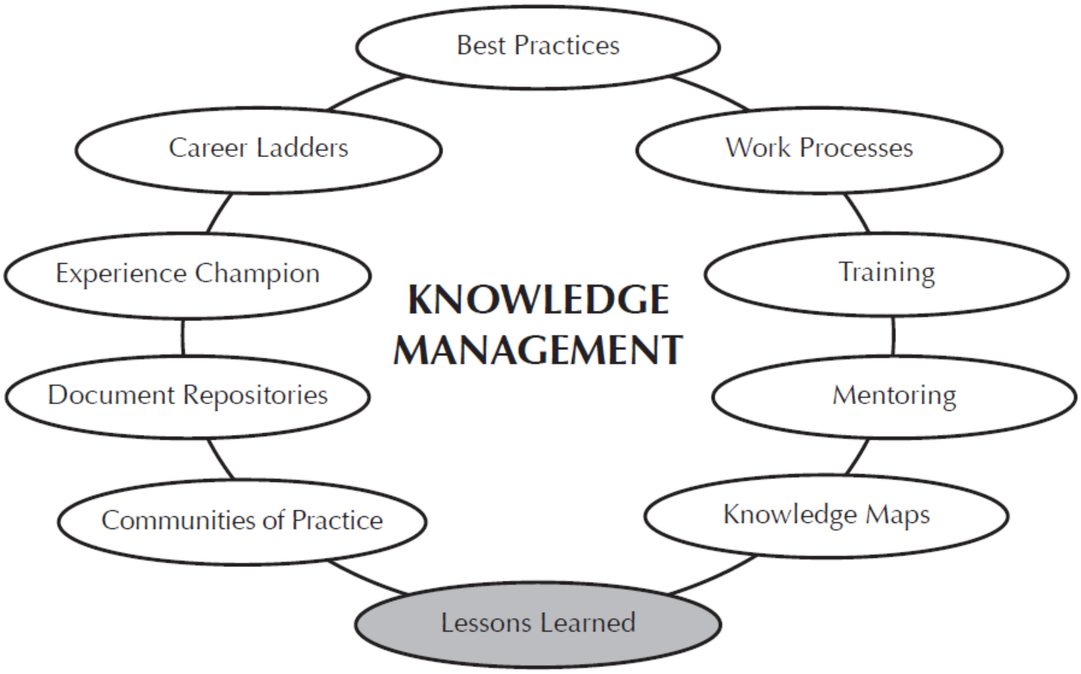


Figure 3.1: Knowledge Management Context Diagram (Construction Industry Institute 2007).

Proper use of lessons learned may provide competitive advantage to organizations (Carrillo et al. 2013). Purpose of lessons learned overlaps with the knowledge management system purposes such as; preventing loss of knowledge and providing cost savings, reducing rework, etc. (Caldas et al. 2009). Soibelman et al. (2003) state that “translating an individual’s unique project learning into corporate knowledge is essential and critical to providing a quality product”. Therefore, experiences gained in projects as problems and solutions to these problems need to be added to organizational knowledge within a process figured as below (Figure 3.2) (Lin and Lin 2006).

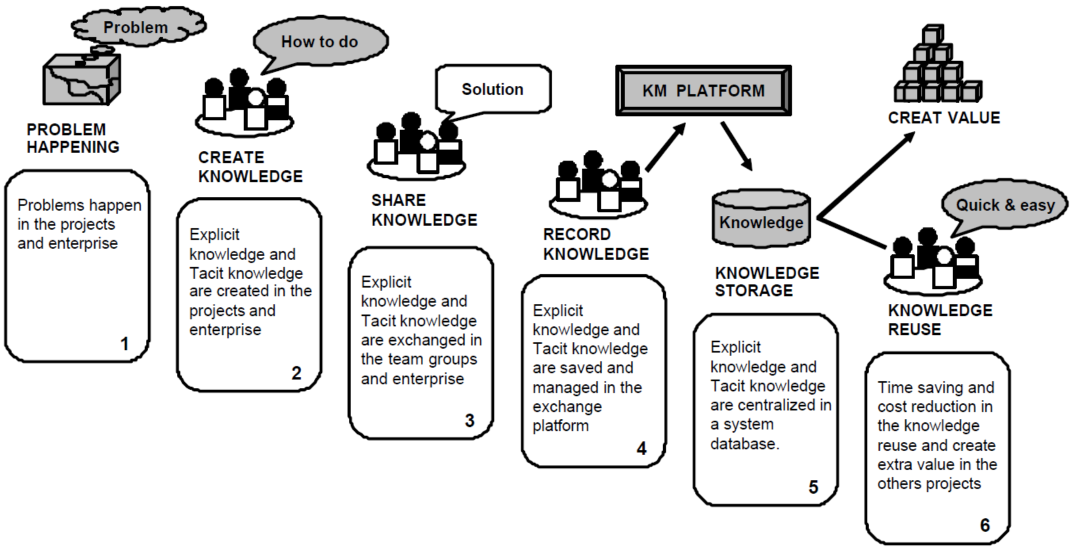


Figure 3.2: Application of Knowledge Management in Construction (Tserng and Lin 2004)

Thus, key project knowledge ranging as in Figure 3.3 can be captured within the knowledge bases of the organization and serve for future of the organization. Accordingly, lessons learned in one project would not be the lessons learned of the forthcoming projects (Soibelman et al. 2003)

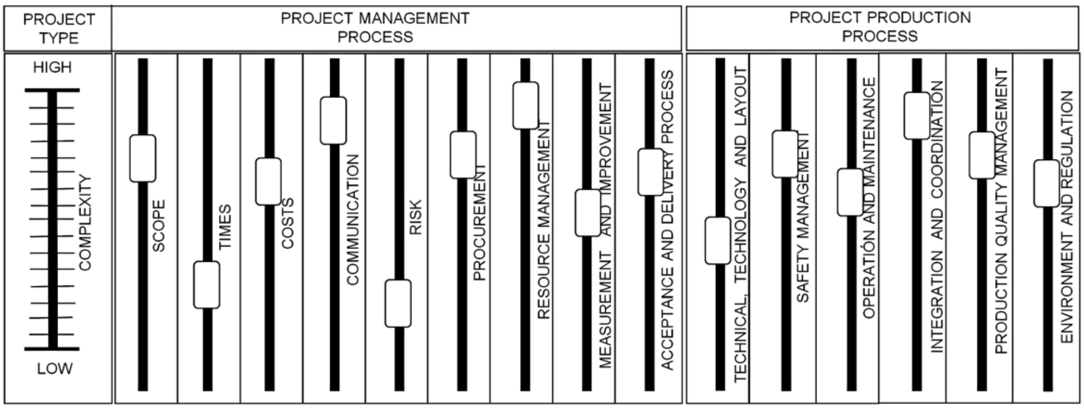


Figure 3.3: Key Project Knowledge (Arriagada D. and Alarcón C. 2014)

As mentioned before knowledge types can be classified as tacit knowledge and explicit knowledge (El-Diraby and Zhang 2006; Green et al. 2004; Kivrak et al. 2008; Nonaka and Takeuchi 1995; Ozorhon et al. 2005). If the tacit knowledge is to be kept by individuals, it may not add value at organizational level. In order to develop a successful knowledge management system, capture, share, reuse and maintenance of tacit knowledge should be achieved as well as explicit knowledge. Therefore, ideas or lessons learned from experiences should be externalized through stories, images, or other narrative forms of expression (King et al. 2008; Snell and Hong 2012). Knowledge sources defined by Tan et al. (2010) show that, tacit knowledge constitutes important part of project knowledge and lessons learned is a common type of tacit knowledge. Electronic storage and distribution of data facilitate explicit knowledge management and handled at considerable level; however, tacit knowledge management which also contains lessons learned, has not been succeeded yet, at least potential benefits have not been obtained (Arditi et al. 2010; Caldas et al. 2009; Carrillo 2005; Shokri-Ghasabeh and Chileshe 2014; Tidd and Bessant 2013). Documentation of explicit knowledge in terms of drawings, standards and specifications, constitute sound knowledge; however, capture of implicit knowledge on tools and methods in terms of problems and successful/unsuccessful solutions to these problems is more critical since it is people centered (Carrillo 2005). Conversion of tacit knowledge to explicit constitutes the link between individual and organizational learning (Fong and Kwok 2009; Graham and Thomas 2008; Tidd and Bessant 2013). These processes explained by Tan et al. (2010) as third dimension of knowledge. According to their definition apart from being explicit and tacit knowledge, there is another knowledge type which is tacit but can be converted to explicit with the necessary tools and efforts. This definition is represented in Figure 3.4.

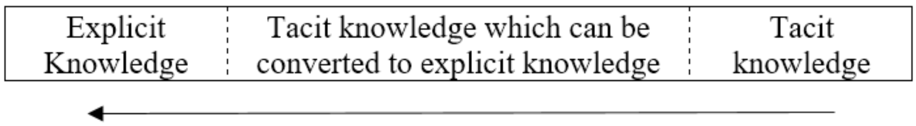


Figure 3.4: Third Dimension of Knowledge (Tan et al. 2010)

In his study Hwang (2014), investigates the maturity of organizational ecology in the construction industry considering the tacit knowledge sharing within the companies. He reveals that construction industry professionals appreciate the importance of tacit knowledge and identifies the management functions that most benefit from sharing of tacit knowledge. The sorted functions beginning with the highest importance are as follows:

- “learning best practices (know-how)”,
- “assessment of project uncertainty and risk management”,
- “scheduling and time management”,
- “analysis of job hazards and safety control”,
- “cost estimating and management”,
- “learning about local practices”,
- “site investigation for preconstruction study and mobilization”,
- “preparation for bidding”,
- “learning about rules, codes, and regulations relevant to projects”,
- “productivity or production rate study”,
- “material/equipment selection”,
- “design review for planning”,

- “quality control on site”,
- “learning about organizations involved in a project”,
- “project administration”, and
- “prequalification of contractors and suppliers for procurement”.

Thus, the study reveals the importance of lessons learned in sharing of tacit knowledge in the construction industry. In the same study Hwang (2014) also investigates the means for sharing tacit knowledge and finds out that tacit knowledge has not been successfully codified or reachable in construction companies yet. There is also not enough effort/investment or managerial support to establish systems for knowledge sharing. Companies have formal procedures for management of quality and safety; however, the case is not the same for knowledge management. As a result, practitioners count on their knowledgeable colleagues and prefer connections with their internal collaborators to reach data mainly with the means as;

- “informal face-to-face chatting/story telling with colleagues”,
- “job meetings”,
- “telephone communication”,
- “e-mail exchange”, and
- “project briefing and review sessions”.

This study indicates the importance of codification of tacit knowledge within the industry and establishment of systems to increase collaboration and communication within the construction companies. Formal structures are needed to foster the company culture to provide participation in enhancement of knowledge within the company. Besides, measures as “performance evaluation toward promotion”, “company-wide recognition”, “self-satisfaction”, and “monetary rewards” are rated as the most important measures as possible drivers to increase the knowledge sharing in a construction company (Hwang 2014).

As a summary, tacit knowledge specifically the lessons learned in construction industry is considerably required for creating value. Means for lessons learned and importance of lessons learned systems for construction sector is discussed in next part but it is obvious that managing tacit knowledge is very important to develop successful knowledge management systems in construction sector as well as other sectors. Therefore; since lessons learned which depends on the past experiences, constitutes considerable part of tacit knowledge, there is a need to develop a system to provide codification and diffusion of lessons learned (Fong and Kwok 2009; Tidd and Bessant 2013).

3.3. Construction Industry and Lessons Learned

Systematic evaluation of information about business processes, projects, initiatives, products, and personnel and programs is required mainly for problem solving and decision-making. It is needed to clarify options, reduce uncertainties, guide decisions, and provide information about programs, policies and processes. Evaluation can provide reliable and sound basis for decision-making and organizational learning; therefore, use of this information can support reducing uncertainties, improving effectiveness, and identifying causes of successes or failures. Besides, it acts as a means to provide continuous adaptation to the internal/external changes of the organization, so it is essential for organizational learning that fosters organizational growth and improvement. Accordingly, evaluation is also required for knowledge construction and capacity building. Evaluative processes play an important role in transformation of lessons into knowledge. Lessons are only acquired as knowledge as long as they are analyzed, systematized, disseminated and internalized within an organization to be used in similar projects/processes or changing initiatives in the future (Vakola and Rezgui 2000). However, construction projects generally depend on the information provided by informal methods like verbal interaction rather than formal methods like management control systems. A formal system, where participants of a project share knowledge and information, may be more advantageous in terms of learning and effective use of the intellectual resources had (Ferrada et al. 2016; Styhre et al. 2004). Main consideration of the companies should be that creation, storage and retrieval, transfer and share, and application of the knowledge that is required for development and delivery of products/services (Alavi and Denford 2012). Since projects are the main products of construction companies, project knowledge related to the product and its production are main sources of the organizational learning for construction companies. Project knowledge as knowledge gained on site is at the heart of construction knowledge domain as being the source of most of the knowledge. It constitutes the potential reusable knowledge as repeating solutions to technical problems, avoiding repeated mistakes, and so forth (Carrillo 2005; Ferrada et al. 2016; Rezgui 2001). Thus, project delivery can be enhanced through this key ability of learning from activities and utilizing this learning to continuously improve/innovate while providing a quality service or product to clients (Fuller et al. 2011). Project knowledge contains (Kasvi et al. 2003):

- Technical knowledge: related with the product, its parts and technologies,
- Procedural knowledge: in terms of producing and using the product and acting in a project, and
- Organizational knowledge: including communication and collaboration.

Therefore, project reviews constitute a vital role in transferring experience from one team to another in construction industry (Opoku and Fortune 2010). Studies indicate that construction companies accumulate knowledge and so learns mainly through problem solving and changes in construction processes (Senaratne and Malewana 2011). Tan et al. (2010) groups these learning processes as:

- Formal events: site meetings and project reviews, and
- Ad hoc events: problems and unforeseen conditions.

Construction companies need to codify knowledge, identify their critical success factors, and register the lessons learned through structured reviews of projects in order to learn from past. The lessons learned are a type mechanism for organizational learning and they can help construction companies to increase efficiency and effectiveness in their current or future actions. They may also give insight regarding the future processes that are dissimilar to current practices. However, there is not formalized procedures for project review processes so this is stated as the main reason of problems related with poor project performance in the construction industry (Kululanga and Kuotcha 2008; Love et al. 2000).

3.3.1. Importance of Lessons Learned Systems

Learning is stated to be at particular importance in the construction industry since quality of the end product is mainly affected by the "lessons learned" from projects (Vakola and Rezgui 2000). Capture of document-based knowledge is achievable by collaborative knowledge-bases; however, intrinsic knowledge such as decisions may be lost and this negatively affects the collective knowledge of the project (Paranagamage et al. 2012). Lessons learned systems provide "an effective way to share information across all segments of an organization, including employees, projects, business lines, and cultures" (Caldas et al. 2009). Besides, there is an increasing need for lesson learned systems in the industry due to "globalization of project execution" and "a considerable number of employees are approaching retirement" (Caldas et al. 2009). Construction companies need to effectively capture lessons learned at all phases of their projects and keep them alive for future use. By this way, the companies can foster the benefits such as better performance (and profits) with fewer mistakes, strengthened project team relationships and enhanced client relationships once they effectively utilize the knowledge from previous projects or the "lessons learned" and pave the way for continuous improvement (Paranagamage et al. 2012). Repeating the same mistakes in the construction industry is not affordable, while there is an opportunity of reaping the benefits of repeating the positive actions of the past. Therefore, an effective lessons learned system is crucially important for organizational knowledge in the industry. By keeping and utilizing the knowledge of experienced people in the organization, processes and procedures can be improved and the organization can take direct advantage of organizational knowledge in the competitive industry (Caldas et al. 2009). Accordingly, individuals are seen as the main repositories of knowledge in construction industry; however, change of individuals in every project makes construction companies vulnerable to individuals. "Lessons learned" is appreciated as an effective mechanism in transfer of knowledge from individual level to organizational level in the industry (Opoku and Fortune 2010; Senaratne and Malewana 2011). In the study of Kululanga et al. (1999) "review from failures/successes" has been appreciated as one of the leading learning mechanisms by the construction contractors. Carrillo et al. (2013) define lessons learned as "the intellectual assets used to create value based on past experience". They mention the importance of lessons learned by its ability to contribute competitive advantage of a company, and even to foster innovation to the extent permitted by absorptive capacity of the organization. Similarly, Paranagamage et al. (2012) have ranked the reasons for handling lessons learned between UK construction professionals and found out the following list of reasons in the rank of their importance:

1. to learn for similar projects in the future,
2. to avoid making mistakes and repeat successes,
3. to provide for a competitive edge over other companies and encourage innovation,
4. to learn lessons from consecutive stages of ongoing projects,
5. to comply with the company's knowledge and quality management procedures

They have also noted the reasons that lessons learned "helps to improve resource efficiency", "improves customer satisfaction", and "assists in the career development of the employees". Additionally, it is stated that lessons learned are also handled to "avoid corporate 'brain drain', a problem compounded by redundancies and retirement" and "encourage innovation" in the organizations.

Caldas et al. (2009) present the motivations on establishing a lessons learned system in the industry as: "to learn from past experiences", "to stop making the same mistakes", "to improve work processes and project performance", "to facilitate communication between projects and employees", "better distributing knowledge" and "helping the organization continuously improve". In addition to motivations, companies also reported some difficult-to-measure benefits of lessons learned system due to effects of multiple variables that cannot be adhered to lessons learned only. These benefits are stated as follows: “facilitate knowledge dissemination” “cost savings, increased application of best practices, and improved execution for new projects”, “reduced rework, more satisfied employees, and increased profits”.

To achieve these expected/reported benefits there needs to be an effective program to foster communication and information within the organization to add value. A lessons learned program should include “the people, processes, and tools that support the collection, analysis, and implementation of validated lessons learned in organizations” (Caldas et al. 2009). There should be a balance between the areas of (Caldas et al. 2009):

- People: support and involvement of people as the source of knowledge;
- Processes and practices: for facilitation of knowledge collection and sharing; and
- Technologies: for assisting knowledge transfer between individuals.

However, there is not a structured method, established criteria or guidelines available to learn from project reviews for lessons learned during execution of projects or after completion of projects (Kululanga and Kuotcha 2008). Thus, an effective “lessons learned database” system for construction companies that would help successful utilization of lessons learned is highly recommended since it may enable acquirement and assimilation of more knowledge by individuals and prevent dependence on individuals (Senaratne and Malewana 2011) and may also respond to challenges of globalization as culture, language, distance, and diversity (Caldas et al. 2009).

3.3.2. Barriers for Lessons Learned

It is obvious that effective handling of lessons learned is important for management of knowledge in the industry. Capture of implicit knowledge in terms of lessons learned through post-project appraisals is a well-known method in this area (Shokri-

Ghasabeh and Chileshe 2014). More specifically, the shortcomings in handling lessons learned can be evaluated as barriers to tacit knowledge sharing in the construction organizations. The obstacles can be presented in the rank of their importance as follows (Hwang 2014):

- lack of time and burden of extra work,
- lack of employees' participation,
- poor (or, ineffective) mentoring system,
- lack of motivation for sharing,
- geographically distributed employees,
- lack of organizational continuity due to project-based team,
- lack of upper management's involvement,
- lack of trust between employees, and
- burden of liability.

Fong and Yip (2006) investigate the reasons preventing adoption of lessons learned systems in Hong Kong construction industry and find out them as: (1) lack of success model, (2) lack of resources, (3) lack of time, (4) lack of top management support, (5) lack of participation, and (6) idea of "project performance is good enough".

Paranagamage et al. (2012) identify barriers for implementing/improving a lessons learned strategy in the UK construction companies as follows:

- lack of incentives
- lack of a learning culture
- being unaware of value added
- the lack of technical infrastructure
- lack of outlets to share lessons learned
- pressure of time to devote to lessons learned
- the reluctance to share problems; and
- lessons learned exercises are too generic to be of value

Carrillo et al. (2013) identify barriers to processes for recording and disseminating lessons learned in UK construction industry as:

- Process: investigating lessons learned at completion rather than at project stage gates,
- Reluctance to obtain external advice: as denial of sharing mistakes, documenting lessons learned or learning from others,
- Duplication of workload: lessons learned already existing in different formats,
- Lack of perceived value: not recognizing the value of lessons learned,
- Internal competition: reluctance to ask for help/advice between units,
- Legal issues: hindering the actual causes of problems due to possible negative consequences of acts.

Besides, (Carrillo et al. 2013) investigate the barriers for overall lessons learned practices and present the following barriers:

- Inadequate communication: different perception of site teams and head office, lack of clarity in the outcomes of site teams' actions,
- Silo environment: operations of site teams with little contact with other projects/head office,
- Little value added: there is perception of lessons learned are not useful,
- Time constraints: any action other than job on site is deemed to be ambient, there is no opportunity to deal with lessons,
- Too process driven: rather than looking the 'big picture' it is more perceived as completing the documents and submitting them in the right format,
- Culture: there needs to be a change in the perceptions as encouraging learning and being willing to offer/take advice.

Similarly, study of Shokri-Ghasabeh and Chileshe (2014) on Australian construction industry presents the identified barriers to lessons learned process as in the rank of importance as follows:

- lack of employee time,

- lack of resources,
- lack of clear guidelines,
- lack of incentive,
- the process does not capture the useful lessons, and
- lack of management support.

Besides these studies, Ferrada et al. (2016) identify the main barriers to knowledge acquirement and storage as “lack of time during projects execution” and “lack of organizational procedures to manage knowledge” in the case study on Chilean construction companies. The identified barriers are important and need to be taken into consideration in assessment of critical success factors for developing effective lessons learned strategies and their implementation as well (Shokri-Ghasabeh and Chileshe 2014)

3.3.3. Processes for Lessons Learned

Caldas et al. (2009) group processes required for management of lessons learned into three as follows:

- **Collection:** acquirement of knowledge and experience from the individuals through electronic means or by communication in formalized workshops;
- **Analysis:** analyzing and validating the collected lessons learned by a team or an individual before dissemination to ensure the information is correct and comprehensible; and
- **Implementation:** putting into action the lessons learned to derive their benefits through different methods such as; publication in an electronic database, or regenerating practices and procedures according to the lesson learned.

The mentioned lessons learned processes can be summarized with the following figure (Figure 3.5).

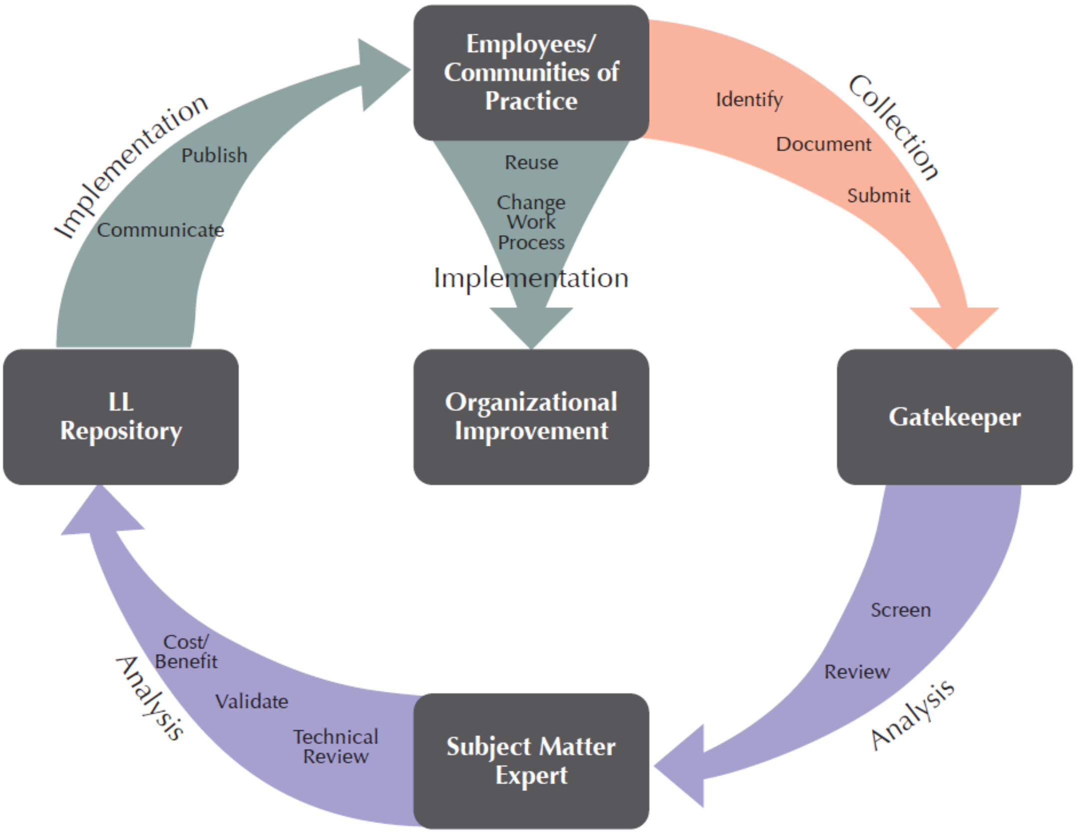


Figure 3.5: High Level Lessons Learned Process (Construction Industry Institute 2007)

In the light of the stated processes Caldas et al. (2009) present the key areas affecting the success of a lessons learned program as follows:

- **Leadership:** is required for establishing the environment required for success within the organization;
- **Lesson collection:** a system for collection of lessons is required and should be compatible with the intended data collection process;
- **Lesson analysis:** is required to transform data to usable information by ensuring the data consistency and prioritizing the data according to their contribution in organizational value;
- **Lesson implementation:** is required for reaping the benefits of lessons learned rather than just leaving them as 'best-kept secrets', circulation of

lessons learned in the organizational processes needs to be achieved by effective communication of lessons learned through database and business processes;

- **Resources:** as human, monetary, material and technology need to be allocated effectively according to the requirements;
- **Maintenance and improvement:** are required to minimize waste, promote efficiency, and increase value; and
- **Culture:** a 'learning and teaching culture' needs to be developed in the long-term by obtained positive outcomes in the progress of actions and behaviors.

Project review process requires systematic and timely assessment of identifying, abstracting, codifying and sharing all the lessons learned from project (Kululanga and Kuotcha 2008). These processes can be evaluated and so affected by the following variables used to measure project review process (Kululanga and Kuotcha 2008):

- timing for project reviews: such as after action reviews, mid-term project reviews and post-project conferences, timely analysis is required for sound identification of value adding truths;
- project review team: structure and extent of the team established to identify and analyze the root causes of the successes and failures;
- systems approach to a project review: is the technique where successes and failures are examined as a whole at the macroscopic level first then investigated in detail by the elements at the microscopic level;
- total quality management tools: indicates that the team has the required skills to perform all the review process, management weaknesses also affect the review process;
- recording experiences in project review: it should not be writing all the past, the review process should focus on the root causes of successes or failures;
- project review depositories for lessons learned: systematic and logical codification of lessons learned within knowledge repositories as hardware/software databases for easy retrieval;

- specific lessons learned from project reviews: identifying the exact lessons learned from the project;
- sharing lessons learned from project review: knowledge should be accessible by the personnel from different levels; and
- implementation plan for lessons learned in a project review: establishing shared understanding of the captured knowledge and successful use of this knowledge within the context of organizational learning principles.

More specifically Collison and Parcell (2001) recommend the following steps for capturing lessons learned:

1. call the meeting;
2. invite the right people;
3. appoint a facilitator;
4. revisit the objectives and deliverables of the project;
5. revisit the project plan or process;
6. ask "what went well?";
7. find out why these aspects went well, and express the learning as advice for the future;
8. ask "what could have gone better?";
9. find out what the difficulties were;
10. ensure that the participants leave the meeting with their feelings acknowledged;
11. determine "what next"; and
12. record the meeting.

Fuller et al. (2011) present an event-based approach for capturing lessons learned by propagating deutero-learning principles and generating outputs for codification of lessons learned and measurement of benefits as well. The identified elements are as depicted in Figure 3.6.

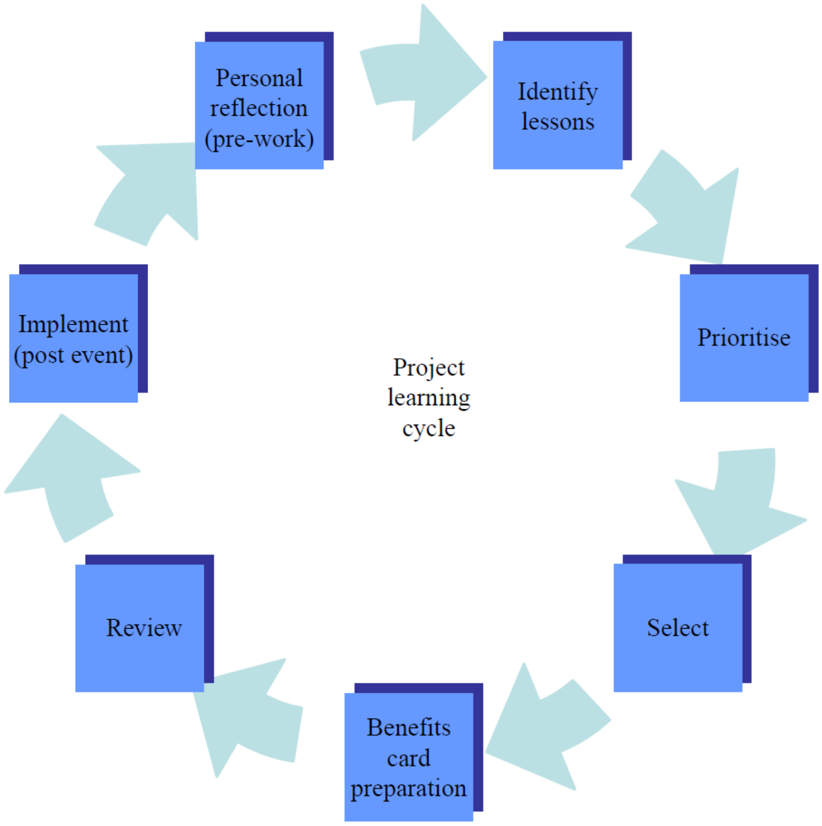


Figure 3.6: Project Learning Cycle (Fuller et al. 2011)

Besides the given studies on processes, Carrillo et al. (2013) develop a more detailed process overview for handling lessons learned. They focus on overcoming the current barriers in the UK industry and present a "Project Learning Roadmap" that would provide adoption of lessons learned practices according to requirements of stakeholders within an environment where the right lessons are conveyed to the right people at the right time. The roadmap includes processes together with; "key elements" that would create the change in lessons learned practices, "actions" need to be taken both at corporate and project levels, and "implementation guide" giving information and advice. The roadmap and its details are provided in Figure 3.7.

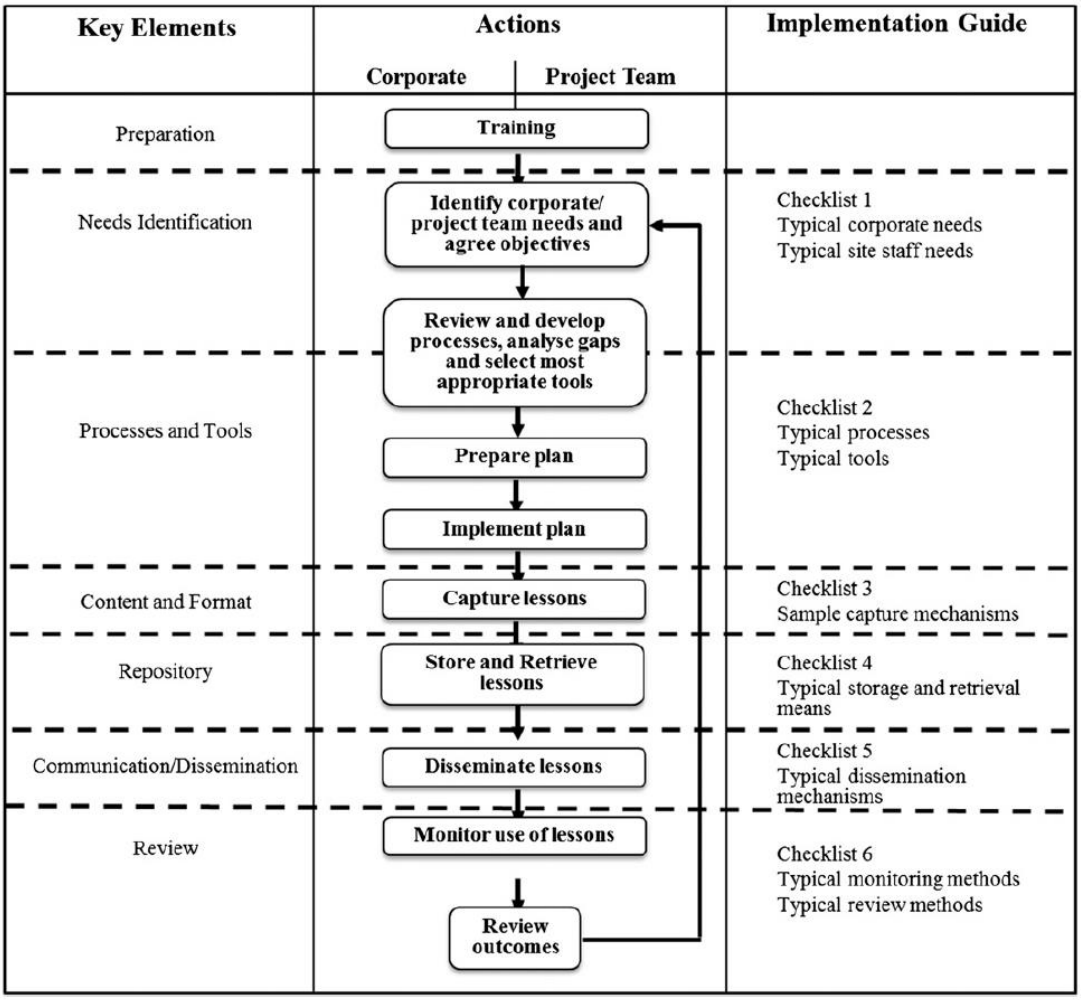


Figure 3.7: Project Learning Roadmap (Carrillo et al. 2013)

3.3.4. Review of Lessons Learned Studies in the Industry

Despite the fact that potential advantages of the "lessons learned" in the industry has been appreciated, there has been no indicator that the project teams receive the benefits of lessons learned (Paranagamage et al. 2012). Lately, lessons learned programs have been adopted more than before; however, these programs have not brought about the expected improvements and savings yet (Caldas et al. 2009). The research efforts in the area point that problems originating from characteristics of the industry such as its fragmented nature, production of unique projects and lack of organizational learning obstruct establishment of effective feedback mechanisms on the work held. The endeavors as tools and techniques undertaken in the industry have been in variety. Most popular ones are “post project reviews, face-to-face meetings and company intranets”. Other techniques such as, tacit techniques as “brainstorming and telephone conversations” and explicit techniques as “minutes of meetings, knowledge repositories and project files” are used by less than a third in the industry. Besides, “technical forums, communities of practice, knowledge repositories” are used by less than a quarter (Paranagamage et al. 2012). With the advances of IT, there has been small adoption of automated analyses, artificial intelligence and other hands-off features as support (Caldas et al. 2009). Most of the work held in the industry has been through a wider angle including “knowledge management” and so have some relation with “lessons learned” issue (Carrillo et al. 2013). The studies more specifically focusing on “lessons learned” are presented as in Table 3.2. The studies generally have been on two areas such as:

- systems and tools for capturing lessons learned (e.g.; Kartam (1996), Saad and Hancher (1998), Soibelman et al. (2003), Tan et al. (2007), etc.) and
- case studies on analysis and overview of practices on lessons learned in a specific country (e.g.; Carrillo (2005), Gibson et al. (2007), Carrillo et al. (2013), etc.).

Summary of the studies as notable studies can be provided as follows:

Table 3.2: Examples of Lessons Learned Studies in Construction Industry

Lessons Learned Studies	**Source**
LLG: presents a computer program named as “Lessons-Learned Generator (LLG)”, which enables identification of utilization frequency of lessons learned from design reviews	(East and Fu 1996)
IKIS-Constructability: an interactive knowledge-intensive system (IKIS) is generated through identification of feedback channels in a project life cycle and developing a constructability feedback prototype for making effective use of construction lessons learned in medium to large-size construction firms	(Kartam 1996)
CLLD: a system named as “Constructability Lessons Learned Database (CLLD)” is generated for automatically gathering, systematically organizing, and efficiently applying vital construction information for construction contractors	(Kartam and Flood 1997)

Table 3.2: Examples of Lessons Learned Studies in Construction Industry (continued)

Lessons Learned Studies	Source
COML2: a system named as "Constructability, Operability, and Maintainability Lessons Learned (COML2)" that focuses on achievement of organizational learning through total quality management and continuous improvement program initiatives	(Vanegas and Nguyen 1997) cited in (Arditi et al. 2010)
A study undertaken to model the lessons learned process in the construction industry	(Construction Industry Institute 1998) cited in (Caldas et al. 2009)
OKBank: a system named as "Organizational Knowledge Bank (OKBank)" for effectively capturing, processing, and disseminating organizational knowledge civil works projects, in terms of not only organizational experiences such as lessons learned, good work practices, and success stories, but also project information through use of world wide web and other relational software programs	(Nguyen et al. 1998)
Project Navigator: a decision support tool for construction managers by tracking progress on a construction project while collecting, documenting, storing, sorting, and retrieving the lessons learned by multimedia technology for transferring them to forthcoming team members	(Saad and Hancher 1998)
COLA: a facility named as "cross-organizational learning approach (COLA)" for recording, storing, making available, disseminating and tracking lessons that have been learnt in previous projects by organizing and managing learning-focused, value-enhancing reviews of construction projects; thus improving the quality of feedback and increasing organizational knowledge as well as resolving immediate concerns	(Cushman 1999)
KyTC Lessons Learned System: a study on development of a centralized and web-based lessons learned system for Kentucky Transportation Cabinet (KyTC) for collecting, archiving and disseminating lessons learned in design and construction of roadway and bridges	(Goodrum et al. 2003)
DrChecks/CLL: A design review checking system (DrChecks) together with a system of corporate lessons learned (CLL) where DrChecks provides a framework to standardize the design review process and CLL enables collection of experiences and lessons learned to add the collected data to corporate knowledge/database remotely with the advances of internet, thus continuous development and improvement of design review process is to be established	(Soibelman et al. 2003)
A case study on lessons learned practices of Canadian engineering, procurement and construction (EPC) companies	(Carrillo 2005)
A study investigates the application of lessons learned systems in construction industry in specific to Hong Kong	(Fong and Yip 2006)
A case study on lessons learned practices of a leading Irish company	(Graham and Thomas 2007)
A study on lessons learned practices of US construction organizations and development of a high level lessons learned process including collection, analysis and implementation	(Gibson et al. 2007)
CAPRIKON: A case study on requirements for the 'live' capture and reuse of knowledge; and development of a methodology (Capture and Reuse of Project Knowledge in Construction – CAPRIKON) that allows live capture of knowledge from ongoing projects and also validation and dissemination of knowledge	(Tan et al. 2007)

Table 3.2: Examples of Lessons Learned Studies in Construction Industry (continued)

Lessons Learned Studies	**Source**
KPfC: development of a web-based Knowledge Platform for Contractors (KPfC) to manage both tacit and explicit knowledge in construction projects based on a survey conducted on Turkish construction contractors operating in the international market	(Kivrak et al. 2008)
A study that focuses on identification of effective management practices and technologies for lessons learned systems in construction industry	(Caldas et al. 2009)
CMAID: A study that aims creation of a lessons learned system for acquiring, storing, retrieving, and disseminating lessons learned about construction management practices through utilization of a database named "CMAID – A lessons learned system in construction management practices"	(Arditi et al. 2010)
An empirical research (with an organization serving construction/engineering consultancy-based operations) for enhancing capture of lessons and measuring outcomes in project-based organizations using workshop-based processes	(Fuller et al. 2011)
A study that investigates the gaps in practices of the contractors in UK for capturing and disseminating lessons learned	(Paranagamage et al. 2012)
Project Learning Roadmap: A study for development of a project learning model and a conceptual model (based on research study on UK contractor organizations) in the form of "Project Learning Roadmap" to make organizations to construct individual solutions and improve lessons learned practices through establishing access to the most relevant lessons at the most appropriate time, in the most appropriate format	(Carrillo et al. 2013)
A study that focuses on storage of lessons learned information in the objects provided in a BIM model and extraction, classification and dissemination of this knowledge	(Deshpande et al. 2014)
An on-going study on design and main characteristics of a prototype system for handling lessons learned in the industry in a cloud environment (for smartphones and web)	(Ferrada et al. 2014)
A study to identify the barriers of capturing lessons learned by focusing on Australian construction industry	(Shokri-Ghasabeh and Chileshe 2014)
MCSW: A study on development of a lessons-learned system that would help construction companies to handle the limitations in the industry. Mobile Cloud Shared Workspace (MCSW) platform enables recording, representing and distributing organizational knowledge during the construction project management process	(Ferrada et al. 2016)

3.3.5. Construction Management Literature on Learning-related Concepts: Gaps and Potential Areas of Progress

As it is presented in the previous sections; construction industry is a project and people-based industry that makes it heavily knowledge sensitive as in the case of most of today's industries, where knowledge assets overweigh tangible assets (Caldas et al. 2009; Fong and Kwok 2009; Tserng and Chang 2008). Even if the projects are executed according to the rules and the ultimate aim of meeting the objectives pursued during every stage of the projects, they are open to result in failures because of the risks entailed (Akatsuka 1994). Additionally; even the projects are unique, they consist of some repetitive actions that require technical know-how (Arditi et al. 2010; Carrillo 2005). There exists considerable amount of repetition in the construction work; so the knowledge of lessons generated by one team should be shared with the other teams in the same project, and also with teams of other and forthcoming projects (Kartam 1996). Due to characteristics specific to the industry, where it is already difficult to ensure a sound coordination within a project, knowledge is lost and cannot be accumulated during course of various projects undertaken by different enablers such as workers, technicians, contractors, consultants, and decision makers (Abu Bakar et al. 2016; Al-Reshaid and Kartam 2000; Fong and Kwok 2009; Tserng and Chang 2008). Besides these, effort is required to formalize methods and establish systems that would enable keeping such kind of information and actively using it in the forthcoming projects (Akatsuka 1994; Carrillo 2005; Chinowsky et al. 2007; Fong and Kwok 2009; Wang and Leite 2016). Thus, analysis of the performance of a project with the causes and results of the failures and the best practices can prevent the problems to be repeated, and can result in cost, schedule, quality benefits together with a safer and more efficient working environment (Akatsuka 1994; Caldas et al. 2009; Carrillo 2005; Kartam 1996). An organizational memory that keeps knowledge acquired during course of a project or term of employment of personnel can resolve loss of knowledge due to staff turnover. Generic knowledge for an organization with continuous improvement of the procedures owned can bring a key competitive advantage, can constitute a concrete step for becoming a learning organization and can foster innovation in the long term (Abu Bakar et al. 2016; Arditi et al. 2010; Caldas et al. 2009; Chinowsky et al. 2007; Fong and Kwok 2009). There are not complete methods or systems formulated to use in handling and dissemination of such kind of knowledge; however, current practices are made up of use of information systems to help this issue. Information technology based knowledge management and communication systems have become compulsory to respond the needs of evergrowing, challenging and competitive industry (Martínez-Rojas et al. 2016). To successfully respond to this need, an established system is required for sharing of information and knowledge within a project, and even between different projects undertaken contemporaneously or non-contemporaneously (Al-Reshaid and Kartam 2000; Ferrada et al. 2014; Fong and Kwok 2009; Shokri-Ghasabeh and Chileshe 2014).). Capture of explicit knowledge is handled at considerable level with the help of information technologies; however, due to characteristics specific to industry, capture of implicit knowledge has not been succeeded yet, at least potential benefits have not been obtained (Arditi et al. 2010; Caldas et al. 2009; Carrillo 2005; Shokri-Ghasabeh and Chileshe 2014).

Initial attempts for knowledge management in the industry have been through people-centered strategies rather than IT supported strategies. Besides, these attempts were more focused on efficiency as “improved project delivery” instead of “generation of new knowledge” or “adaptation to changes”. There have been partial solutions to manage process knowledge; however, most of the companies of that period did not have a formal knowledge management strategy. There has been a need for viable and cost effective knowledge management solutions. As being a project-based industry, knowledge that would be obtained from projects is essential. To achieve this, efforts have been through “the reassignment of people from one project to the next, the use of standards and best practice guides, contractual arrangements (for example, framework agreements), intranets, and specific activities such as post-project reviews (PPR)” (Kamara et al. 2002b). These have been organizational arrangements rather than being a part of a knowledge management strategy and as a result, they have not been successful in capturing lessons learned from projects. PPR may be useful in codification of lessons learned for the personnel of those projects; however, they are not effective in transferring this knowledge to other participants (Kamara et al. 2002b). Because, the crucial knowledge in the industry, the tacit knowledge, is dispersed within the processes, trades, and people (Hwang 2014). Thus, the reliance on sharing of knowledge through people creates vulnerability to high staff turnover. They are also not effective since conducted when the project is completed (Kamara et al. 2002b). The established solutions have not also been complete to capture project knowledge due to deficiencies in the following considerations, which are based on different studies focused on investigating the lessons learned practices in the construction industry. The considerations are provided in a taxonomic representation structured on the major areas of “overall system”, “knowledge capture”, “knowledge dissemination”, “knowledge retrieval” and “knowledge validation:

- **Overall System:** The system should be developed following a research on review and evaluation of the available systems to satisfy the need (Fong and Yip 2006). It should be structured on the foundations of integration of both organic and mechanic systems (Kamara et al. 2002b). The system should provide facilitation in integration into the existing operations and procedures to increase its usability potential (Kartam 1996; Paranagamage et al. 2012). Lessons learned should be handled in a systematic way to ease their integration to business processes. Achievement of this, further enables establishment of databases where useful knowledge is stored and thus lessons learned can be used in the forthcoming projects (Carrillo 2005). The possible considerations on the system should be as follows:
  - **Extent/Scope of the System:** Frequency of recording bad/good practices is observed to be unbalanced in the industry (Fong and Yip 2006; Kartam 1996). System should encourage recording of bad practices as much as recording of good practices, so balance should be established. Because, learning from failures is crucially important since they may cause heavy losses for the construction organizations and learning from best practices has a potential to bring efficiency in processes. Additionally, recording of practices at different stages of construction projects is discovered to be not common in the industry (Fong and Yip 2006). Most of the initial attempts have been on the design phase; however, collection and utilization of lessons learned in all phases of the projects should be established, since lessons learned opportunities can occur in all phases of the project life cycle (Kartam 1996). Most of the available tools are limited with capturing

knowledge of only specific types of projects (Arditi et al. 2010; Tan et al. 2007). The system should be able to capture all project knowledge “irrespective of the type of project, the type of construction organization and project phases, and particularly capturing the knowledge ‘live’ has not been adequately addressed” (Tan et al. 2007). If live capture is not possible, periodic conduction of lessons learned studies is required, which can be linked with the project stage gates to reduce the vulnerability of lessons learned to elapsed time or leaving personnel. Lesson learned investigations in these meetings should be carried out with all team leaders and the supply chain in an open discussion environment to identify the different perspectives on the problems and their root causes (a trained facilitator can also be included to draw out problems) at an extent including all business processes (such as; line and staff operations) (Carrillo 2005; Soibelman et al. 2003). These investigations should be conducted for all projects that meet certain prescribed criteria such as; innovative design and construction aspects, complex projects, substantial deviation to schedules, method of construction, etc. (Carrillo 2005). Adequately captured lessons learned may be focused on different areas according to the business needs of the organization and may be attractive for different business units. For example, owners may be more interested lessons on front end planning, overarching project control and operational issues, whereas contractors may consider lessons about project design, construction, and turnover issues. Therefore, each party has a potential to gain insight and knowledge from lessons of others (Caldas et al. 2009). Thus, great participation of the people in the organizational network should be achieved to benefit from the conclusions drawn (Kartam 1996).

- **Culture:** The role of culture within a lessons learned system should be seriously taken into consideration (Caldas et al. 2009). A mature organizational ecology is needed for effective sharing of tacit knowledge at the workplace, where coordination between upper and lower management is successfully achieved by organizational investment for facilitating tacit knowledge sharing (Hwang 2014). Mechanisms for encouraging the people to correspond to the organizational standards for conducting, recording and dissemination of lessons learned should be generated (Carrillo et al. 2013; Paranagamage et al. 2012). Blame culture should be prevented through use of an experienced facilitator that may help codification of lessons in an unbiased and blame-free way (Carrillo 2005). The system should be capable of overcoming the cultural differences within the organization (such as differences between engineering, construction or operations) or differences due to different geographical locations/languages. It should encourage consistent use of the system by different disciplines (Caldas et al. 2009). Setting a framework aimed for effective capture and use of project knowledge through framework (long-term partnering) agreements with clients, suppliers, etc. can be considered for successful utilization of the system among different disciplines (Kamara et al. 2002b). Offering different kinds of incentives can be one of the mechanisms that would support fostering the culture within an organization (Paranagamage et al. 2012).

- **Leadership:** Top-level leadership can be an important factor in achievement success in a lessons learned system, so leadership role should be established within the culture (Caldas et al. 2009). The leadership style that would foster the culture should be shown and breadth of vision developed by senior management should be broad enough for delegation of responsibility for generating (capture and analysis) and disseminating the lessons learned (Paranagamage et al. 2012).
- **Prioritizing and Sharing Objectives:** Lessons learned programs should be established based on the prioritization of the organizational objectives by focusing on the areas of loss of knowledge is at most (Paranagamage et al. 2012). Additionally, there has been poor

communication channels between construction experts and the less experienced individuals taking role in these systems (Kartam 1996). There has been a great emphasis on people-to-people dissemination habits; despite the organizational tools provided for facilitating these processes. Therefore, the lack of communication and transparency between site teams and head-office teams should be overcome for the sake of the established lessons learned systems (Carrillo et al. 2013). The system should be generated as a result of an interaction process between the designers and the users of the system to structure an effective solution responsive to the need (Paranagamage et al. 2012). Training for ensuring that every individual within the organization is aware of the importance and utilization such a lessons learned system can be provided (Fong and Yip 2006). Therefore, lessons learned system should be institutionalized in a way to create the atmosphere for capturing of lessons learned and investigating the lessons before starting new projects and whenever it is needed (Carrillo 2005; Paranagamage et al. 2012).

- **Cost:** The lessons learned system adopted for the capture and reuse of the useful project knowledge should not cause considerable additional cost to the companies. Cost components such as; staff costs of knowledge management team; organizational costs for knowledge management process; and knowledge management infrastructure costs as information and communications technologies (hardware and software) and their maintenance should be considered in development of a lessons learned system. The system workload should be carried by ICT and should not require any significant additional staff or increase the workload of the personnel to minimize the cost. Additionally, some level of adaptation should be provided for building the system on the existing practices and available ICT systems and platforms (Paranagamage et al. 2012; Tan et al. 2007)

- **Workload:** The system should not impose any considerable workload to the individuals of the company, since it may not be described in the individual's current job description or covered in his/her employment contract (Tan et al. 2007). Therefore, the system should adopt effective mechanisms and formal policies that would support a culture where company-wide interaction among individuals is boosted and individuals are voluntarily participating in transfer and dissemination of their tacit knowledge, and not considering this process as extra workload (Hwang 2014). To establish such an effective system; adoption of online systems/websites, use of centralized databases and process automation can be considered for integration to the system (Soibelman et al. 2003).
- **Integration of Web/Mobile Technology/Cloud System:** Integration of intranets/extranets to the system has advantages in overcoming the barriers due to distributed teams and establishing knowledge-push based dissemination processes (Carrillo 2005; Kamara et al. 2002b). Construction organizations have already adopted use of web through searchable web based databases (on the internet or an intranet). These systems provide flexibility in lesson collection without regard to locale; however, careful attention should be provided for establishing, operating, and maintaining the database, while considering security issues due to web-based system (Caldas et al. 2009). Moreover, use of mobile devices provides additional advantages for the system; however, their limitations in storage and processing capabilities require integration of a third component as cloud systems to meet the storage of constantly growing amount of information where it is impossible to store them all in the smartphone/tablet (Ferrada et al. 2016).
    - **Security:** Ensuring security should be one of the main considerations when a web/cloud based system is to be generated (Ferrada et al. 2014).
- **Legal Issues:** A legal framework should be set between the project team members for capture and reuse of the knowledge to prevent restriction of information/knowledge disclose. The framework should clear the issues on

the sharing, capture and reuse of knowledge from a project. It should set out that these actions are to be voluntarily and do not cause breach of copyright or the conditions of contract (Tan et al. 2007).

- **Resources:** The required resources such as; human, monetary, material and technology need to be allocated effectively within the system according to the requirements (Caldas et al. 2009).
- **Dynamic System:** the system for lessons learned should be dynamic in nature to respond the changes in priorities of the company or the sector (Paranagamage et al. 2012).
- **Performance Measurement:** In most of the established systems there have been a gap between utilization and usefulness of the system, benefits of the used techniques and tools have not been investigated properly. This gap acts as a barrier and prevents generation of fully effective solutions according to the need. Therefore, a reliable performance measurement mechanism needs to be established for evaluation of the adopted system (Paranagamage et al. 2012).

- **Knowledge Capture:** The major success of a lessons learned system should be first, effective capturing of the tacit knowledge (Hwang 2014). Effectiveness should be provided through establishing a corporate memory and generating successful strategies in timely capture and successful representation of the knowledge within the memory.
  - **Corporate Memory:** Feedback systems in the industry generally have been based on verbal transfer of the information among a limited group of people; however, lessons learned should be preserved in a system where they would be readily available and easy retrieval of these lessons should be provided in a format to make them reachable for its users (Kartam 1996). Knowledge bases should be considered in the lessons learned system as effective means for enabling a corporate memory culture within the organizations and overcome the barrier of "most of the knowledge/lessons learned reside in the individuals' mind" (Vakola and Rezgui 2000). However, available

systems have not been successful in fully transfer of the tacit knowledge to corporate memories (Hwang 2014; Soibelman et al. 2003).

- **Timing of Capture/Live Capture of Knowledge:** Another main consideration in development of a lessons learned system should be generating cost effective methodologies for live capture of project knowledge (Kamara et al. 2002b). Most of the available systems are structured on collection of the data generally after construction process when the related people has left for another project, rather than capturing them at the time that they are created (Vakola and Rezgui 2000). This lengthy time-lag between a lesson being learned and recorded, and also the timing of the review cause the evaluation processes to be poor in detail (Carrillo 2005). Individuals generally forgot the issues and lessons by the conclusion of the project, even if they remember particular issues, they become far from recalling/stating and documenting the contributory circumstances. Following completion of a project, individuals become eager to think more about the future rather than thinking and codifying the past, and they think this process as an extra burden (Kartam 1996) Thus, those people that are collecting and archiving the data may be far from the specific needs of the potential users of the data (Vakola and Rezgui 2000). These habits in the current systems cause the loss of the important experiences that would be potentially used in construction projects (Fong and Yip 2006). Therefore, timely capture of lessons learned in a collaborative environment is required to overcome the construction industry specific barriers as “time lapse in capturing the knowledge”, “staff turnover” and “people’s reluctance to share knowledge” (Tan et al. 2007).
- **Knowledge Representation:** A standard approach is required to provide consistency in codification of the lessons learned across the whole projects (Carrillo 2005; Tan et al. 2007). The captured knowledge should be organized and represented in a logical and easily understandable format to make them fully accessible to other individuals in the organization (Tan et al. 2007). Thus, lessons learned should be provided with a suitable level of

‘indexing’ and stored electronically to enable their easy access (Carrillo 2005). A standard format for representing the reusable project knowledge should be set, which may be through: (1) attributes describing lesson itself, (2) supportive source and context information describing the lesson, and (3) means for classifying/indexing by multiple parameters for fast and clear retrieval of the lessons (Kartam 1996).

- **Content and Format of Lessons Learned:** The major limitation of the evaluations after project completion has been the inadequate documentation of lessons learned in an unmanageable format, which prevents their access, retrieval, and updating and so prevents their usage in the future (more important for the large companies with several offices) (Kartam 1996). Most of the time captured lessons learned are not well organized, companies keep historical data of the projects and the lessons are buried in excessive details which may only be understandable by their authors rather than conveying their actual meaning to others (Vakola and Rezgui 2000). In construction industry, lessons learned can take any shape; so a simple, comprehensive and flexible framework is needed to document a lesson learned (Kartam 1996). Lessons learned should be provided in a suitable content and format for nature of the use and ease of sharing (during and after project), they should address the objectives at project and corporate level and the processes should be responsive to handle the identified problems (Paranagamage et al. 2012; Tan et al. 2007). The lesson may be described through:
  - ✓ **Abstract/Lesson Title:** as a short description of the captured knowledge (Kartam 1996; Tan et al. 2007), and
  - ✓ **Details:** Case studies or detailed explanation of the knowledge through case studies to make them understandable and reusable (Tan et al. 2007). These may be description of the problem/situation, description of the solution/method,

responsibility, additional comments and some more supportive information (Carrillo 2005; Kartam 1996).

- **Supportive Information:** In most of the lessons learned systems, the intent behind the decisions have not been recorded. It is very troublesome to track and record the ad hoc messages, phone calls, memos, and conversations for sorting out the project-related information between all (Vakola and Rezgui 2000). Therefore, supporting information of projects, namely browsing "projects" together with discovery of "best practices" to comprehend the reasoning behind the success or failure is required (Kamara et al. 2002b). The system should provide flexibility in supporting different file formats and storage mechanisms (Paranagamage et al. 2012). Attachment of compatible files to the lessons learned such as; documents, photographs, illustrations, and graphics (e.g.; Word, Excel, JPEG) to enable further explanation on the lessons learned and establishing a discussion forum for the lessons learned can be integrated to the system to promote dialogue between participants (Saad and Hancher 1998; Soibelman et al. 2003). Supportive information for the lessons learned can be as follows (Tan et al. 2007):
    - ✓ **Project background:** Project title, project location; project sector; type of project; type of contract, start and completion dates, duration, companies/participants involved, and date on which the knowledge is captured (to address the knowledge obsolescence issue) may also be included for further comprehension and effective retrieval of the lesson,
    - ✓ **Compatible Files (Document/Multimedia):** such as Word file, Excel file, pdf file, video clips, images and photographs can be attached to provide further explanation for the lesson details,
    - ✓ **Conditions for reuse:** to inform the user about the possible conditions that the particular knowledge entry may be used,

- ✓ **Reference:** may be provided for other relevant knowledge captured in the system, project documents, publications (e.g. books and reports), websites and people, as sources of further details,
- ✓ **Knowledge network:** such as people's personal profile and knowledge network supported by IT-systems (e.g., discussion forum) for fostering the communication and knowledge sharing, and
- ✓ **Knowledge map/index:** for presenting the summary/overview of the available knowledge.

- **Indexing:** Most of the established systems lack a suitable classification system. A classification system is needed to make the users to easily review and extract relevant lessons for the intended use (Kartam 1996). Standardization in knowledge-sharing is to be established through indexing of items to facilitate classification and retrieval of the information. Therefore, identification of specific items and retrieval of lessons learned can be effectively achieved (Soibelman et al. 2003). Available systems have been targeting some level of classification through sorting lessons learned according to some criteria (e.g., by project type, size, location, discipline, etc.) in a text format; however, more efficient classification systems are needed (Saad and Hancher 1998). Lessons learned need to be contextualized as much as they need to be generalized to provide effectiveness and value of the lessons (Carrillo et al. 2013). If the classification system is established to be too general with broad categories, lessons may be easily classified but it would be relatively impossible to retrieve the lessons effectively (due to inability in narrowing down the scope of the search query). Whereas, if the classification system is too specific with excessive categories, indexing lessons learned effectively would be very difficult and ineffective (Kartam 1996). Indexing of lessons learned can be based on:

- ✓ project characteristics (such as; project type, client, location, and discipline/administrative department) to provide cross-referencing between the phases of processes (Arditi et al. 2010; Soibelman et al. 2003);
- ✓ reason of the lesson (such as; reason of an error, a commission, or a coordination issue) (Soibelman et al. 2003);
- ✓ date of the lesson (Arditi et al. 2010);
- ✓ topic of the lesson or area of the concern (such as; functional/technical design, construction, or operation) (Arditi et al. 2010; Soibelman et al. 2003); or
- ✓ expected effects of the lesson (such as; cost, time, quality, or scope) (Soibelman et al. 2003).

- **Knowledge Dissemination:** The established systems have been passive in knowledge dissemination in construction organizations, namely they have been the systems that require individuals to find the relevant lessons learned. However, this process deemed to be an extra burden for the individuals and they were not eager to investigate the lessons unless they are forced to do. Therefore, improvements are needed in selection of the lessons to be shared and sharing mechanisms that enable dissemination of lessons learned through "knowledge push" principles while preserving confidentiality, and also providing validity and integrity of the lessons learned. Considerable focus should be provided on the mechanisms that would target the lessons to the individuals needing most that particular lesson. Additionally, consideration should be given on alerting mechanisms for the lessons learned to make the individuals aware of the existence of the lessons learned (Paranagamage et al. 2012). To establish such systems, lessons learned should be captured and electronically stored in a standard format together with the attributes that provide adequate search of the lessons. Additionally, use of intranet for establishing "knowledge push" systems may be required (Carrillo 2005).
  - o **Knowledge Push:** To establish an effective lessons learned system, organization should gain abilities of "teaching" organizations, rather than

organizations that only collect or expect to learn from the past in an ad hoc manner. The organization should develop an active and broad-based implementation strategy rather than passively waiting for participation of the individuals in the system. With adoption of this strategy, organizations can provide utilization of lessons learned by “pushing” lessons out from the database to the active field (Caldas et al. 2009). Therefore, knowledge push systems are required for “alerting, retrieving and targeting lessons to those who need them most” (Paranagamage et al. 2012). Such a system can be achieved through support of IT and internet; for example, through automatic e-mail notification of a potential or an approved lesson to the related people (Soibelman et al. 2003). This alerting mechanism can be improved with several properties such as; providing lessons in an abbreviated form, extending to the full lesson in case of an interest, and list of keywords that would be ignored by specific individuals may be provided, etc. (Carrillo 2005).

- **Knowledge Retrieval:** Considerable focus should also be provided on the mechanisms for finding and retrieving the lessons stored (Paranagamage et al. 2012). Through the support of IT, more advanced and effective techniques can be adapted for improving the search and retrieval capabilities of the lessons learned systems. The techniques such as; case-based reasoning, data mining, and knowledge discovery in databases can support retrieval of lessons from the databases (Soibelman et al. 2003).
- **Knowledge Validation:** Any lessons learned system should be established to be capable of capturing and representing the knowledge correctly (Tan et al. 2007). As it is underlined by Caldas et al. (2009), “the quality of lessons learned is more important than the quantity of lessons in the database”. Therefore, establishment of a maintenance effort can keep the lessons more valid and utilizable (Caldas et al. 2009; Carrillo 2005). The validation mechanism should bring improvements to the system through providing that knowledge is required. It should be there to ensure that the knowledge is accurately entered and it is complete in details specified in the set format. This makes the available

knowledge is important and useful. It ensures that the knowledge is reusable and does not cause any knowledge overload (Arditi et al. 2010; Tan et al. 2007). Since generalized component of the knowledge is difficult to share with others, it should be validated within the system. To serve for this purpose, a knowledge manager should be integrated into the system at the initial stage to help with the issues of generation and maintenance of the lessons learned system (Fong and Yip 2006). Capture of spontaneous lessons learned while dispersed people are doing their work should not be prevented to overcome the knowledge acquisition barriers; however, potential new lessons learned should be validated by experts in the area by selecting and editing the lessons (Soibelman et al. 2003). The captured new knowledge can be kept hidden and not published on the intranet of the organization until it is validated by an expert in the area (Tan et al. 2007). Additionally, quality of the lessons learned knowledge base may be enhanced through tracking the utilization and benefits of lessons learned by analyzing the feedbacks from application processes (Paranagamage et al. 2012; Soibelman et al. 2003). In this regard, frequency of the lesson usage or benefits of lessons in monetary values (if possible) can be used to evaluate the quality of the lessons available and to improve the knowledge base accordingly (Carrillo et al. 2013). As a summary; duties of the evaluators in the system may be determination of cost/productivity of the lessons in detail, comparison of expected performance to actual performance, categorization of the lessons according to different attributes, assessing the quality of the lessons in terms of existence of enough information to understand the lesson, evaluating the system periodically to eliminate duplications and outdated lessons, making the contributor of the lesson to believe that his/her suggestion is appreciated, and finally assessing the innovativeness of the lesson and its safety and quality-related implications (Arditi et al. 2010).

As it is presented, there have been various limitations of the existing systems and requirements are stated in the light of these. Examples for the observed limitations from the notable studies can be provided as follows:

- LLG: the program of “Lessons-Learned Generator (LLG)” generated by East and Fu (1996)) is focused on design reviews and requires improvement in representation of lessons learned and application of “data-mining” techniques. Type of work is provided for selection in a tree structure together with perspectives indicating the content and context of comments respectively. In addition, tagging is provided through six “keywords”; however, management of tagging should be enabled to track the extent of indexing. A referencing system on tags should be provided for search of identified tags while entering and searching the lessons learned.
- COLA: the system of cross-organizational learning approach (COLA) presented in the study of Cushman (1999)is lacking web integration (Kamara et al. 2002b).
- KPfC: the web based system Knowledge Platform for Contractors (KPfC) generated by Kivrak et al. (2008) is based on capturing of lessons learned mainly in the form of ‘event histories’ in terms of “problems” and “solutions”. Event histories generally cannot completely respond to retrieval and dissemination of lessons learned entries, whereas codification of lessons learned only in terms of pre-defined attributes may cause loss of information. Therefore, a system in mid-between of these properties should be more effective. This study provides some supportive information in terms of project attributes; however, the indexing of the lesson history is very limited since it is categorized only with the “subject”.
- CMAID: Most of the work in the area is focused on design-related problems or specific type of projects and there is no work focusing on construction management practices. To overcome this Arditi et al. (2010) present a system (CMAID – A lessons learned system in construction management practices) that handles lessons in a wider concept and provides lessons learned management considering construction management practices; however, it is limited with focus on management concepts in indexing and lacks construction practices. Additionally, more improvements in efficient retrieval mechanisms supported with techniques such as data-mining and statistical

analysis, discussions of legal ramifications, and integration into a web-based system are required.

- MCSW: the system generated by Ferrada et al. (2016) as Mobile Cloud Shared Workspace (MCSW) platform provides a web and mobile based system; however, it needs improvement in database search.

Therefore, any lessons learned system should be developed following the investigation of the stated requirements. As a result of the literature review lessons learned management model and a web based tool that is aimed to developed in this study must have following features;

1. There have to be well-structured user responsibility definitions that would help to implement the model in a real company,
2. A simple lessons learned capture method has to be developed to record tacit and explicit knowledge without omitting any parts of the lessons
3. A well-organized information flow shall be defined to easily manage lessons learned within the company
4. A flexible tool has to be developed to support establishment of a company specific lessons learned management system
5. The tool has be online to ease accessibility of the users to lessons learned management system
6. A method has to be found to interact with other IT-solutions to be able to access necessary documents
7. A codification system has to be generated to ease entry of lessons learned to the database
8. A tagging system has to be developed for effective classification and retrieval of lessons learned,
9. Different retrieval methods shall be available to increase reachability of the related lessons learned
10. An evaluation system is necessary to manage the lessons learned and to eliminate the useless knowledge

11. A flexible tool that makes it possible to define different types of users provided in the developed model as well as adjustable to company specific requirements has to be developed.

CHAPTER 4

DEVELOPMENT OF THE LESSONS LEARNED MANAGEMENT PROCESS MODEL

This research aims to develop a lessons learned management system which contains a model and tool for construction companies. Knowledge is unique and inimitable resource for companies and it provides competitive advantage; however, exact and fully accepted solution to manage knowledge is not existing in construction domain. Main target is developing a framework for knowledge acquisition from construction sites and departments in head offices, validating this knowledge through expert reviews, storing valuable knowledge in a company database and facilitating reuse of the company knowledge in new projects. In this system, best practices and failures are captured together with the reasons and recommendations, so that system helps to develop corporate memories for the companies. Starting point for developing the "lessons learned management process model" has been the project portfolio management tool that is named as "COPPMAN (Construction Project Portfolio Management)". Development of COPPMAN has been the main aim of research project, which is supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK), and lessons learned management constitutes the knowledge management part of this project. In summary, COPPMAN is a decision support system for helping construction companies in adoption of portfolio management solutions. It mainly facilitates portfolio formation and provide its management. Therefore, this decision support system contains a series of components such as; system management module, knowledge management module, risk assessment module, strategic assessment module, portfolio analysis module as a response to the requirements of portfolio management processes (Figure 4.1). Learning from past projects is determined as one of the important considerations for the decision support systems in the construction sector since past project knowledge may provide valuable data about profitability, possible problems and prevention actions as well as information about countries, clients, and project types. This knowledge is considered to be important also for project portfolio management concept, so it is decided to develop and integrate a lessons learned database to COPPMAN.

The established lessons learned database system as a part of the research also has a potential to be used separately as a stand-alone platform. In this perspective, lessons learned management process model and its tool have been developed as a standalone module in addition to being a part of the COPPMAN. Lessons learned management module is named as "Learning in Construction Tool (LinCTool)" and it has been developed in computer environment in a way that it does not need any other components of the COPPMAN in order to work. System management module and knowledge management module of the COPPMAN which are identified with the red color in the Figure 4.1 are constitutes the main structure of the LinCTool. This provides a simplified tool to manage organizational memories of construction companies.

LinCTool is generated as a web based computer program, which targets facilitating knowledge flow within the company, but it must be supported by the company culture. This means that companies have to build an organizational structure to operate LinCTool effectively. In this research, first of all needs analysis has been done to develop effective lessons learned management system and then process model is formed, which includes organizational structure in addition to computer program itself. Need analysis and process models are given in the following sections. After these sections, details of the model and development methodologies are presented under three categories which are authorization system, data entry, and data retrieval. Lastly, brief introduction about computer implementation of the tool is provided.

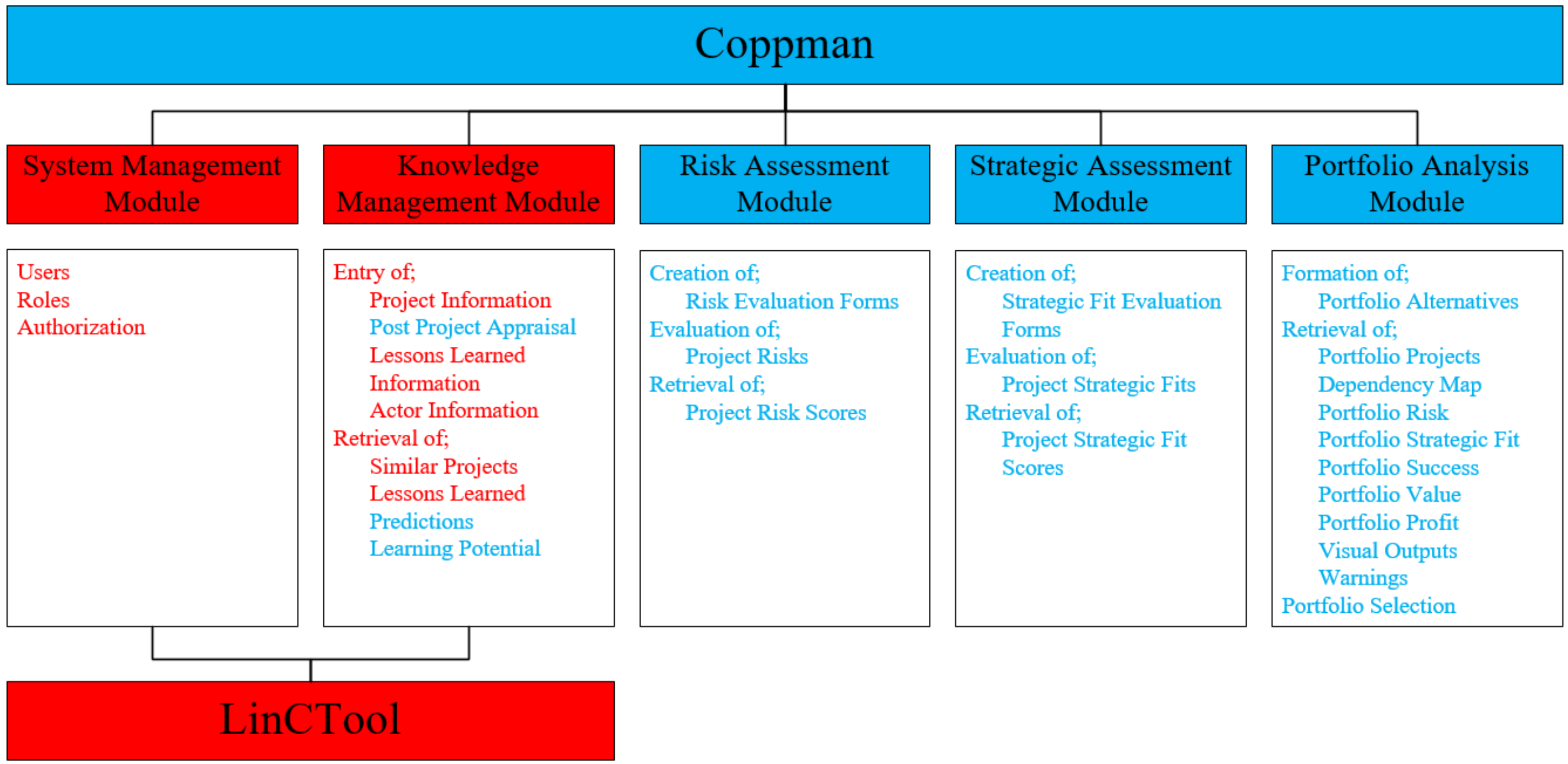


Figure 4.1: Relation Between the COPPMAN and the LinCTool

4.1. Needs Analysis

As it is mentioned in the literature review sections, knowledge is an important asset for companies in the construction industry, because even if the projects are unique, improving company performance requires experience from repetitive actions. Knowledge is gained through the course of project, but it may not be preserved after finishing the project and it may be lost. Main reason to this knowledge loss is the industry itself due to high staff turnover and project based structure. For establishing a learning organization in the industry, there is a need to develop a model that would be supported by company culture and information technologies. Developed tool should be flexible to respond company specific needs. It is appreciated that, live capture of the knowledge is also an important factor for improving the performance of the knowledge management system, so that web based system may provide ability to capture knowledge as live. Most of the barriers to implement successful knowledge management system in construction industry are related with time. To overcome these problems, developed system has to maintain well organized structure to decrease necessary time for capturing and reusing the knowledge. Another important point is capability of capturing implicit knowledge successfully. Explicit knowledge may be captured easily due to its nature; however, capturing implicit knowledge and transferring it to explicit is more difficult to achieve. Lessons learned concept is considered as a solution for implicit knowledge capturing. As it is mentioned before, system has to be supported by the company culture, and this requires proper consideration of two issues. First one is related with attitude of top managers to the system and their support. This is a human related factor and it cannot be achieved with any tool or model, if they are not eager to achieve this. Second one is involving all the employees to the system with different roles. This will help developing organizational memory as well as promoting the system usage and increase recognition level. Multi-user structure has some benefits, but control mechanism has to be developed also. In this perspective, user roles have to be clearly defined and a system that would be capable of controlling value of the knowledge gathered from users should be integrated.

Requirements, which are stated above, are analyzed in detail, and necessary system abilities and features have been determined as follows:

1. Development of a web based tool to foster knowledge capturing and sharing.
2. Identification of user roles in the system with different accessibility options to the tool menu.
3. Identification of necessary project information to store projects.
4. Development of the lesson learned form to capture implicit and explicit knowledge.
5. Identification of retrieval mechanisms to facilitate knowledge sharing.
6. Identification of administrative areas to increase system integrity and improve maintenance options.
7. Identification of the logic for determining project similarity and developing a calculation method for similarity based search.
8. Establishment of filtering based search and calculation capabilities.
9. Developing a tagging system to enter a lesson learned and query with these tags. Additionally, a management mechanism for tag tree is needed.
10. Developing interfaces for entry of lessons learned.
11. Developing interfaces for review of lessons learned.
12. Developing menus for lesson retrievals.
13. Creating menus for creating and viewing projects and querying in the database.
14. Defining a method for sharing extra documents with the lessons in a safe and easy way, and integrating this method into the developed knowledge management system.

4.2. Process Model

Knowledge management system based on lessons learned concept is developed according to the predefined needs. Simple presentation of the proposed structure is provided in Figure 4.2. Model contains four different user definitions with different roles. Web based lessons learned management tool, which is named as LinCTool, is located in the center of the system. The system is designed to be accessible through web clients from personal computers. In the proposed model, there is no need to setup any program to user computers, because standard web clients are enough to access and use the tool. Four different roles are necessary to operate the system. Basic roles are identified as "knowledge source" and "knowledge seeker" that are the reasons for the implementing the system in a company. Capturing knowledge to develop organizational memory is one of the objectives in the system and this is realized by knowledge sources. Employees, who are identified as qualified enough to convey their experience to the knowledge management system, are authorized with the privileges of "knowledge sources". However, other employees, who are eligible with accessing corporate memory, are privileged to access to the lessons learned through the "knowledge seeker" role.

Documents are not directly added to the LinCTool server, but cloud system has been added to the model to enable sharing extra documents with lessons learned. Sharing links may be added to lessons learned forms by knowledge sources but access control has to be arranged in the cloud server or document management system of the companies. Details of this document sharing system is not handled within the scope of this research.

In addition to these two basic roles, two special roles are integrated to the model. "Knowledge manager" is responsible from maintaining the system and reviewing the entered lessons to ensure that only valuable lessons are kept in the database. This role is assigned to a specific person, who is responsible from the quality of knowledge management system. In addition to "knowledge manager", who is responsible from managing lessons learned entries, "project coordinator" role is also defined as a part of the system. "Project coordinator" role is assigned with entering projects to the system and managing them. This privilege has been given to a specific person in order to ensure system integrity in terms of projects undertaken by the company. Proposed model contains different menus, which can be arranged in the system preferences for different roles so that each user role can access different areas safely. Application, which is accessed by web clients from user computers, is hosted in a server and all the information is stored in a SQL (Structured Query Language) database.

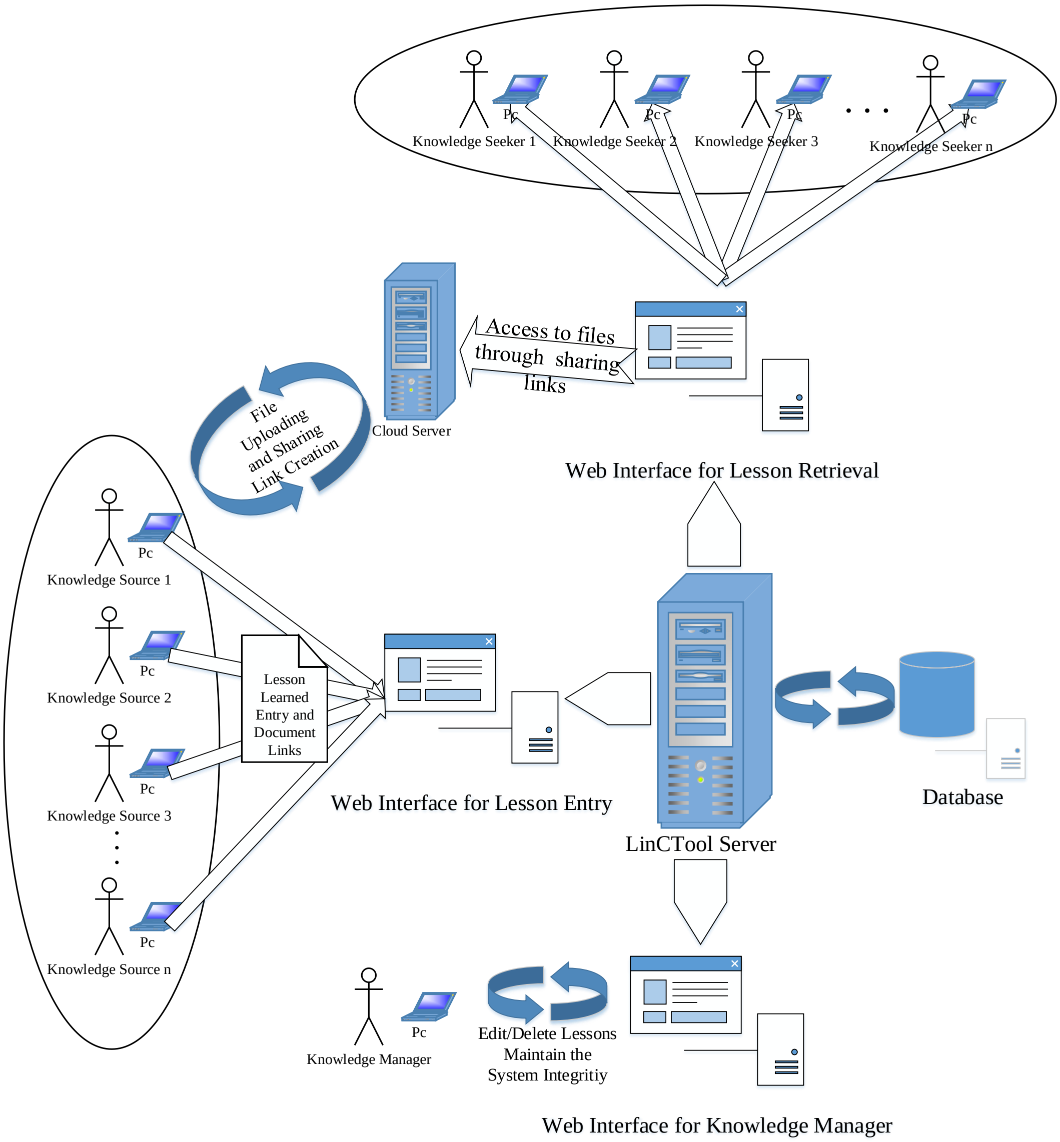


Figure 4.2: Proposed structure for lessons learned capture and sharing

Process model of the developed system can be seen in the Figure 4.3. In step one project inputs that is needed for project creation are defined in the system. This process is done by “project coordinator” user role according to project needs. Each project input is defined when it is needed and it is used in the upcoming projects without defining it again. In step 2, actors are added to system either by “project coordinator” or “knowledge source” types users. Actors information is used as input for both projects and lessons learned. Add actor step is controlled by the necessity of it according to project creation or lesson learned entry. This helps to development of actor database with the contact information. After all the necessary project inputs are defined and actors related to project are added, project is created in the system by “project coordinator”. Outputs of step one and step two are used as inputs in step three.

Lessons are associated with a project and actors so that project information and actor information are used as inputs in lesson learned entry step. Lessons can be entered either by “knowledge source” and “knowledge manager” when an event occur. "Tag tree" is control point which guides user to enter lesson in a structured form. Output is named as lesson candidate in the process model because it has to be approved by the “knowledge manager” to become part of organizational memory. Lesson candidate is reviewed by the “knowledge manager” according to value of knowledge, company needs and perspectives, and approved, edited or deleted. If lesson is approved, it become part of the organizational memory and according to knowledge need is retrieved by “knowledge seeker” in step six. In this step 3 different search mechanism is used to retrieve lessons. Output of the step six is related lessons according to knowledge need which may also be solution for the event in a project. In this step process may complete or new lesson can be added to system with the help of new event. Process can be summarized as explained in this section with the help of Figure 4.3 however details are given in next sections with the explanations.

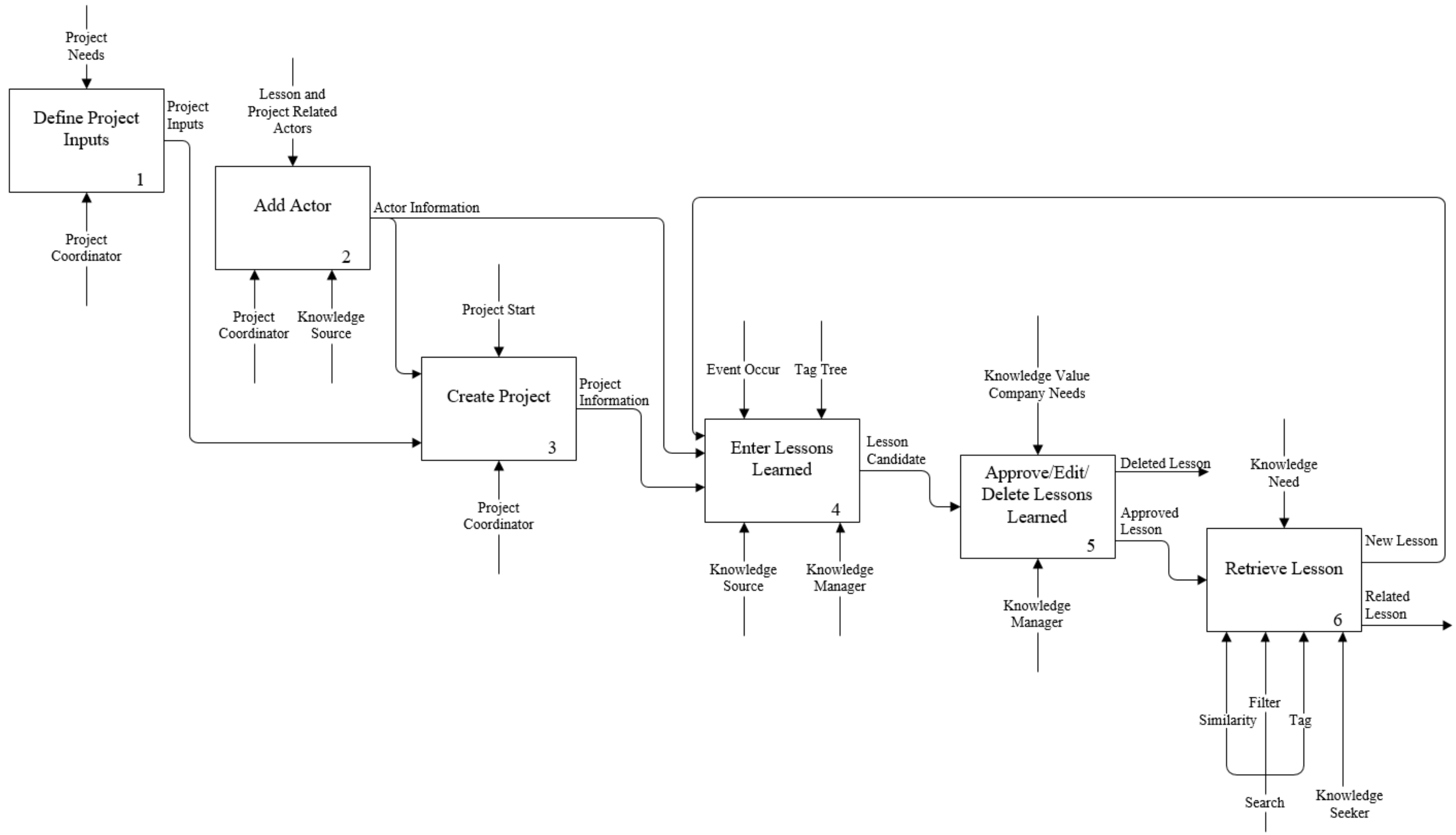


Figure 4.3: Process Model

Lessons learned are grouped under projects in the proposed model. Thus, in order to add a lesson, the project, which the lesson is related with, must be available in the system. In addition to that, lesson has to be reviewed and approved by the knowledge manager in order to be added to the organizational memory.

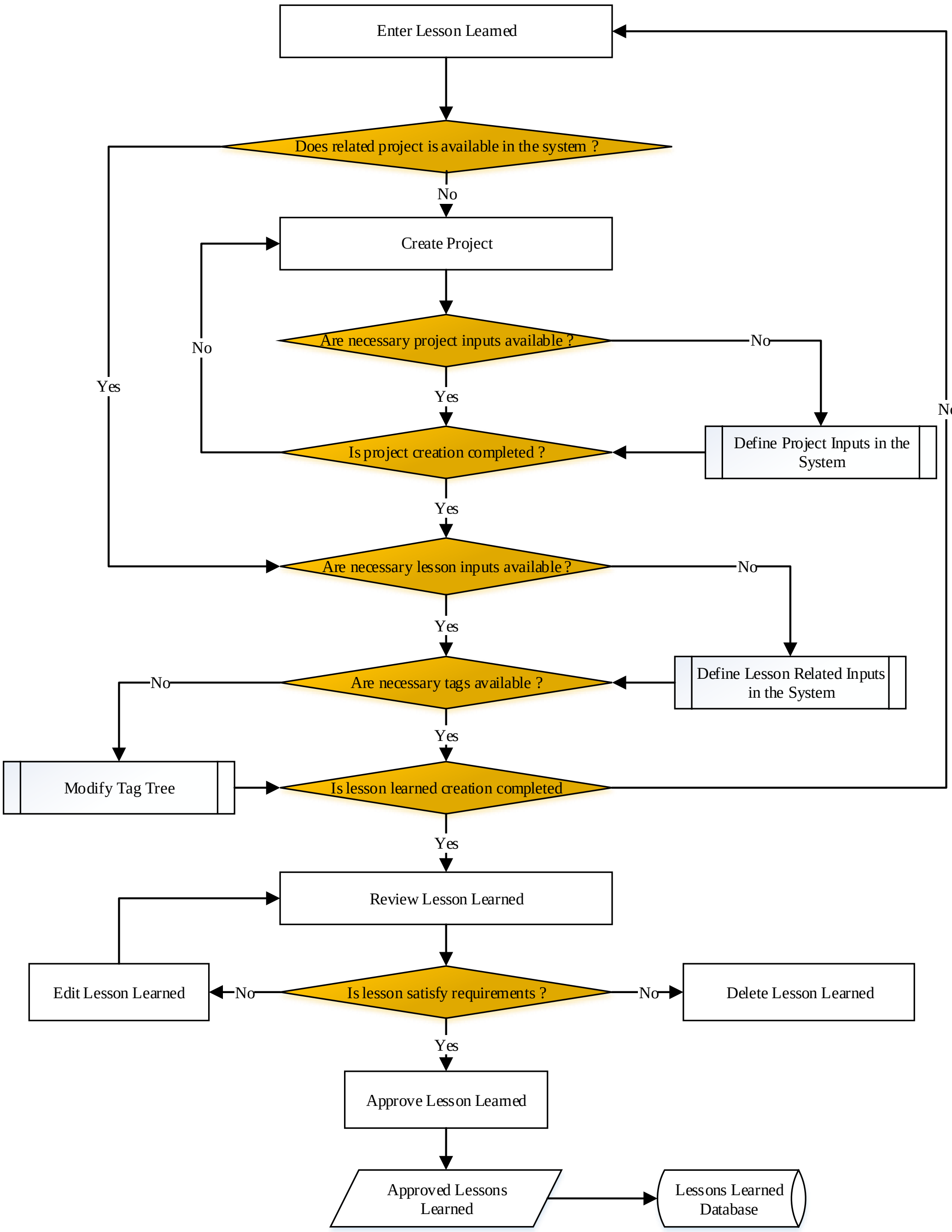


Figure 4.4: Flowchart for the Lesson Entry

Flowchart for the lesson entry is provided in Figure 4.4. This figure represents process details of adding a lesson learned to the lesson learned database. When a lesson is to be added to the system, first of all, existence of the related project has to be checked. If the project is not entered to the system earlier, it has to be created by the “Project Coordinator” before adding the lesson. There are some predefined project attributes, which are under responsibility of “Project Coordinator”, and details of them are presented in “4.3.2.1 Project Information“ section. After defining necessary inputs for project attributes, project can be created and lessons can be added to the created project. Lesson entry is in the responsibility of the “Knowledge Source” role; however, quality checking of the entered lesson is done by “Knowledge Manager”. Lessons are created with the predefined information that details of it is provided in “4.3.2.2 Lessons Learned Information“. Once a lesson is created, it is stored in the database, but it is not presented to the user until it is approved. “Knowledge Manager” can edit lesson before approving or can delete it without approving. After a lesson is approved, it can be reused by other employees in order to fulfil company objectives easily.

Creating a structure that would be capable of facilitating retrieval of the right lesson when it is required is an important and challenging process in developing a knowledge management system. In the developed system, users, who want to find a lesson learned, is named as “Knowledge Seeker”. Model contains three search options as retrieval mechanism for lessons. Details of these three search options are presented in the “4.3.3 Data Retrieval“ section and the flowchart presented in Figure 4.5 summarizes the lesson retrieval system that is developed under this research. Search can be done according to the project attributes or lesson content. Tag tree is used to find lessons in “tag based search” and details are provided in “4.3.3.3 Tag Based Retrieval section”. In addition to that, project attributes are used in two different search options, which are “filtering” and “similarity search”. If there are specific attributes, which the related lessons are wanted to be found through, “filtering” option is more suitable. On the other hand, lessons that are related with the whole project can be found by “similarity search” more effectively than “filtering search”. In the proposed model, lessons are listed following the search and user can also use “secondary search” to narrow down the results according to the lesson attributes. After that, the listed related lessons can be reviewed by the user and knowledge transfer is completed.

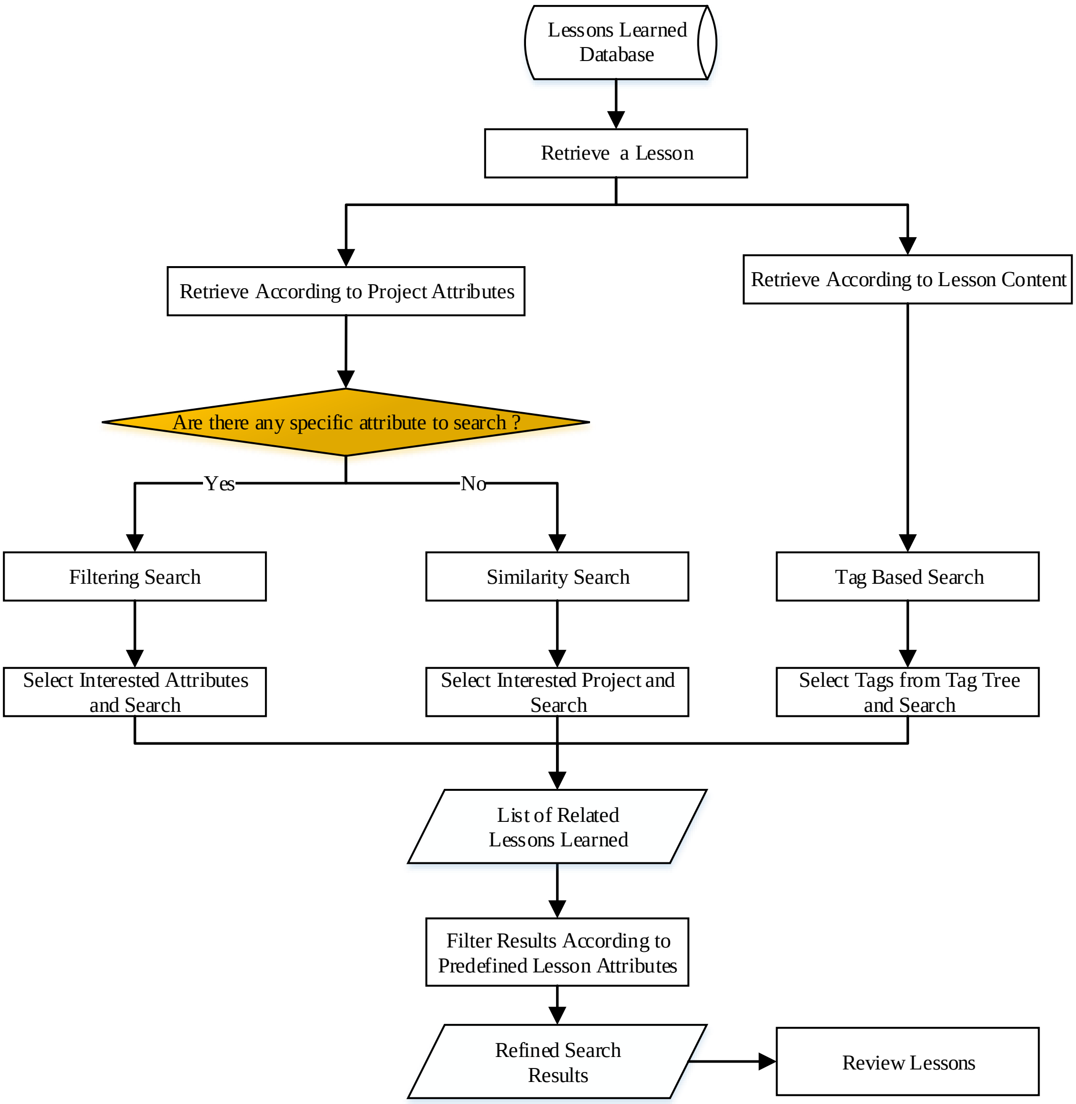


Figure 4.5: Flowchart for the Lesson Retrieval

As mentioned before, different user roles have different privileges in the developed model. User roles and privileges are explained through a use case diagram as in Figure 4.6 in order to define the responsibilities in the system that are provided through the flowcharts in Figure 4.4 and Figure 4.5. Details of each component are presented in the sections of “4.2 Process Model“ and “4.3 Main Components of the Model“.

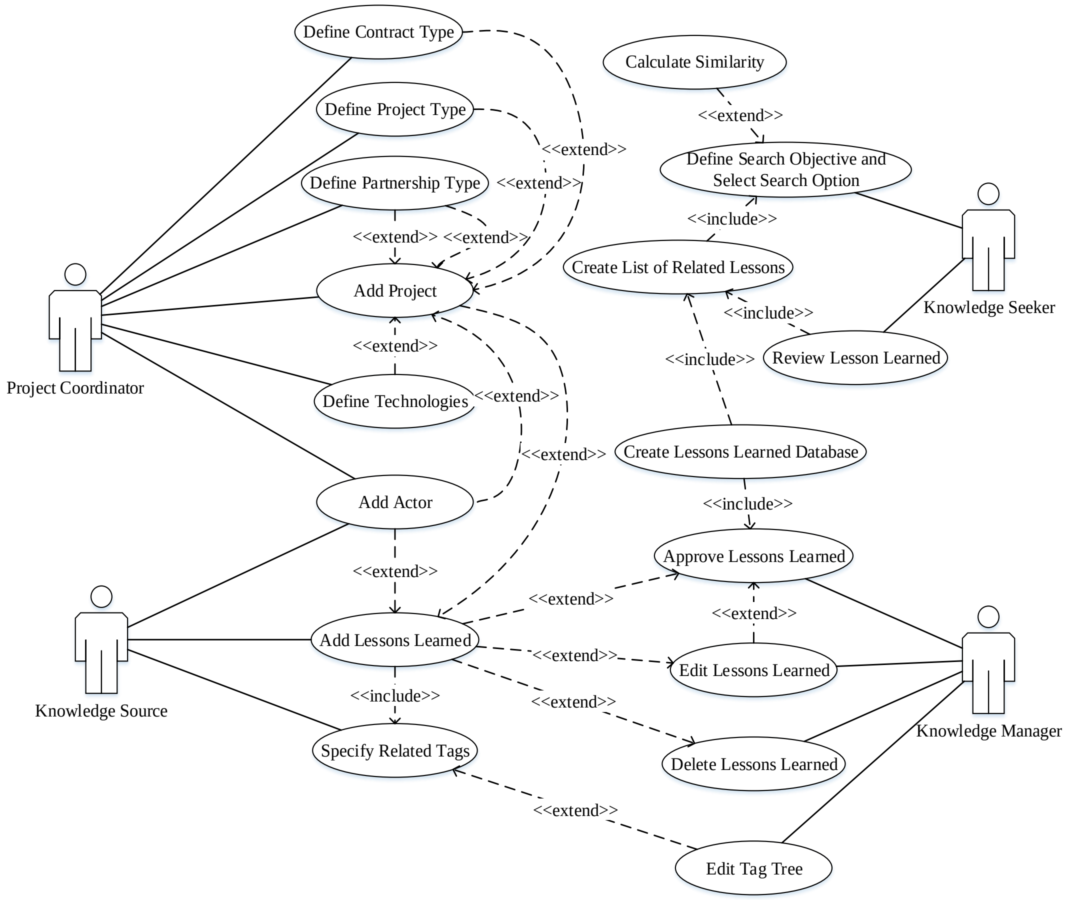


Figure 4.6: Use Case Diagram for the Lessons Learned Management Tool

In order to present the relations between the inputs that would be entered by the system users, entity relationship diagram of the database developed for the process model is provided in Figure 4.7. The diagram includes all the tables that are related with projects and lessons; however, it does not indicate the tables related with the user roles, system users, menu role relations, etc. Other tables and relations have been developed together with the software company according to the needs while LinCTool is being developed in computer environment. However, main structure of the database, which is necessary to store and retrieve the lessons learned, is provided in Figure 4.7. Definitions and explanations for each attribute are provided in the next section.

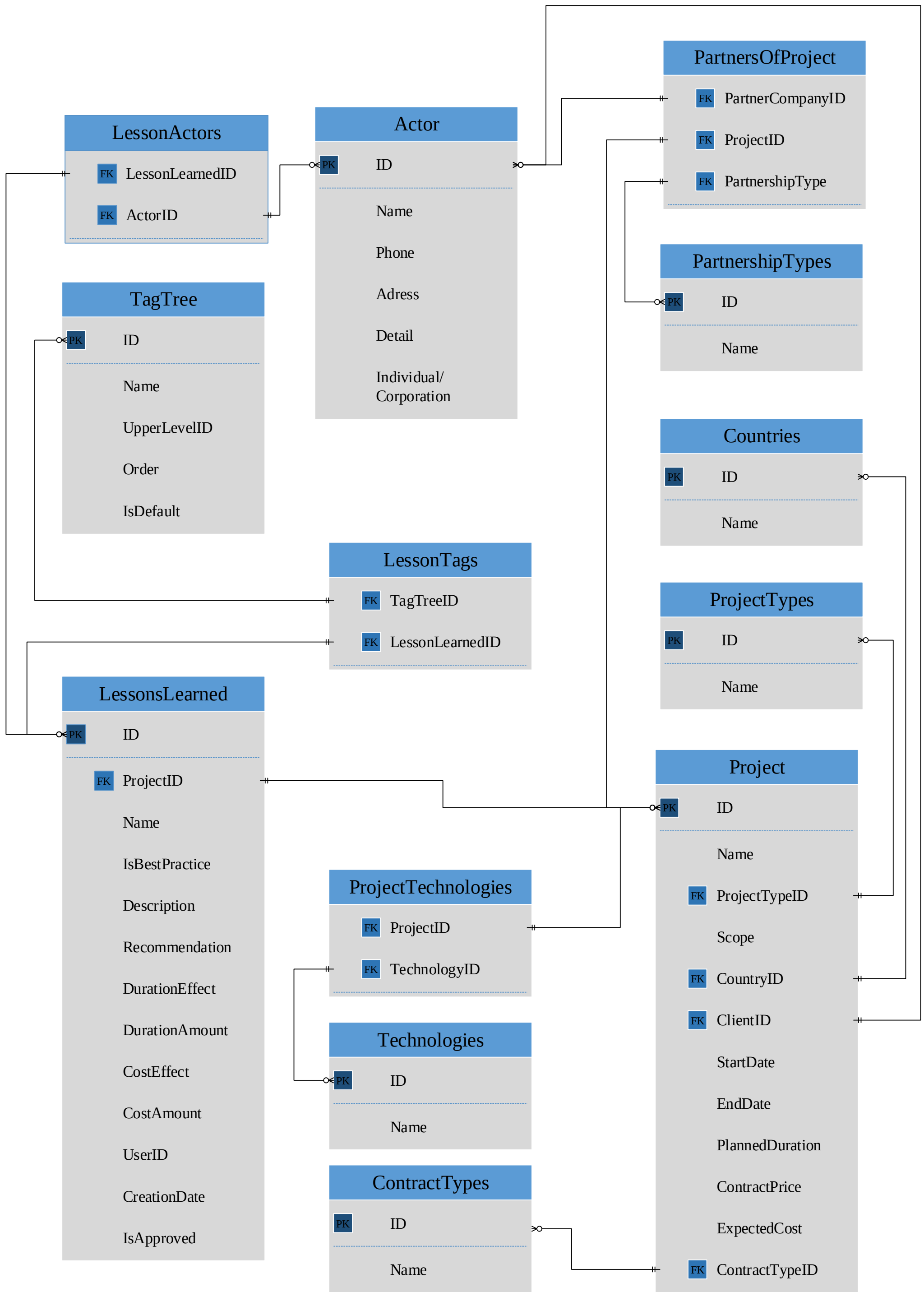


Figure 4.7: Entity Relationship Diagram of Database

4.3. Main Components of the Model

"Lessons Learned Management Process Model" (LLMPM), which is provided in the previous section, is explained in detail by dividing the system into three main components. First one is the "authorization system", which is needed to operate the knowledge management system through different roles. In this section, roles are provided with the logic behind them. In addition to that, link between authorization system, which is defined in the process model, and privileges in the computer program, which are developed in this research are also provided in this section. Project information and lessons learned information details are grouped under "Data Entry" section. Last group of the components are presented under "Data Retrieval" section. In this section, retrieval options are provided with the methodologies and their details.

4.3.1. Authorization System

There is a need of different type of roles and responsibility definitions to implement the developed model properly. As presented in the LLMPM, live capture of knowledge is provided; however, value of the entered lessons must be controlled by experts to eliminate useless data and improve the quality of the system. Defining roles is also important to preserve the structure of the proposed system. Rights of entering project, editing tag-tree, deleting/modifying existing lessons cannot be given to every user in the system, since irresponsible changes can ruin the system integrity. To overcome this problem, roles have been created, and authorization level for each role is identified in terms of actions. As explained before, informative documents, videos, images are also important for increasing quality of the entered lessons; however, proposed system, namely LinCTool, does not have an integrated document management system. Therefore, privacy of these documents are managed in a complementary system, which is defined in the model as cloud document sharing system. The separate document management system provides ability to authorize users differently in terms of lessons learned access and document access. To illustrate importance of this, a user in LinCTool may have rights to access lessons but may not have been authorized to access the full contract document. In this model, user can access to the system to read the entered lesson; however, contract document that is attached to the lesson with a link may not be accessible to this user. Users can access these confidential documents only if they are also authorized in the document sharing system.

In this section, only roles for LinCTool and their permissions are presented. Rights in a document sharing system are highly dependent on the company needs, thus defining these rights are not included in the scope of this research.

Defined roles in the lessons learned management process model are listed below;

- Project Coordinator
- Knowledge Manager
- Knowledge Source
- Knowledge Seeker

These defined four roles are belonging to the lessons learned management system and may not be found as a position in a construction firm directly. For example, it is obvious that companies do not hire an employee as "knowledge source" or "knowledge seeker"; however, senior site engineer can act as a "knowledge source", which enters lessons to the database directly from the construction site. All the site engineers including junior, senior and the project manager also have privileges to accessing entered lessons and this makes them "knowledge seeker" in the lesson learned management system. Details of each role are explained in below.

Project Coordinator: The role was defined to limit the number of users which are authorized to define projects in the system. This role is privileged to create, modify, and delete the projects in the system. In addition, "lesson view" and "lesson entry" privileges may be added to the user accounts according to company preferences but distinctive feature of the role is the project operations. Integrity of the knowledge about project information is guaranteed by this role. Only relevant employees can change this information so that responsibilities are defined clearly and this prevents possible mistakes. This role can be assigned to an employee, who works in the head office and responsible from project contracts.

Knowledge Manager: Differently than other three roles, "knowledge manager" role may refer to a real position in the company. "Knowledge manager" is responsible from reviewing the entered lessons, maintaining the system by editing, deleting, and approving lessons according to its value. As mentioned before, lessons are to be captured through web as live, therefore it may lead to an overload in the system with useless information. Because of that, company may hire a person to work as the "knowledge manager". When a lesson is entered to the system, it is automatically labelled as "unapproved", so the "knowledge manager" must review the new lessons on a daily basis to assess whether they are useful or not. If a lesson is considered as 'valuable', it is approved by the "knowledge manager"; otherwise, it can be deleted from the database in case of it is considered as 'useless'. Only the "knowledge manager" is privileged to edit lessons in the model. Lesson approval, entering and deleting operations are under the authority of only the "knowledge manager". Expected benefits of these restrictions can be stated as increasing reliability of the knowledge stored in the system by restraining unqualified personnel from doing aimless changes in the lessons.

Knowledge Source: "Knowledge source" role is not directly referring to a position in the company; it refers to all employees, who has authorization to enter lessons to the system. These employees may work in construction site as a site engineer or work in bidding department as a manager. "Knowledge manager" and "project coordinator" roles may also have privileges of "knowledge source" role; however, person, who has privileges of "knowledge source" role, is only able to add a lesson to the system and display lessons. Distinctive rights of the "knowledge source" role in the system can be stated as "lesson entry" when compared to "knowledge seeker" role.

Knowledge Seeker: The "knowledge seeker" is the most basic role type in the system. Users, who are defined as "knowledge seeker", are able to search and display lessons that have been entered already; however, they cannot make any change in the system or add anything to the system. This user type can be assigned to junior site engineers, new hires, etc. to control the data flow. "Knowledge seeker" rights are also valid for all the other roles. All users may access to lessons whatever their roles so there is no any distinctive right that defines the "knowledge seeker" role. To conclude, roles in the system are independent from company positions and they are differing in terms of operations, which they are authorized with. These operations can be listed as "lesson approval", "lesson editing", "lesson entry", "lesson view", and "project creation". The roles and the authorized operations to each role is presented in Figure 4.8. The red arrows show the descriptive operations of the roles and the dotted black arrows imply useful operations to facilitate operations performed by the users.

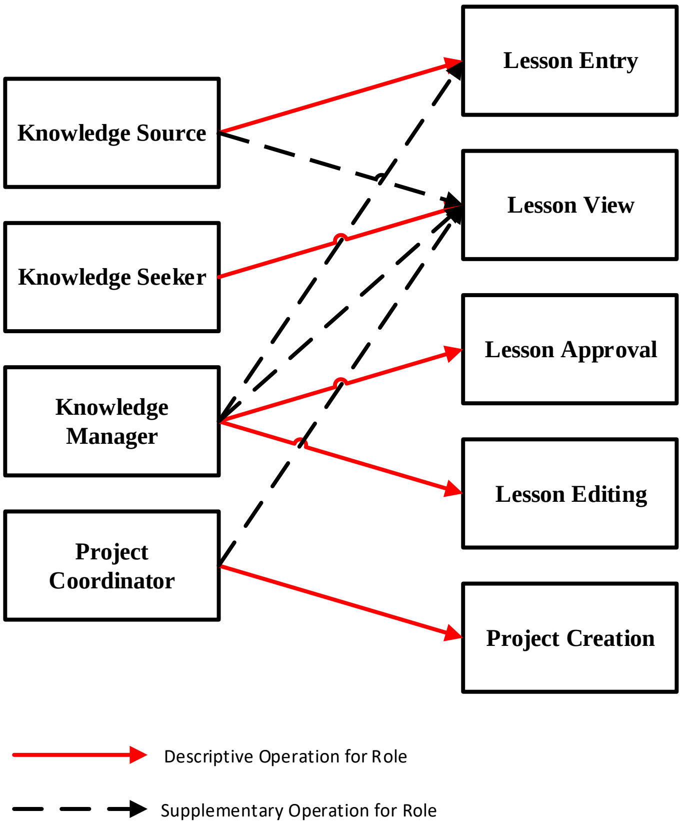


Figure 4.8: Roles and Operations

4.3.2. Data Entry

In this section, what information is needed to capture and organize lessons is presented with its reasons. Necessary inputs are divided into two groups. First project related inputs are presented and these inputs are entered only to projects not to each lesson. However, since each lesson is also assigned to a project, project inputs also become part of the lesson's attributes. Benefits of the system is explained in "4.3.3 Data Retrieval" section. Second group contains information related directly with lessons. Inputs that are used to capture and organize lessons are provided in this group.

4.3.2.1. Project Information

The idea behind the capturing lessons learned for the project based industry is based on improving common procedures between the projects. This means that lessons would be more meaningful with the context, which is project, because similar problems may be faced in similar projects or solutions for problems may be successfully applied to similar projects rather than other projects. Each lesson has to be recorded with project information not to lose this context; however, repeating project information for each lesson in the project is unnecessary and problematic in terms of integrity of system. To overcome this issue, the system is designed in a way that projects can be created with defining the information for once and each lesson should be added to the one of the created projects. Project information can also be updated easily in this method, because once project page is edited, each lesson also becomes updated automatically. It also facilitates the lesson retrieval procedures, which is explained in detail in the "4.3.3 Data Retrieval" section.

Determination of necessary project information has been done according to two criteria and necessary information was kept to be simple as possible. First criterion is determining the value of project attribute in the lesson retrieval process. If attribute is to be used in the lesson retrieval process, it was added as a project input. Second criterion is defining the project with minimum information in terms of duration and financial aspects. The list of the project attributes used to define projects in the system is provided below in two groups together with explanations.

Necessary information to retrieve lessons: The system uses project attributes to retrieve lessons in “similarity search” and “filtering search”. Survey has been conducted to determine the project attributes, which are used in these calculations, and details of the survey is presented in the “4.3.3.2 Similarity Based Retrieval“ section. According to the results, necessary project information to create a project in the system are determined. The identified attributes through the survey can be listed as;

- Project Type
- Country
- Technologies
- Contract Type
- Client

“Project type” is used to save information about construction type such as “highway”, “high rise building”, “dam”, etc. This attribute is captured in the form of text consisting of one or two words. “Contract type” information is used to capture information about contract. Name of the standard, which is used for preparing the contract, is entered to contract type. Possible inputs can be stated as “FIDIC” or “Turkish Public Procurement Law”. “Client” and “country” attributes are filled with client name and project's country respectively. On the other hand, technology attribute is more subjective than others. Any “computer program”, “construction equipment” or “construction technique” can be entered to this area, if it is considered as new or rare for the company. For example, if the company is not an expert in building information modelling, it can be entered to the technology attribute with the purpose of finding projects, which are done with this technology. “Project type”, “country” and “client” areas have to be entered in each project, whereas “contract type” and “technology” attributes are not mandatory. The reason for that, there is possibility that a project contract may not be prepared according to a specific law or standard contract, and a special technology may not be used in a project.

“Partnership type” and “partner company name” are asked in the project creation step for using it in the filtering search. According to survey, “partner company name” is not important like other attributes in terms of project similarity; however, it may be necessary when user wants to find lessons of the projects that are executed together with a specific company. To provide this flexibility, “company name” is saved with the “partnership type” in the project creation phase. All projects done with the selected partner can be filtered easily in the developed system. Similarity survey results are also used in “filtering search” as an input. Details of “similarity search” and “filtering search” are provided in the related sections.

To conclude, “project type”, “contract type”, “country”, “client”, “partner company” and “technology” are asked in project creation step in order to provide ability to retrieve lessons in “filtering” and “similarity search”.

Necessary information to describe projects in terms of duration and financial information: Only attributes related with search options may lead to misguidance about projects. Lessons are more meaningful with the project data like project start/finish dates. In this perspective, necessary information to create project were increased with “project name”, “project scope”, “start and finish dates”, “project duration”, “contract price” and “expected cost”. “Project name” is used to easily distinguish projects from each other. An informative short name must be added to each project. “Project scope” input is used for capturing details of projects and defining responsibilities of the company within a project. Both of them are entered as ‘free text’, which is decided by the users responsible for projects. “Duration” and “financial information” are entered according to contract and bidding documents as indication of expectations defined at the beginning of the project. Each lesson also contains information about “effect on duration and cost” but these initial project values are important to form an estimate.

In conclusion, projects are created with “Project Name”, “Project Scope”, “Project Type”, “Client”, “Country”, “Contract Type”, “Partnership Type”, “Partner Company”, “Start/Finish Dates”, “Planned Duration”, “Contract Price”, “Expected Cost” and “Technology” information. Lessons have also this information indirectly since lessons are entered to projects. It can be stated that projects are used simply for grouping the lessons.

4.3.2.2. Lessons Learned Information

Knowledge is captured through the lessons learned form in the model. Way to capture tacit knowledge and making them a part of the corporate memory is developed through the literature review. Lessons may be a ‘best practice’ or a ‘failure’ and they can be related with all steps and parties of the construction projects such as contract, bidding documents, construction equipment, construction method, clients, workers etc. Lessons for each subject need different structures to capture, if every detail is wanted to be codified. It is decided that codifying everything may not be succeeded in the scope of the research and also it may lead a very complicated system, which is hard to manage in a construction company. Decided method is using histories for capturing knowledge about an event or a situation together with recommendations. This method also satisfies simplicity in system management and it is achievable within the research limitations. Two different areas are used for capturing details of an event. First area has been designed to capture “description of event” in detail as free text. Users are able to enter reasons, consequences, personal experiences, supplementary documents, videos, pictures etc. in this area. This part is important to understand the condition, problems and practices. Similarly, “recommendation” part is also designed or entering personal opinions as free text. Expected usage of this section is entering recommendations about possible prevention actions and possible improvements, as well as expressing subjective interpretations. Experience together with personal point of view are considered as basics of tacit knowledge and these two sections are enough to capture “tacit” and “explicit” knowledge. However, quality of a lesson is highly dependent on the text content because of that users have to be trained about the basics of the system. In addition to that, “knowledge manager” is also responsible for analyzing the content of the texts. As mentioned before, extra documents, videos and pictures are useful materials to improve the quality of input;

however, these are not directly added to these two areas. System does not accept extra documents for two main reasons. Concerns about privacy is the first reason for this limitation. As mentioned in “4.3.1 Authorization System“, employees from different positions have same privileges in the system. Because of that, unauthorized people can access these extra documents even if they are not authorized to access them. Possible example for that, lesson about bidding process can be supported with a part of a bidding document; however, access of these documents may be limited for junior site engineers. Controlling authorization issues about documents are not included to the scope of this research and each company may have different/unique document control systems. This is defined as the second reason to exclude document upload option from the lessons learned management system. Uploading documents to more than one system may lead to integrity problems in terms of updating, etc. Solution to this without losing benefits of extra documents is found as adding ‘access links’ to the documents. In this model, documents, videos and pictures can be accessed through the links that are added to the free text area. These links redirect users to the related system and user can access to document only if the user account has permission in the related system. This solves problems like opening contract documents to everyone such as from junior engineers to top managers. It also provides chance of managing documents from one center. In the example model, private document sharing server was used for testing the system. This server has its own software to manage documents and to define privileges. Combining these two systems provides both flexibility and security simultaneously.

Finding a right lesson may be problematic and time consuming among the numerous lessons, since event and description are entered as free text. To overcome this issue, some attributes have been identified as special areas to enter. First of all, lessons are labeled with their types as “best practices” and “failures”. Labeling the lessons according to their type is considered as important, because users can easily focus to the ‘failures’ to eliminate possible problems or can review ‘best practices’ quickly to improve their productivity, quality, etc. in their projects. Secondly, “effect on project duration” and “effect on project cost” are entered in the proposed model in “5 scale” format as “very low”, “low”, “moderate”, “high”, and “very high” in order to filter lessons according to ‘importance level’ in terms of ‘cost’ and ‘duration’. These attributes are used to group lessons according to their importance and for accessing easily to the most important ones. Entering this effect in terms of ‘value’ is also possible but calculating these values is considered to be very difficult since it may be difficult to assess the combined effects separately. However, if they can be determined, entrance areas are provided in the proposed model for these values but these are not used for filtering the lessons, they are kept to be informative. These values are not used for filtering because total effects on projects are considered to be more meaningful than numerical values. Entering information to the lessons about specific client, specific employee, sub-contractor, etc., which are namely all the project parties, have also potential to improve effectiveness of lesson retrieval process. “Actor name”, which is namely the related party, is entered to lessons to use them in filtering the lessons. In addition to these three attributes of a lesson, “name” section is also provided to get a clue about content of the lesson in the list of the search results. “Lesson name” is entered in a form of short sentence in the provided area. Process for searching according to ‘name’ is not provided because recalling the “lesson name” may not be possible and it is decided that it may be a useless alternative to find a useful lesson.

“Related actor”, “cost” and “duration” information is captured in special sections as provided; however, ‘context’ of the lesson remains secret inside the free text. Context is the most useful information to find and review related lessons. “Project similarity” may be used for finding the related lessons; however, it does not guarantee finding useful lessons always and reviewing all the lessons in a project may be time consuming. To solve this problem, each lesson is labelled with tags to help searching through the lesson database. It is considered that when users are allowed to add tags freely, it may damage the integrity of the system. Main reason for that, context may be entered in various ways in order to label a lesson. Wrong and incomplete spelling is also another possible problem and it may lead to missing a lesson in the search. “Tag tree” is designed to overcome these problems. Details and development process is provided in the “4.3.3.3 Tag Based Retrieval“ section. In the lesson creation step, user has to select related tags from this “tag tree”. Only authorized users are able to modify the “tag tree”. Adding “tags” from one place guarantees that each user uses the same term to label lessons according to the context. This also improves effectiveness of the lesson retrieval system. Number of tags, which can be added to lesson, is left un-limited and correctness of the tags according to the content is under responsibility of the “knowledge manager” as well as the users as “knowledge source”. This means that “knowledge manager” has to check and edit “tags” before approving the lesson. Expected benefits of the system can be summarized as finding the related lessons easily, easy categorization of the lessons and increased system integrity. Usage of tags are provided in “4.3.3 Data Retrieval“ section in detail. In addition to all of these, “project name” is also entered to lessons to create link between the project and the lesson. Each lesson can only have one project name.

In summary, necessary information to create a lesson is listed below,

- **Project Name:** Necessary to create link between the lesson and the project.
- **Lesson Learned Name:** Used to get quick information about the context of the lesson in the search results.
- **Lessons Type:** Used to group lessons as “best practices” or “failures”.
- **Event Description:** Detailed information about the lesson and it is one of the main areas to capture personal experience.
- **Recommendation:** Text area that is used for capturing personnel perspectives, recommendations and solutions for similar events.
- **Effect on Project Duration:** “1 to 5 scale” selection area to identify importance of events in terms of “duration”.
- **Effect Amount (Duration):** Area to save actual “duration effect”, if it is known.
- **Effect on Project Cost:** “1 to 5 scale” selection area to identify importance of events in terms of “cost”.
- **Effect Amount (Cost):** Area to save actual “cost effect”, if it is known.

- **Actors:** Name of the actor is entered to this section to indicate if the lesson is directly related with someone.
- **Tags:** Lessons are labelled according to their context by selecting the “tags” from the structure designed as “tree”.

4.3.3. Data Retrieval

“Data entry” section presents which information is used in the model, whereas “Data retrieval” section is related with how this information is used for facilitation of knowledge reuse. System relies on search mechanisms to easily disseminate the knowledge within the company. Developed model does not send every approved lesson to the users automatically, because users may ignore these notifications when they do not really need them. This may also lead to a negative attitude to the system like seeing it as spam source or extra burden. In this perspective, main objective of the research is creating a system to access lessons when it is necessary. Search mechanism is developed with three different options. “Filtering” and “Similarity search” options use “project attributes” to find lessons; however, “Tag search” option uses “tags” to find related lessons. On the other hand, all search options are supported with the optional “secondary search” mechanism to help users narrow down the results as much as possible. This “secondary search” mechanism is the same in each search option and it uses lesson related attributes to filter them. Details of each “primary search” options and the “secondary search” option are presented together with their development processes in the following sections.

4.3.3.1. Filtering Based Retrieval

“Filtering based retrieval” is done according to “project attributes”, which is entered in the project creation phase. As mentioned before, main idea is to use relevant projects to find related lessons. In this perspective, for example, user may want to get information about a specific "country" from the past project experiences, and best way of doing that is searching lessons according to the projects executed in this country. In the proposed model, lessons are filtered according to their "project attributes" and listed under the groups of "project names".

The developed model mostly uses "attributes", which are identified by the survey results for "project similarity", to filter projects. The survey is explained in detail in section 4.3.3.2. However, as mentioned in "4.3.2.1 Project Information" section, "partner company name" is added to the identified attributes. This provides a chance to concentrate easily on the lesson learned in the project, which is specifically related with the "country", "project type", "contract type", "client" or "partner company".

"Filtering search" can also be done through combination of the "attributes". For example, lessons related with "highway" projects constructed in "Russia" can be listed in the system by selecting "country" and "project type" as "Russia" and "highway" respectively. This system is more useful when users know what they want in terms of projects. Because in "similarity search", more lessons are considered as related; however, "filtering search" forms more exact borders for knowledge gathering. "Secondary search mechanism", which is presented in 4.3.3.4, is used to refine the search results according to "lesson attributes".

4.3.3.2. Similarity Based Retrieval

"Similarity based search" option is designed to provide flexibility in retrieval process. Main idea is that similar projects may cause similar problems and similar procedures may be applied for executing projects effectively. "Filtering" option is another way for focusing on lessons according to the "project attributes"; however, it may limit the results. In the developed system, "filtering search" gathers lessons only on the condition that the entered attributes are completely matching. Moreover, adding more attributes may further decrease the number of results. In "filtering" option user also has to be knowledgeable about past projects' attributes. This means that "filtering" option is a powerful mechanism when search is to be done with a clear aim but the case may not always be like that, so “filtering” may not be enough for such situations. To eliminate disadvantages of “filtering” lessons according to “project attributes”, “similarity based search” option is developed. This system is based on the matching ratios of the attributes to calculate similarities between projects. Attributes and their weights used in project similarities are defined through the online survey. The survey results, the calculation method and the main components are explained in the following sections.

4.3.3.2.1. Similarity Survey

Questions in order to find attributes, which defines project similarity and their weights, are identified through the part of the survey that is done within the scope of the TUBITAK research project. Survey has three main objectives that can be listed as defining strategy and risk related relations, and finding similarities between projects. Only the “similarity” section of the survey is used in development of the model for the LinCTool. Other two sections are used for developing the project portfolio management tool. Survey has been sent to participants through internet with an access link. The link is shared with 280 different construction professionals and 108 replies are obtained. Participants were selected according to their relevance to the topic and all of them have been working in construction sector. “Education levels” of the participants, their “current positions” and “experiences” are presented in Figure 4.9.

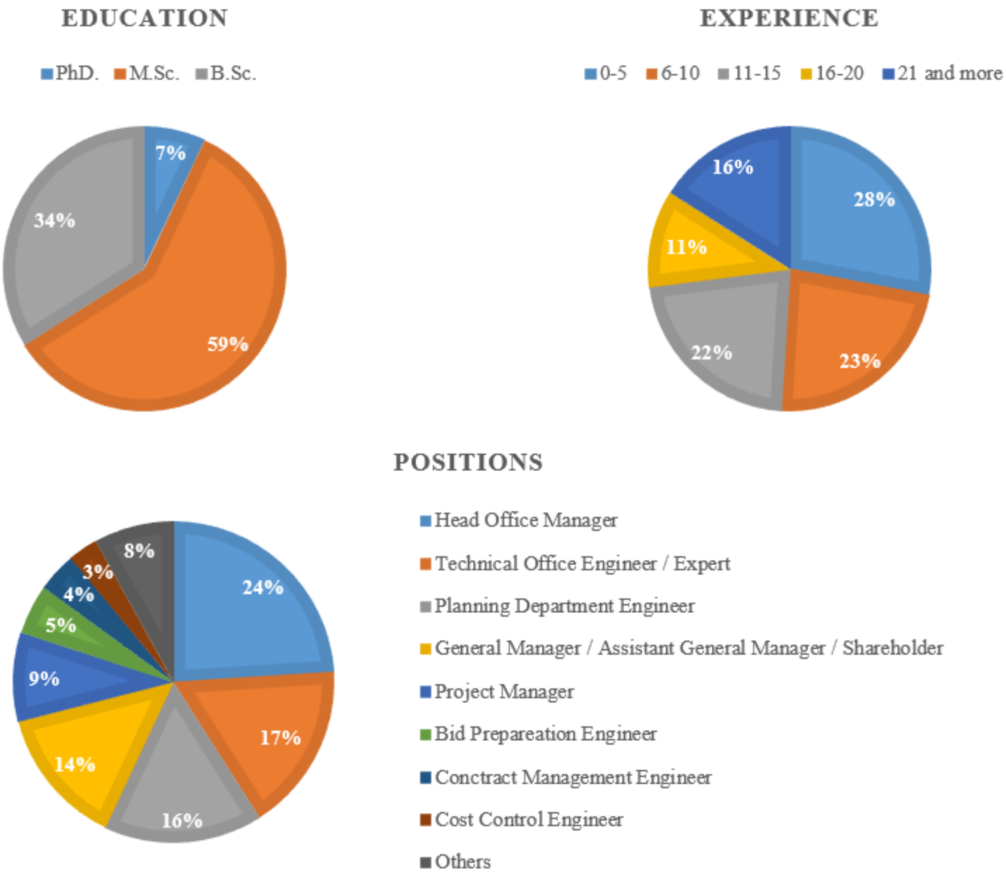


Figure 4.9: Participant Profiles

In addition to personal information, company information, which the participants are currently working for, has been also collected in terms of "company age" and "company turnover" as provided in Figure 4.10.

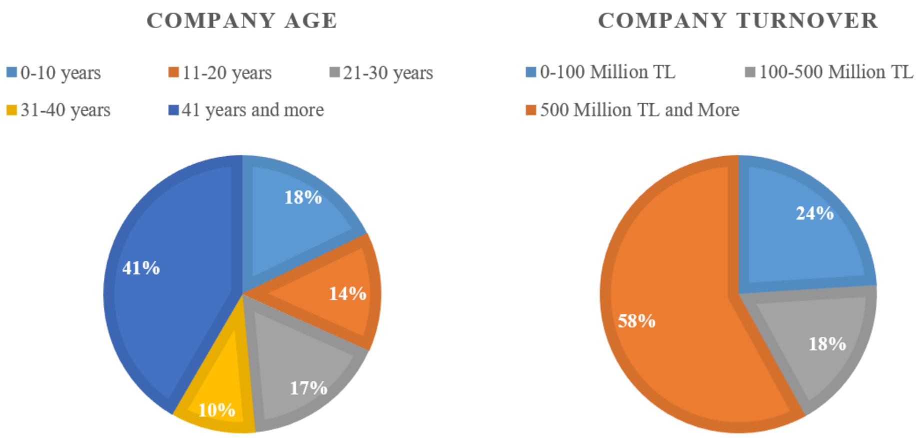


Figure 4.10: Company Profiles

Similarity section of the survey is designed to define important project attributes and their weights in project similarity calculation. Five attributes are defined in the survey preparation step by brainstorming by the research team in order to form the initial attributes as a base for the participants. The predefined attributes can be listed as, “Same/Similar Country”, “Same/Similar Project Type”, “Same/Similar Client”, “Same Technology” and “Same Contract Type”. Participants were allowed to add new attributes to this list. Survey results show that predefined attributes are found adequate to define similarities. Only two respondents added new attributes. One of them was capturing “company responsibility” information in the project such as contractor, consultant, designer. This has not been added to the attributes because in the “similarity search”, “project similarity” is considered as the main focus rather than “company responsibilities”. This means that, company experiences according to responsibilities are the topic of the lessons itself. Second recommendation was adding “project location” as an area of the country rather than just adding name of the country. This may be logical for countries like Iraq, because of the instability of some regions; however, it can also be solved by adding country names with descriptive words such as north, south, west, east, etc. In conclusion, only the predefined project attributes are used in similarity calculation.

As mentioned before, each attribute also has different weights. In the survey, importance of each attribute is asked to the participants in “1 to 5 Likert scale”. “1” is for the “least important” and “5” is for the “most important”. Sorting attributes was another option for defining the weights; however, it is considered that the participants may want to assign the same weights to different attributes. So that, first method is selected that provides a chance to evaluate each attribute freely. Results for each attribute are as presented below.

Same/Similar Country: Question is asked as “same/similar”, because countries may have the same conditions in terms of construction sector. So that, participants have evaluated this attribute as “when the project country is same or similar, how much is this important in terms of similarity of the projects”. In this attribute one participant assigned “low” (2); however, 79% of the participants assigned as “high” or “very high". Totals of the responses are presented in Figure 4.11. The standard deviation is determined as "0.78" and the average is obtained as "4.17". The average is accepted as the importance level for the "country" attribute.

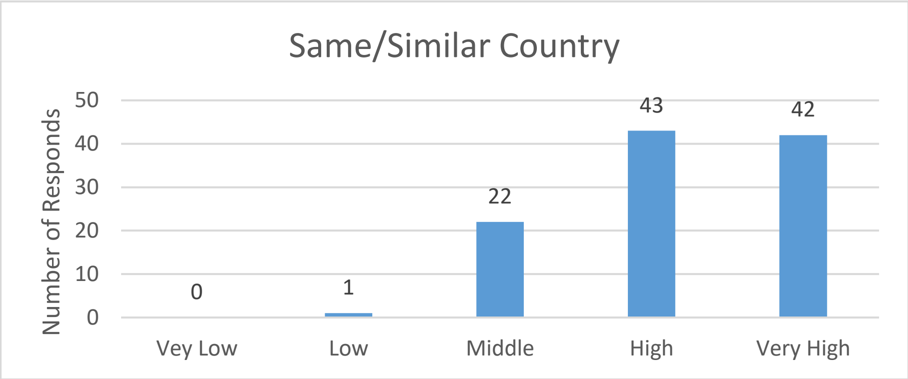


Figure 4.11: Same/Similar Country Results

Same/Similar Project Type: Different types of projects are not always completely different from each other. For example, "highway" projects and "railway" projects may be considered as very similar project types. As a result, this attribute is asked in the form of "same/similar". As in "country" results, only one participant defined the effects of project type attribute as "low" (2), and 87% of the participants defined it as "high" (4) or "very high" (5). All answers are provided in Figure 4.12. The standard deviation is calculated as "0.73" and the average is determined as "4.41". The average is accepted as the importance level for the "project type" attribute.

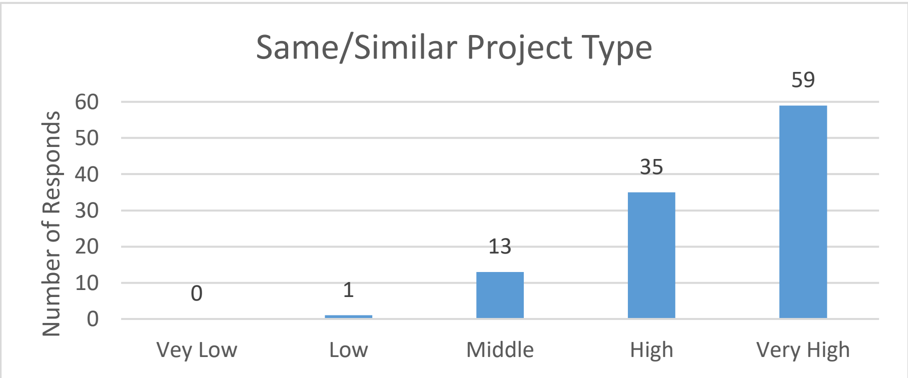


Figure 4.12: Same/Similar Project Type Results

Same/Similar Client: Different clients may also have similarities. For example, public institutions in Turkey may be considered as similar even if they are different. In this perspective, participants are asked to answer this attribute as "same/similar" client. 3.7% of the participants consider effect of this attribute as "low" (2) or "very low" (1); however, 69.4% of the participants' assign "high" (4) or "very high" (5) importance. All answers are provided in Figure 4.13. The standard deviation is determined as "0.88" and the average is calculated as "3.91". The average is accepted as the importance level for the "client" attribute.

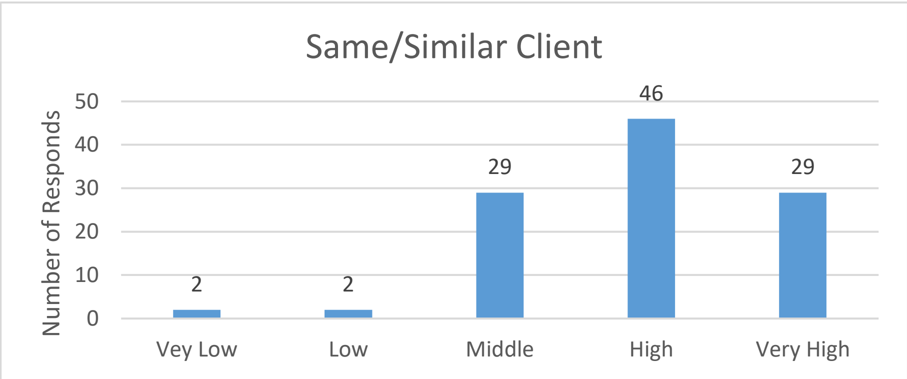


Figure 4.13: Same/Similar Client Results

Same Technology: It is considered that technology may be very specific and similarities between technologies may not be identified easily. As a result, question is formed as the "same technology" in the survey, but the system is developed in a way for allowing addition of other technologies as the same with the concerned one. Details of the system is provided in the next section. Same technology weight in determination of the similarity is assigned "low" (2) or "very low" (1) by the 7.4 % of the participants; however, 68.5% of the participants considered it as "high" (4) or "very high" (5). All the answers are presented in Figure 4.14. The standard deviation is determined as "0.93" and the average is obtained as "3.89". The average is accepted as the importance level for the "technology" attribute.

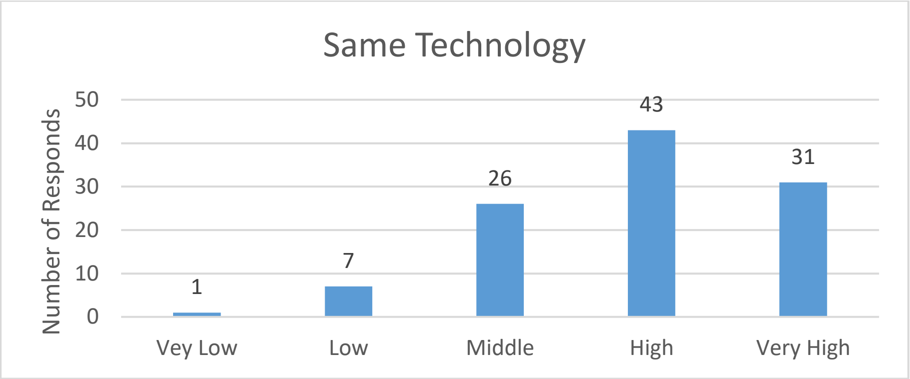


Figure 4.14: Same Technology Results

Same Contract Type: Contract types are considered to be the same or completely different in similarity calculation and question about contract type is asked in parallel with this logic. Survey results show that the least important attribute is the "contract type" in calculation of project similarities. Effect of the contract type is considered as "low" (2) or "very low" (1) by the 16.7% of the participants. However, "high" (4) and "very high" (5) ratings are still considerably high with 55.5%. All responds are provided in Figure 4.15. The average of the responds is determined as "3.6", but the standard deviation is calculated as high. There is no common idea about the importance level as in others, but the average is accepted as the importance level for the "project type" attribute.

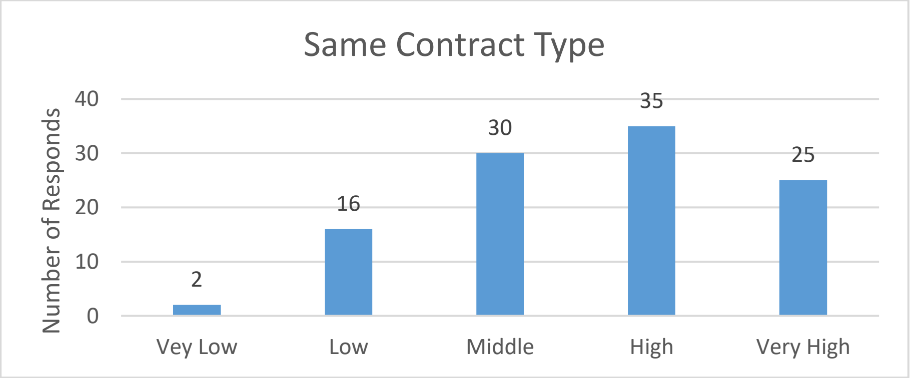


Figure 4.15: Same Contract Type Results

Importance level for each attribute is identified through averages and these averages are used for defining the weight of each attribute. “Country”, “project type”, “client”, “technology”, and “contract type” averages are calculated as “4.17”, “4.41”, “3.91”, “3.89”, and “3.60” respectively. Weight for each attribute is presented with the calculations in Table 4.1.

Table 4.1: Weights of Attributes in Similarity Calculation

Attribute	Survey Result	Ratio in all results	Weight in terms of %
Country	4.17	4.17/19.98=0.2087	20.87
Project Type	4.41	4.41/19.98=0.2207	22.07
Client	3.91	3.91/19.98=0.1957	19.57
Technology	3.89	3.89/19.98=0.1947	19.47
Contract Type	3.60	3.60/19.98=0.1802	18.02
Total	19.98	1	100

4.3.3.2.2. Project Similarity Calculation

In the “similarity search”, one project has to be selected to find the related lessons. Attributes of the selected project are compared with the attributes of other projects in the database and the “similarity rate” is calculated between the selected one and the others. This method is named as “Overlap” similarity measure. The process is based on identification of the categorical data similarities using the project attributes, simply the number of matching attributes between two projects (Boriah et al. 2008). In this model, each attribute has a weight, which is presented in the previous section, and when the project attributes are matched, the project “similarity rate” is increased by the amount of the attribute weight. For example, when all the attributes are matched for two projects, the “similarity rate” is calculated as “100%”, similarly if only the “country” and “client” attributes are matched, “similarity rate” is calculated as “40.44%” by adding “country” and “client” weights that are “20.87” and “19.57” respectively. Procedure for the “similarity value” calculation is presented in Figure 4.16.

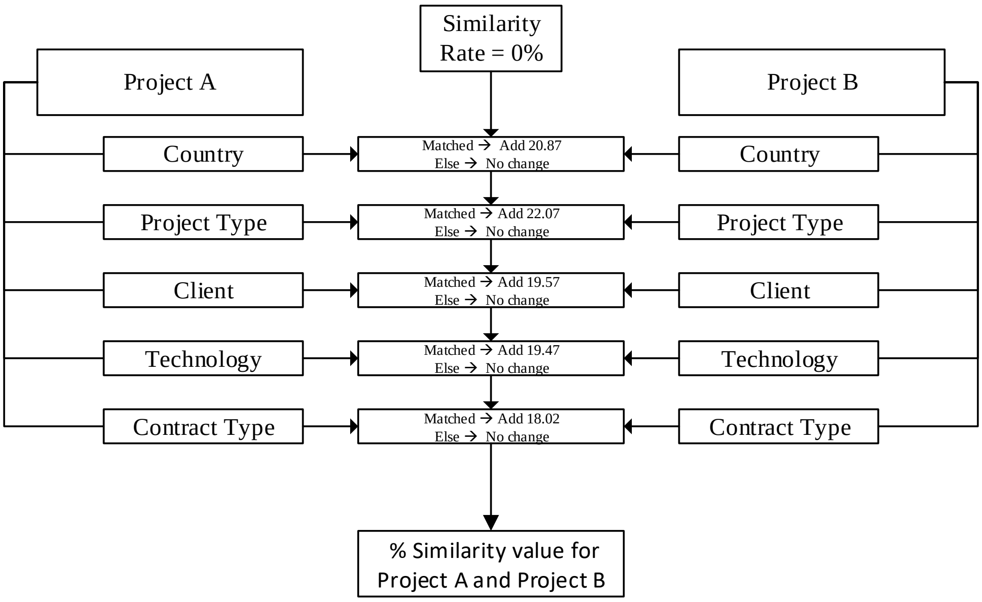


Figure 4.16: Similarity Value Calculation

Calculation method can be formulated as provided below;

A and B implies projects and $S(A,B)$ stands for total similarity rate for the two projects.

$$S(A,B) = \sum_{k=1}^{n_k} w_k * s_k(A_k, B_k) \qquad (1)$$

$$s_k(A_k, B_k) = \begin{cases} 100\% & if\ A_k = B_k \\ 0 & otherwise \end{cases} \quad k = 1, \dots, n_k \qquad (2)$$

where; w_k is the attribute weight for attribute k, $s_k(A_k, Y_k)$ is the per-attribute similarity, and n_k is the maximum number of the attributes for defining similarity.

4.3.3.2.3. Components of the Similarity Search

"Similarity search" is consisting of two steps as in "filter search". First step is selecting the interested project from the list of projects. The purpose in selecting the interested project is actually selecting data of the attributes automatically. As a result of this, interested project must be already created in the system before using "similarity search". In order to provide flexibility, adding "similar attribute" data as an extra input is provided in the first step. Extra inputs provide ability to expand the search scope. As mentioned before, data of the attributes automatically comes from the inputs of the selected project and matching of these attributes and the predefined weights are used to calculate the "similarity values". Attribute data can be increased if the user thinks that another country/client/project type/technology/contract type should be considered as similar to attributes of the interested project. For example, if the project location is "Russia", "Ukraine" can be added in this step as an extra input, and country similarity rate for each project is calculated as "20.87" when this attribute matches with "Russia" or "Ukraine". In addition to that, extra input weights can also be adjusted by entering a similarity amount for the attribute. For example, if "highway" project type is added as an extra input to the "railway" project type with "80%" similarity, effect of this extra input in project similarity is calculated by multiplication of "0.8" and the "project type" weight which is "22.07", and the result will be "17.65". Data of example projects are provided in Table 4.2.

Table 4.2: Project Data for Example Calculation

Project Name	Attributes				
	Country	Project Type	Client	Technology	Contract Type
Project A	Russia	High Rise Office Building	Client 1	Pre-Stressed Concrete	FIDIC
Project B	Azerbaijan	Tunnel	Client 2	Tunnel Boring Machine	FIDIC
Project C	Russia	Mass Housing Project	Client 1	Tunnel Formwork	FIDIC
Project D	Turkey	Mass Housing Project	Client 3	Tunnel Formwork	Public Procurement Law

System is exemplified through the provided example projects in Table 4.2. "Project A" is selected as the interested project and similarity rates are calculated accordingly. In the first calculation, extra input in terms of attributes are not included and the results are obtained as in Table 4.3.

Table 4.3: Example for Similarity Calculation without Extra Inputs

Similarity Calculation for Project A only with Project Attributes						
Project Name	Attributes					Total
	Country	Project Type	Client	Technology	Contract Type	
Project C	☑ - 20.87	☒ - 0	☑ - 19.57	☒ - 0	☑ - 18.02	58.46%
Project B	☒ - 0	☒ - 0	☒ - 0	☒ - 0	☑ - 18.02	18.02%
Project D	☒ - 0	☒ - 0	☒ - 0	☒ - 0	☒ - 0	0%

Same example projects are used to calculate similarity with an extra "country" and "project type" attribute. In this example, "Project A" is selected as the interested project and the "similarity rate" between "Project A" and the others are calculated with extra attributes. As seen in Table 4.2, "Russia" is the project country for "Project A" and it is directly used in the similarity calculation. In addition to that, "Turkey" is identified as similar to "Russia" with a similarity ratio of "75%". In addition, "project type", which is "high rise office building", is accepted "60%" similar to "mass housing" project. In this example, it is obvious that if one of the project country is "Turkey", similarity rate between "Project A" and other one will be increased by "15.65%" that is the result of multiplication of "20.87" and "0.75". Complete calculation details and the total similarity values are provided in Table 4.4

Table 4.4: Example for Similarity Calculation with Extra Inputs

Similarity Calculation for Project A with Additional Attribute		
Additional Attributes	County: Turkey	Project Type: Mass Housing Project
	Similarity for Attribute: 75%	Similarity for Attribute: 60%

Project Name	Attributes					Total
	Country	Project Type	Client	Technology	Contract Type	
Project C	☑ - 20.87	☑ - 0.60*22.07 = 13.24	☑ - 19.57	☒ - 0	☑ - 18.02	71.70%
Project D	☑ - 0.75*20.87 = 15.65	☑ - 0.60*22.07 = 13.24	☒ - 0	☒ - 0	☒ - 0	28.89%
Project B	☒ - 0	☒ - 0	☒ - 0	☒ - 0	☑ - 18.02	18.02%

This method is used to find and list the similar projects through "similarity search" mechanism in this research. After calculating "similarity values", lessons in similar projects are listed to the user grouped under project names. After this step, second search area, which is used in “filter” and “tag based” search options also, can be used by the user to filter lessons according to the lesson related attributes. Details of this secondary search step is presented in “4.3.3.4 Secondary Search“ section. After completing search and filtering steps, lessons, which are expected to be related with the interested project, can be reviewed through the refined results.

4.3.3.3. Tag Based Retrieval

As explained in the previous sections, in “filtering” and “similarity based retrieval” options “project attributes” are used to find the lessons and each of them are designed to meet specific needs. “Filtering” option is more useful when the user wants to retrieve lessons specific to some “project attributes”. On the other hand; if the users do not want to search according to specific “project attributes”, but they want to find the most related lessons for their interested project, “similarity search” option becomes the best choice. Common point of these two options is that, both of them use “project” related information to retrieve lessons. It is obvious that lessons may needed to be retrieved according to “lesson context” directly in some conditions. “Tag based retrieval” option is developed to satisfy this gap, which exists in the other two search options. As mentioned in “4.3.2.2 Lessons Learned Information“, context of the lesson is kept in free text area, which is not designed in a searchable way, but “tags” are used to label the lessons in terms of content. These “tags” are used to create a company defined level of “indexing” to make the lessons easily obtainable among the lessons available in the database. Defining a “tag” freely in the lesson entrance step can ruin the system integrity because the same content may be identified with different words. To prevent this, a “taxonomy” is developed, which is used to structure the “tag tree” in this research to provide generation of the “tag extent” in a controllable and manageable way. First, development method and features of the “taxonomy” are presented and following that principles of the “tag based retrieval” system is explained.

4.3.3.3.1. Taxonomy

As mentioned before, main purpose of developing this "taxonomy" is using it in the form of "tag tree" to label the lessons to make them indexed in an organized way. "Taxonomy" is developed based on literature survey. The structure of the "taxonomy" is based on four main categories as "Project", "Process", "Actor", and "Resource" as it is proposed in the study of El-Diraby et al. (2005). The "Project" category enables "project type" specific tags, whereas the "Process" category is identified as processes during life-cycle of a project as "feasibility", "design", "contract formation", "management", and "construction". The "Actor" category is required to address the problematic/useful parties as "organizations" or "individuals", and the "Resource" category is required to indicate lessons about "personnel", "manpower", "machinery and equipment", "material", "subcontractor", and "software". The "taxonomy" contains tagging of task related factors as well as management level factors. The sub-categories have been identified up to a reasonable level that would enable the retrieval of the available and related/expected lessons learned, and also prevent excessive information that would restrict the usability of the taxonomy. The initial aim is to present a "default taxonomy" to the user that would be sufficient for any company for tagging of the lessons learned; however, the "taxonomy" would be editable in the tool for specific use of companies. The "taxonomy" is structured with more than 2000 concepts identified as a result of the literature survey.

The "Project" category is composed of "125" items in order to label the lessons in terms of "project types". Within this context, three different sources, which are published by EuroStat (1997), International Organization for Standardization (2014) and Construction Project Information Committee (2013), have been used for developing the "Project" main category. These documents have been analyzed and the extracted concepts are merged in a single body to develop a "tag tree" that would be comprehensive enough but be simple as well as much as possible. Complete “taxonomy” is presented in Appendix A; in addition to that, summary of the “project taxonomy” up to outline level “2” is provided in Table 4.5.

Table 4.5: Project Taxonomy Summary up to Level 2

Items	**Outline Number**
Project	1
Buildings	1.1
Permanent Buildings	1.1.1
Mobile And Temporary Buildings	1.1.2
Underground Buildings	1.1.3
Civil engineering works	1.2
Ground contouring	1.2.1
Transport infrastructures	1.2.2
Harbours, waterways, dams and other waterworks	1.2.3
Pipelines, communication and electricity lines	1.2.4
Complex constructions on industrial sites	1.2.5
Other civil engineering works	1.2.6

Main objective of creating the “actor taxonomy” is labeling the lessons with the related parties. As it is mentioned before, the lesson entry step has an actor area to capture actors with their names; however, “taxonomy” is designed not for capturing “actor name”, it is designed to present information about “duties” only. This means that lessons can be labelled with the related departments, sub-contractors, employees, etc. The “Actor” category contains “71” items and these items have been collected from two different sources. In this category, a book named as “Roles in Construction Project: Analysis and Terminology” (Hughes and Murdoch 2001) is used as the main source. In addition to that, ISO 6707-2:2014 standard (International Organization for Standardization 2014b) is used as supplementary document. All actors are categorized under “Client”, “Constructer”, “Dispute Resolvers”, “Regulators” and “Staff” items, and the “actor taxonomy” up to outline level “2” are presented in Table 4.6. Complete “taxonomy” can be investigated in Appendix A.

Table 4.6: Actor Taxonomy Summary up to Level 2

Items	**Outline Number**
Actor	2
Client	2.1
Project Sponsor, Funder	2.1.1
Client's Representative	2.1.2
Client liaison officer	2.1.3

Table 4.6: Actor Taxonomy Summary up to Level 2 (continued)

Items	**Outline Number**
Constructors	2.2
Main Contractor	2.2.1
Design Contractor	2.2.2
Management Contractor	2.2.3
Principal Contractor	2.2.4
Partial Responsibility	2.2.5
Direct Contractor	2.2.6
Dispute Resolvers	2.3
Adjudicator	2.3.1
Arbitrator	2.3.2
Mediator	2.3.3
Regulators	2.4
Statuary Authorities	2.4.1
Local Authority	2.4.2
Staff	2.5
Feasibility Consultant	2.5.1
Construction Manager	2.5.2
Design	2.5.3
Financial	2.5.4
Administration	2.5.5
Site Inspector	2.5.6
Worker	2.5.7

The “Process” main category is divided into five sub-categories that are “Feasibility”, “Design”, “Contract Formation”, “Construction” and “Management”. These five categories contain “1588” items in total. Different sources have been used for development of each category. “Feasibility”, “Design” and “Contract Formation” categories are mainly developed according to “Roles in construction projects: analysis and terminology” book (Hughes and Murdoch 2001). Works of El-Diraby et al. (2005) and Dykstra (2011) are also the other two resources, which are used to develop these sub-categories.

The “Construction” sub-category is structured with the help of four different sources but it mainly depends on the classification of CSI (2014). Other three resources, which are used to identify the concepts for this sub-category, can be listed as El-Diraby et al. (2005), Hughes and Murdoch (2001) and Chudley and Greeno (2010).

The “Management” sub-category needs more resources than other categories to be developed because, there is not any resource available, which may be used in lessons learned system in the "tag tree" directly. Fourteen different resources are investigated to make the "taxonomy" complete enough to label the lessons in terms of management related topics. Resources used for structuring the "Management" sub-category are presented in Table 4.7.

Table 4.7: Resources Used to Develop Management Taxonomy

Lessons learned system in construction management	(Arditi et al. 2010)
An Ontology-Based Approach For Delay Analysis	(Bilgin 2011)
Construction Project Management: A Complete Introduction	(Dykstra 2011)
Construction Project Management: An Integrated Approach	(Fewings 2012)
Development Of A Knowledge-Based Risk Mapping Tool For International Construction Projects	(Yıldız 2012)
Project Management for Construction: Fundamental Concepts for Owners, Engineers, Architects and Builders	(Hendrickson 2000)
Construction Planning and Scheduling	(Hinze 2004)
Project Management: A Systems Approach to Planning, Scheduling, and Controlling	(Kerzner 2003)
Project Management for Engineering, Business and Technology: Principles and Practice	(Nicholas 2004)
Construction Accounting and Financial Management	(Peterson 2010)
A Guide to the Project Management Body of Knowledge (PMBOK Guides)	(PMI 2000a)
Construction Extension to A Guide to the Project Management Body of Knowledge	(PMI 2000b)
Management of Construction Projects: A Constructor's Perspective	(Schaufelberger and Holm 2002)
Construction Project Management: A Practical Guide to Field Construction Management	(Sears et al. 2008)

The "Process" taxonomy up to outline level "2" is provided in Table 4.8 and the complete "taxonomy" with the "1588" items can be investigated in Appendix A.

Table 4.8: Process Taxonomy Summary up to Level 2

Items	**Outline Number**
Process	3
Feasibility	3.1
Design	3.2
Stage	3.2.1
Design Branch	3.2.2
Contract Formation	3.3
Define the work to be done	3.3.1
Agree Contractual Terms	3.3.2
Identify the Builder	3.3.3
Identify the Price	3.3.4
Construction	3.4
Site Works	3.4.1

Table 4.8: Process Taxonomy Summary up to Level 2 (continued)

Items	Outline Number
Construction Works	3.4.2
Conveying Equipment	3.4.3
Mechanical Systems	3.4.4
Electrical, Communication and Automation Systems	3.4.5
Utilities	3.4.6
Transportation	3.4.7
Waterway and Marine Construction	3.4.8
Plant Equipment	3.4.9
Management	3.5
Time Management	3.5.1
Financial Management	3.5.2
Quality Management	3.5.3
Human Resource Management	3.5.4
Risk Management	3.5.5
Claim Management	3.5.6
Safety and Environmental Management	3.5.7
Procurement Management	3.5.8
Communications Management	3.5.9
Contract Management	3.5.10

The "Resource" taxonomy contains "258" items, which are related about "sub-contractor", "construction machinery and equipment", "software", "manpower", "personnel", and "material". Six documents are used to develop the "resource taxonomy". The "Sub-contractor" sub-category is developed from the "roles" in construction projects (Hughes and Murdoch 2001). Items in the "construction machinery and equipment" sub-category are mostly taken from ISO/TR 12603:2010 (International Organization for Standardization 2010), in addition to that, work of Peurifoy et al. (2006) is used. Other four sub-categories are compiled by using resources provided by El-Diraby et al. (2005), Hughes and Murdoch (2001), International Organization for Standardization (2014b) and Hendrickson (2000). Like others, the "resource taxonomy" is provided in the text up to details of outline level "2" (Table 4.9), and complete list is presented in Appendix A.

The created "taxonomy" is embedded to the lessons learned management system in a form that neither limits the users in identification of the cases nor it leaves them unguided. The "taxonomy" is presented with main categories at first to ease its access, and when the user opens the sub-categories, the taxonomy extends with the items in that sub-category. When a sub-category is assigned as a "tag" for an entry, the ancestor categories are automatically assigned to the entry. With this feature, related entries are obtained in case of a search with an upper level category rather than only providing search with the exactly assigned tag. The "taxonomy" can also be improved in accordance with the company needs. Developed taxonomy constitutes the part of the LinCTool and editing options provided in the LinCTool are presented in section "5.2.1.1 Tag Tree Modification".

Table 4.9: Resource Taxonomy Summary up to Level 2

Items	**Outline Number**
Resource	4
Sub-contractor	4.1
Domestic Sub-Contractor	4.1.1
Nominated sub-contractor	4.1.2
Labour-only Sub-contractor	4.1.3
Specialist Sub-Contractor	4.1.4
Construction Machinery and Equipment	4.2
Earth-moving machinery and equipment	4.2.1
Foundation and drilling equipment	4.2.2
Equipment for preparing, conveying and compaction of concrete, mortar and processing reinforcement	4.2.3
Lifting machinery and equipment	4.2.4
Access machinery and equipment	4.2.5
Equipment for installation, finishing work and maintenance	4.2.6
Road construction and maintenance machinery and equipment	4.2.7
Machines and equipment for specialized works and processes in construction	4.2.8
General-use machinery and equipment used in construction	4.2.9
Software	4.3
Manpower	4.4
Foreman	4.4.1
Labour	4.4.2
Personnel	4.5
Feasibility Consultant	4.5.1
Construction Manager	4.5.2
Design	4.5.3
Financial	4.5.4
Administration	4.5.5
Material	4.6

4.3.3.3.2. Components of the Tag Search

As mentioned before, “tag based search” is based on the “tags” assigned to each lesson. “Tag search” can be done through two steps. In the first step, interested tags are selected form the developed “taxonomy”, which is namely the “tag tree”. According to the selected tags, lessons are listed as grouped under projects. After this step, developed method is the same with other two search options. “Secondary search” option constitutes the second step in the “tag based search”. In this step lesson can be filtered according to the previously assigned “lesson attributes”. The details of the “secondary search” is presented in the next section 4.3.3.4. After completing the search procedure, obtained lessons can be reviewed.

4.3.3.4. Secondary Search

“Secondary search” option exists in the all three search options. This mechanism is developed to provide ability of filtering search results in terms of “lesson attributes”. As mentioned before, three search mechanisms are developed and lessons are retrieved according to the selected “attributes”. However, two of the alternatives works with “project attributes” and the other one uses “tags” to retrieve lessons. Additionally, it is considered that, there may be a need to refine search results according to “lesson type” and “importance”. In this perspective, seven attributes are defined to filter the obtained search results. Two attributes are used to define the “lesson importance” and these are “Effect on Project Duration” and “Effect on Project Cost”. As mentioned before, these attributes are identified in the data entry process and they are used to narrow down the results in the “secondary search”. “Type” of the lesson implies “best practices” and “failures”, and it is entered at the lesson creation step. Filtering the search results according to “lesson types” is done through the “secondary search” area. Fourth attribute that is used to filter lessons in the “secondary search”, is the “actor”. Filtering lessons according to related “actors” is considered necessary since it may facilitate gathering information specific to "company" or "person". In addition to that, "tags" are also used in the "secondary search" area, but it is different than "tag based search" option. In the "secondary search", only the "tags", which have already been entered for the retrieved lessons in the "primary search", are used and this provides ability to narrow down the results according to "lesson contents". In addition to these "lesson attributes", "creation date" and "approval status" of the lessons have been added to the model since 'oldness' and 'validity' of the lesson are also important factors for defining the 'importance' of a lesson. In conclusion, the "secondary search" has a potential to improve filtering capability of the system with the seven attributes that are presented below;

- Effect on Duration
- Effect on Cost
- Lesson Type (Failure/Best Practice)
- Tag
- Actor
- Creation Date
- Approval Status

With the help of "secondary search", necessary effort to find the right lessons for the projects and situations may decrease. Therefore, this mechanism has been defined as a part of the model for all the three search options that are "filtering", "similarity" and "tag based" searches.

4.4. Validation of the Lessons Learned Process Model

Validation of the lessons learned process model has been done through the expert review meeting. Four people are attended to expert review meeting. Two of them are working as academician at construction engineering and management division in

Middle East Technical University. Other two participants were working in the private sector and they were PhD candidates. One of them is working in software firm which their main specialties can be stated as developing construction sector related software. Other participant is working as manager in the construction company which is listed as top construction companies in the Engineering News-Record 250 (ENR-250) list.

Scope of the expert review meeting is not only limited with the validation of the lessons learned management process model but also includes COPPMAN project also. A prototype is prepared and access link provided to participants 10 days before the meeting date and introductory document is sent together with the access link. Participants found a chance to analyze the system within the 10 days' period. After the pre evaluation period, all participants have been invited to meeting and research team made a presentation about developed systems before question and answer section. In question and answer section, participants are able to ask questions about unclear areas.

After completing the question and answer section, evaluation form has been filled by the participants to capture expert opinions about the proposed system. Evaluation form is consisting of six section which can be listed as; "Completeness/Coverage", "Suitability/Accuracy", "Usefulness", "Usability", "Receptiveness" and "Overall". Positively presented expressions are given in the evaluation form and participants select their rates in 1-7 Likert scale (1 totally disagree – 7 totally agree). As explained before this meeting scope covers COPPMAN functions as well as lessons learned management process model. As a result, evaluation form contains question about all COPPMAN functions which also includes lessons learned management model. Expert evaluation form contains 52 questions in total and 17 of them related with lessons learned management process model, which 8 of them directly and 9 of them common with other COPPMAN functions. Lessons learned management process model related questions shows that proposed model was appreciated by the experts (Table 4.10).

Table 4.10: Expert Meeting Evaluation Form Results

Expert	Completeness / Coverage	Suitability / Accuracy	Usefulness	Usability	Receptiveness	Overall	Average
1	5.5	5.5	7	5.6	6	6.14	5.77
2	6.25	6.5	7	6.4	5.67	6.14	5.97
3	6.25	6	7	6.6	6.67	6.14	6.50
4	6	6	5	6	5	5.43	5.75
Average	6	6	6.5	6.15	5.5	5.83	6

Also experts' suggestions for the possible improvements about the proposed system have been asked at the end of the evaluation form. In this section, 3 suggestions were collected related with the LLMPM. One of them is necessity of the search mechanism in the tag tree structure in order to decrease necessary time to find desired tags. Second one is the capturing related actors in lessons learned forms to give ability to find actor related lessons. Last suggestion is improving the lessons approval mechanism to ensure lesson learned quality and decreasing knowledge overload. All suggestions were taken into consideration and LLMPM is revised before developing the LinCTool. Presented LLMPM earlier in this section contains these revisions.

4.5. Implementation of the Model in Computer Environment

This research has been conducted within the context of TUBITAK project, whose grant number is 213M493 and title is "Development of an IT-based tool for portfolio assessment and management for construction companies". Main objective of the TUBITAK project is developing a tool that can be used as a decision support system for portfolio selection and management of construction projects. It is believed that, using past project knowledge to select and manage projects in the portfolio can be a major asset. Learning from previous projects can be facilitated by developing an effective "lessons learned database", implementing to it an efficient retrieval mechanism through successful codification of knowledge. In this perspective, a knowledge management system is developed to support the portfolio management tool. It is appreciated that developed knowledge management system has a potential to be used separately by the small to medium sized companies that would not adopt portfolio management as a strategy. The knowledge management system would be sufficient to be beneficial for creating, sharing and utilizing knowledge within all capacity/size companies, since it is bringing a sound solution in an inexpensive way and with minimum effort. Therefore, the established knowledge management system has been generated as a separate tool (LinCTool) in addition to being a part of the project portfolio management tool (COPPMAN).

In order to provide knowledge management system as a separate tool, it has been developed separately but compatible with the needs of the project portfolio management tool. Implementation of the developed model in computer environment has been done together with a programming company through service procurement. Requirements of the tool were given to the programming company at the beginning and development has been done through several stages. Each completed part of the tool was delivered by the company and suitability of each part is controlled by the research team. The tool has been generated as a cross-browser compatible single page web application developed on top of ASP.NET MVC framework. Server-side components are programmed with C# and client-side components are programmed with JavaScript. The user interface is designed to be functional for data entry and retrieval.

As it is mentioned before, tool is designed as a web application and hosted in a Microsoft server and it can be accessible through the web address of “www.linctool.com” with SSL connection.

CHAPTER 5

LEARNING IN CONSTRUCTION TOOL: LinCTool

In this chapter, details of the web application, which is developed within the scope of the research is provided. Name of the tool is identified as LinCTool as an abbreviation of "Learning in Construction Tool". The tool is developed according to the "lessons learned management process model", which is provided in the previous section. General framework of the tool is presented in the next section, and its details are explained in "5.2 LinCTool Details" section.

5.1. LinCTool General Information

LinCTool is a web application, which is hosted in Microsoft Web Server and developed on top of ASP.NET MVC framework. Tool is compatible with the mostly used web browsers such as "Microsoft Edge", "Google Chrome" and "Safari". In addition to personal computers, it can be accessible through mobile devices like tablets and smart phones. Thanks to its design, client side of the tool does not need any extra installation for executing the program. Server-side components have been programmed with C# and all the calculations are done at the server side. Microsoft SQL server is used as database to store the information both related with the "tool preferences" and the "lessons learned information". The user interface is designed to be editable according to company preferences. Menu links can be opened or closed according to user roles. This provides the necessary flexibility for maintaining the system easily. Client-side components have been programmed with JavaScript and it is functional for data entry and data retrieval. Domain name of "linctool.com" was taken under this project and tool is securely accessible through the address of https://www.linctool.com. Details of the tool are provided under four categories as "Administrative Settings", "Entry of the Required Information", "Lesson Learned Entry", and "Lesson Learned Retrieval" in the next section. In addition to that, login screen of the tool is provided in Figure 5.1. Users can also reset their "passwords" through the link, which is provided in this screen, but new user registration cannot be done from this screen. New user adding is limited and privilege is belonging to the system administrators in order to increase the system security. Users can access to the tool functions according to their authorization levels by entering their "e-mails" and "passwords" after their "accounts" are created by the "system admin". First password is created automatically and sent to the account e-mail.

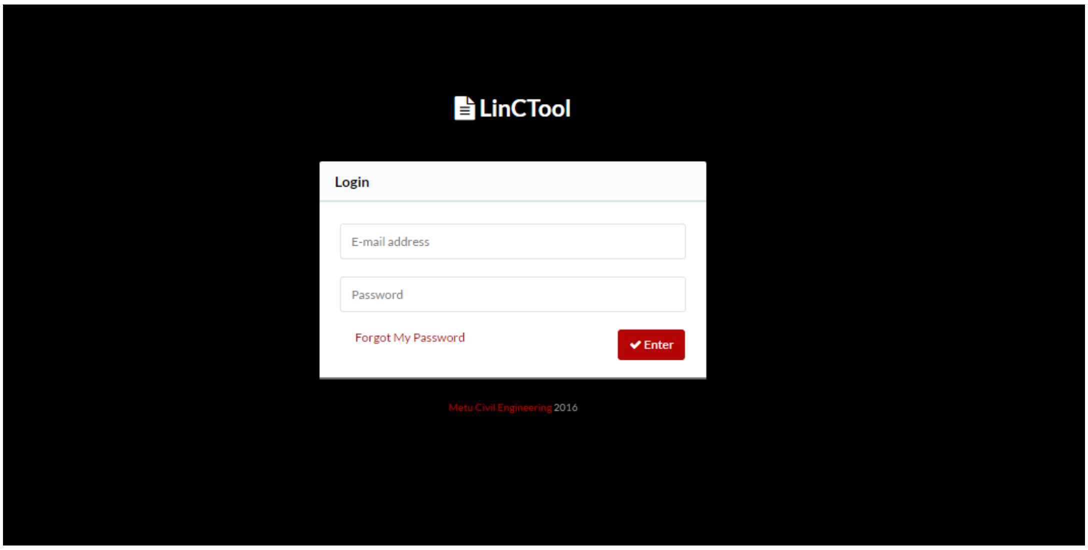


Figure 5.1: Login Screen of the LinCTool

General layout of the tool is available in Figure 5.2. As mentioned tool can be accessible through the mobile devices without sacrificing any function by means of responsive design of the web interface. Accessing to system from mobile devices such as smart phones or tablets provides mobility, which may be very important in the construction sites especially. “Main access menu” is located at the left side and sub-menus are accessible through expanding main menus. Main menu can be shrunk to the “icon view” to increase useful area of the function screens. This feature is very beneficial for accessing through mobile devices due to relatively small screens. In the upper right side, account settings menu located and rest of the screen is changeable according to functions. Details of each section and their functions are presented in the next section.

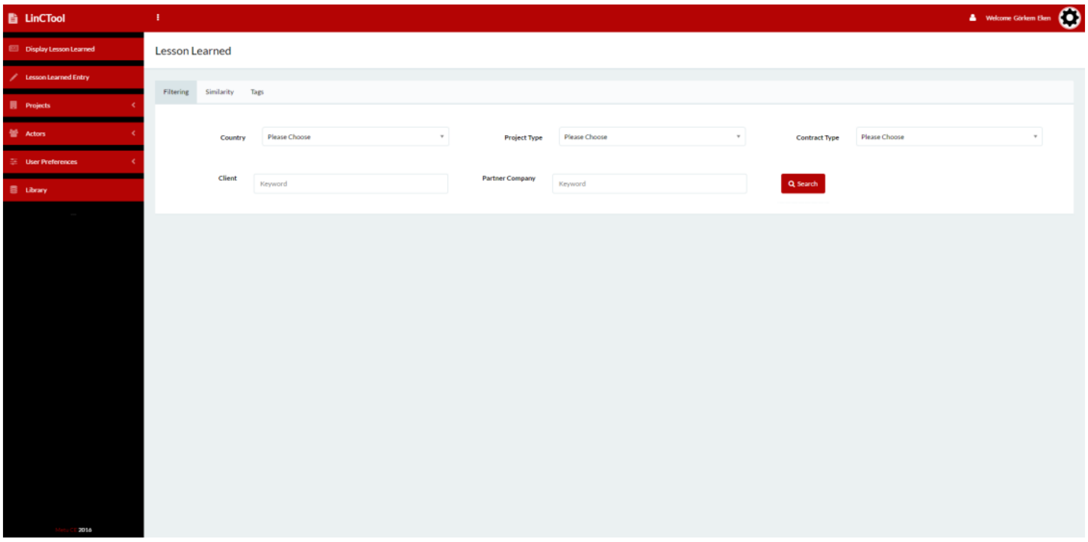


Figure 5.2: General Layout of the Tool

5.2. LinCTool Details

In this section, developed tool is presented in detail. The tool functions can be categorized in four parts as “administrative settings”, “entry of required information”, “lessons learned entry” and “lessons learned retrieval”. Details are grouped and presented according to these four categories.

5.2.1. Administrative Settings

Administrative settings contain information about tag tree modification, project similarity coefficients, user management, roles and authorization, library editing and site settings. Details are presented in the following sections.

5.2.1.1. Tag Tree Modification

The feature is added to the tool in order to provide flexibility to user while adding "new tags" if necessary. The tool becomes ready to improvements through this function. According to company speciality, "predetermined tags" in this research can also be decreased to prevent "tag overload" and this can ease to find "necessary tags". Predetermined tags are labelled as "default tag" and even if they are deleted "tag tree" can be turned to its original state with the "reset tag tree" option. User can access to tag tree modification screen from the link under "User Preferences" which is labelled as "1" in Figure 5.3.

In this page, "Reset Tag Tree" button is located in the upper right side (Figure 5.3 "label 2"). As described before, this button is used for resetting tag tree to predetermined state. User can add new tag or delete existing tag by right clicking on the tag tree area, which opens the "Add" and "Remove" buttons (Figure 5.3 "label 3"). When the "Add" button selected, area that is labelled as "4" is opened (Figure 5.3) and the user is able to enter the "tag name" to the related input area. Added tag can also be labelled as "default tag" to prevent deleting it after using the "Reset Tag Tree" button. Tags can be moved by left clicking to provide the indented structure which is the main function to have tree type structure. In addition, modification on the already added tags is possible by left clicking to the related tag.

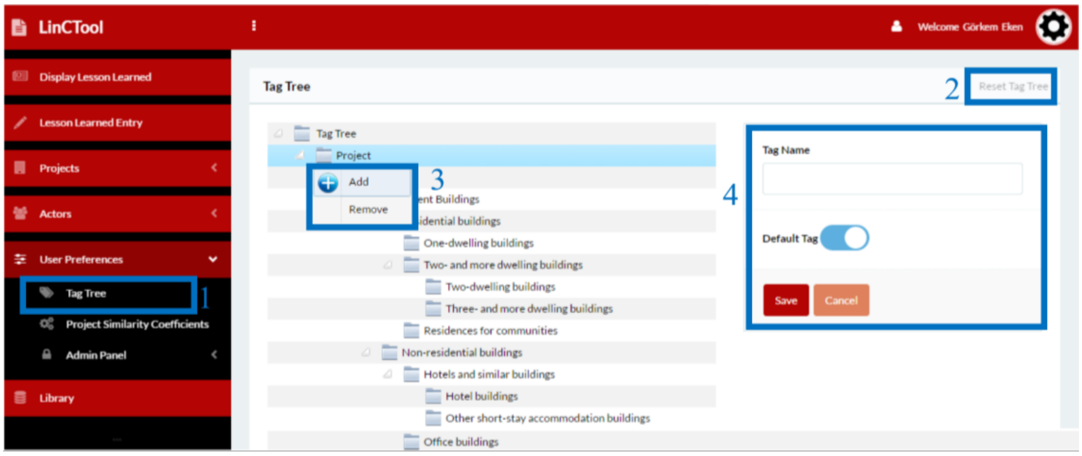


Figure 5.3: Tag Tree Modification Screen

5.2.1.2. Project Similarity Coefficients

As mentioned in the methodology chapter, "project similarity coefficients" have been determined by online survey; however, in the application, these coefficients are not hard coded and user can change these values according to company preferences. Editing screen can be accessible through the "Project Similarity Coefficients" button which is located under "User Preferences" (Figure 5.4 "label 1"). The attributes, which are used for calculation of the project similarity are not changeable; however, weight of each attribute can be changed through the screen that is labelled as "2" in Figure 5.4.

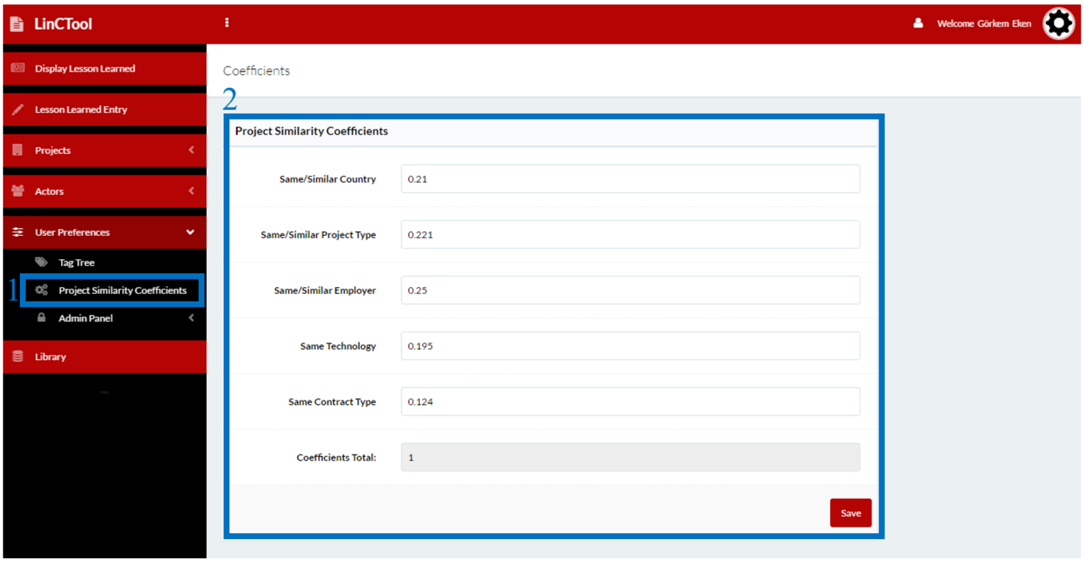


Figure 5.4: Project Similarity Coefficient Update Screen

5.2.1.3. User Management

One of the main objectives in this research is providing live capture of knowledge, as mentioned in the methodology section. In order to achieve this objective, proposed system contains different "types" of users. To be able to define different types of users, the tool must be used by different "user accounts". "User Management" menu of the tool is used for adding a "new user" to the system as well as editing the "existing user" information and "assigning roles" to the users. The system does not allow the new users to "sign up" through a web browser. Only the "authorized users", which are expected to be the "system admins" in the proposed structure, can add a "new user" to the system. Types of the roles and authorization process is provided in the section "5.2.1.4 Access and Authorization", so that, only functions for new user registration and assigning a role to user are presented in detail in this section.

Registration of a new user to the tool is done through the "Add User" button which is located under "User Management" menu (Figure 5.5 "label 1"). Required information are determined as "Username", "Title", "Name", "Last Name", "Phone" and "Password". Usernames must be an "e-mail address" and because of that e-mail information is not required again. After filling the necessary information, user is created by the "Save" button (Figure 5.5 "area 2").

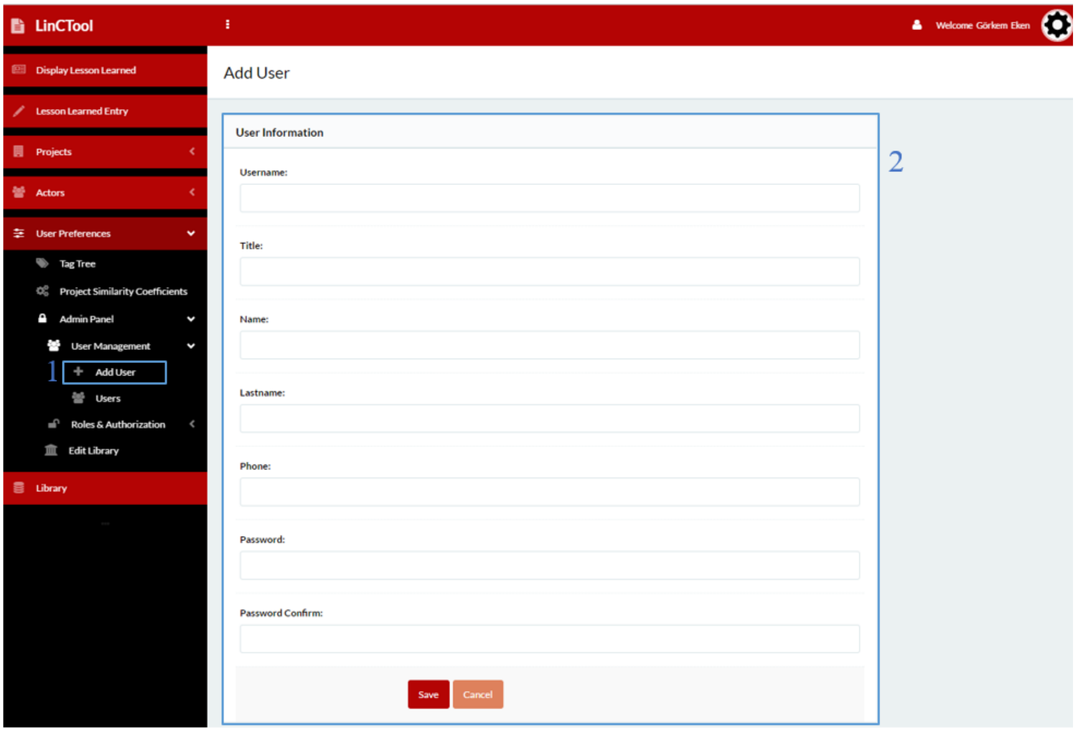


Figure 5.5: Add User Screen

"Users" menu is designed for providing capability to the authorized user of editing, removing and assigning roles for an existing user account and user can access this screen from menu link located under "User Management" as presented in Figure 5.6 "area 1". In addition, search function is developed to ease to find a user. Search can be done according to "username", "title", "name", "last name" or "phone" from the same search box (Figure 5.6 "area 2"). User account can be deleted by the "Remove" button or account passwords can be reset by the authorized users. (Figure 5.6 "area 4").

Account information can also be updated through the "Edit" button (Figure 5.6 "area 3"), which opens the same screen with add user screen (Figure 5.5). Difference between the “add” and “edit” screens can be stated as the edit screen is opened with the information that is entered earlier for the users.

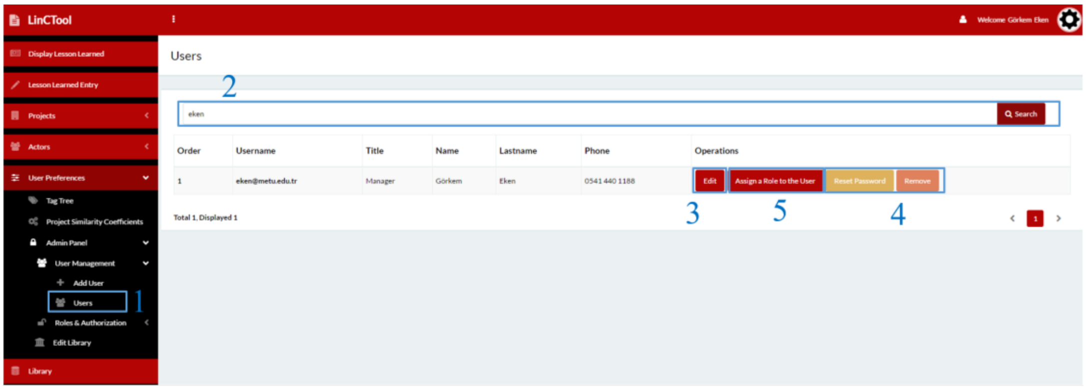


Figure 5.6: User Search and Management Screen

Each account is associated with the roles to satisfy system needs. Details of these roles are presented in the next section but assignments of the roles to the users are done through the “Assign Role to the User” button that is labelled as “area 5” in Figure 5.6. The button contains a link to open the screen, which provides ability for associating users with the roles (Figure 5.7). User name is stated in the area, which is labelled as “1” in Figure 5.7, to show that operation is done to which account. Assignment procedure is provided to be simple. All the roles which are available in the tool are listed in the left side of the screen (Figure 5.7 “area 2”), and the associated roles with the accounts are listed in the right side (Figure 5.7 “area 3”). The “green” buttons are used for adding a new role to an account, and the “orange” ones are used to remove the association. These rights are only belonging to the system admin accounts and these authorizations are done through the access and authorization menu. Details of the authorization function is presented in the next section.

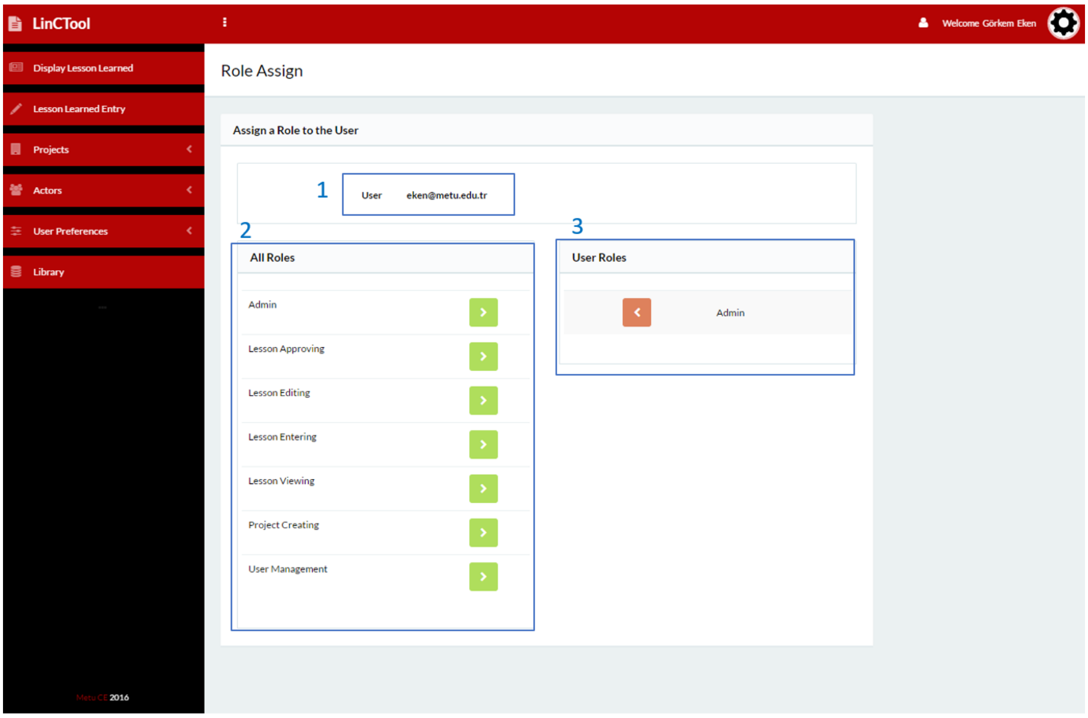


Figure 5.7: User and Role Association Screen

5.2.1.4. Roles and Authorization

Proposed lessons learned management system contains different types of "user roles", and the developed tool is capable of realizing this function. "Knowledge manager" and "project coordinator" are examples for the defined roles in the methodology section; however, the roles in the tool are not entered in this way to simplify the authorization process. Both the "knowledge manager" and the "project coordinator" are capable of reviewing a lesson learned and entering a lesson learned, because of that, tool functions are grouped under six roles and these are listed below;

1. Lesson Approval,
2. Lessons Editing,
3. Lessons Entry,
4. Lesson View,
5. Project Creation,
6. User Management.

Besides these roles, “system administrator” role, which has full access to the tool functions, is also created in the tool. In this section, first role and authorization system is introduced then predefined role privileges are explained in detail.

One of the main objectives in the tool development process was creating a fully customizable system according to company needs. In this perspective, authorization and roles were not developed as hardcoded in the system. Company can add new roles to system from the “roles” screen, which can be accessible from the menu link under “Roles & Authorization” (Figure 5.8 “label 1”). Roles screen provides user ability to adding new role to system or editing and removing existing roles in the tool. Figure 5.8 “area 3” lists all the roles in the system, and the “add role” button is located at the upper part, which is labelled as “2” in Figure 5.8.

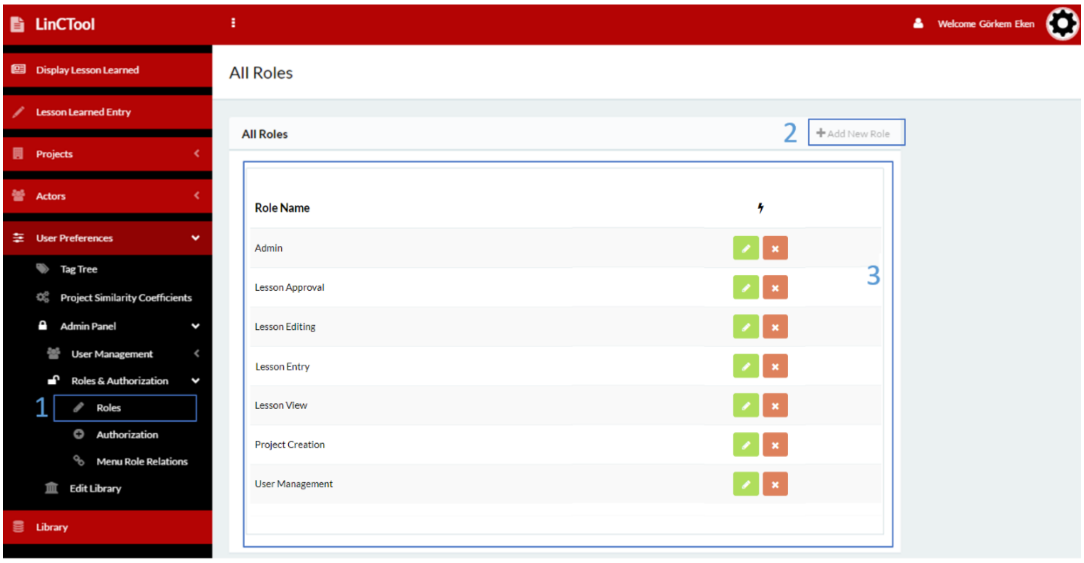


Figure 5.8: Roles Management Screen

Necessary actions such as deleting lesson, approving lesson or adding new user to the system, etc. are assigned to the roles through the “authorization” window. “Authorization” menu link, which is located under “Roles & Authorization”, is used for accessing this area (Figure 5.9 “label 1”). As shown in Figure 5.9, left side of the screen contains the tool operations. Search option for the actions is developed for facilitating the finding an action (Figure 5.9 “area 3”). When one of the operations is selected, the right area is opened. The “Authorize” button, which is labelled as “5” in Figure 5.9, is used for making connection between the roles and the operations. Each operation is named according to their location. For example, deleting a project is done by the button, which is located in display projects menu, and this operation is named as “Project – Display Projects – Operations – Remove”. This naming method is selected in order to ease the user understanding of operations’ meaning. The “admin” role is assigned to each operation but the other roles are assigned only to the related operations. If user do not have privileges to execute the operation, the related button is not shown to the user. Detailed list of the relations between the operations and the roles is provided in Appendix B.

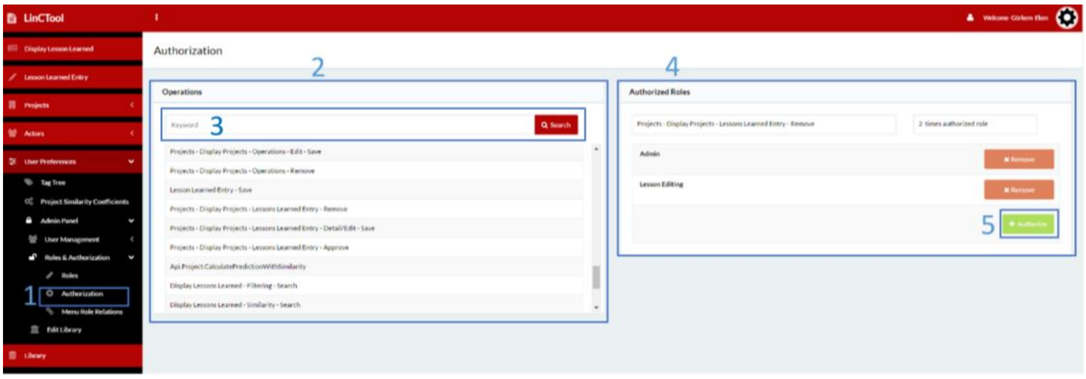


Figure 5.9: Authorization Screen

Other than authorization in terms of operations, left menu access permissions can be assigned to the roles. This provides opportunity to arrange user privileges according to their duty in the tool. For example, if a field engineer is not authorized to create a project in the system, he/she cannot see the “Projects” menu link and its sub-links also. This authorization can be done through “Menu Role Relations” screen that can be accessible from the link located under “Role & Authorization” menu (Figure 5.10 “label 1”). The user, who has privileges to do an operation, can see all the menu names through the dropdown area that is showed with “label 2” in Figure 5.10 and by selecting one of the names, associated roles for the selected menu are listed in the area which is labelled as “4” in Figure 5.10. The “green” buttons are used for associating the roles with the menus, and “orange” ones are used to cancel an authorization. List of all the predefined authorizations in terms of menu - role is provided in Appendix B.

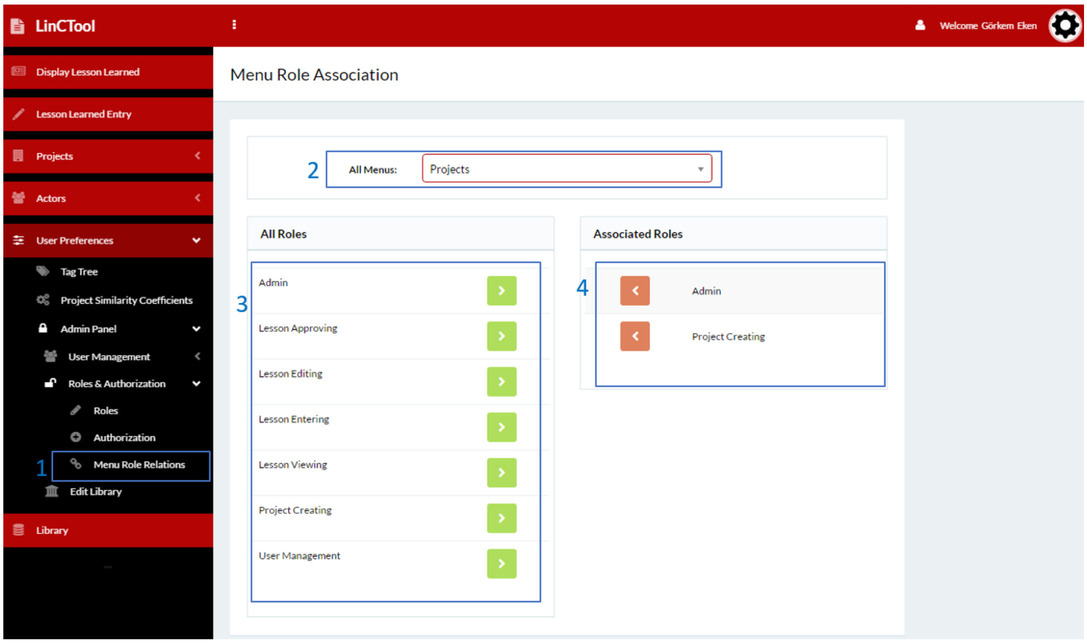


Figure 5.10: Menu Role Association Screen

5.2.1.5. Library

An area is integrated to the system in order to guide the users about the system, and inform the users about the terms which are used in the system. The area is named as “library”, and it can be accessible from the menu link that is provided in the bottom of the left menu (Figure 5.11 “area 4”). This screen shows the text documents, which can be uploaded from the library editing screen. The user, who has the admin privileges, can access this screen from the menu link that is located under the “User Preferences” menu (Figure 5.11 “area 1”). In this section, first of all, subjects are determined, and then they are entered in the system as in “English” and “Turkish” (Figure 5.11 “area 2”). These subjects are shown to the user in the “library” screen and the user is able select the topics from the dropdown menu. When a topic is selected, the uploaded text document appears. Files are uploaded from the "library editing" screen, which is shown in Figure 5.11 "area 3". For each subject, documents can be uploaded in two languages and according to "site settings", the related document is shown to the user. In this research, two documents were prepared and uploaded to the system; however, extra documents can be prepared and uploaded to the system according to company needs.

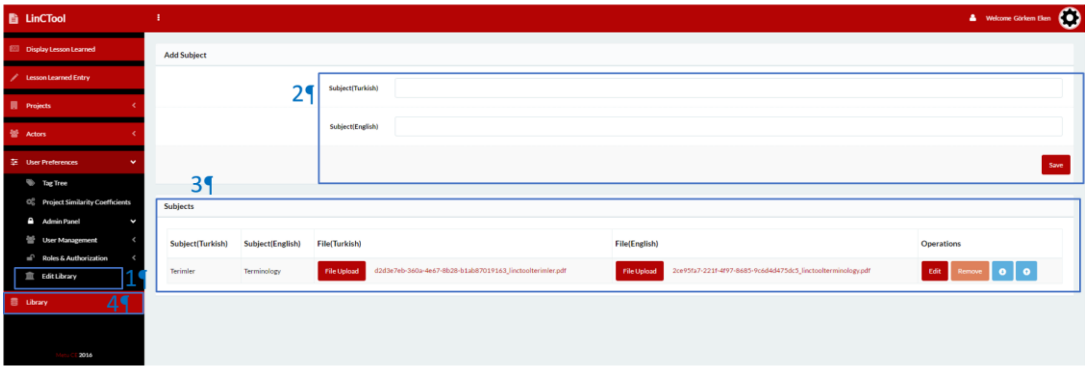


Figure 5.11: Library Editing Screen

5.2.1.6. Site Settings

System is developed in two languages as in "English" and "Turkish". From the "settings" screen, the user, who has admin privileges can change the system language and increase or decrease the number of records that are shown in the lists. The access button of this screen is placed under the icon located at the right upper side (Figure 5.12).

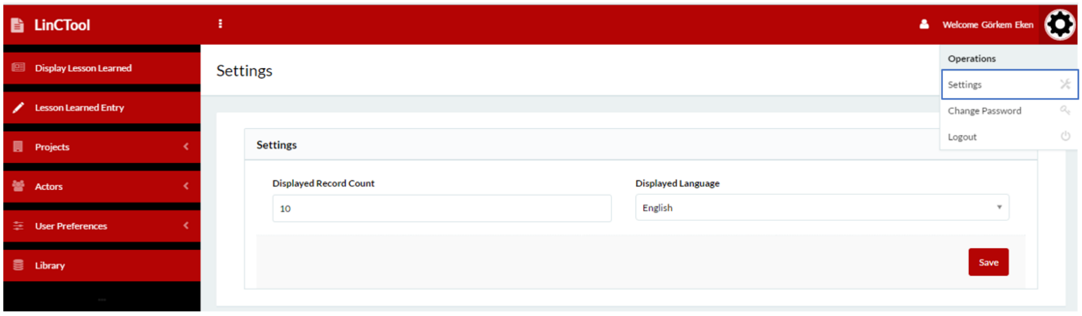


Figure 5.12: Site Settings Screen

5.2.2. Entry of the Required Information

Each "lesson" is entered to a "project" in the tool, and also these projects and lessons may contain information related to a "person" or a "corporation", both of which are named as "actor" in the tool. Thus, before adding a "lesson", the related "projects" and the "actors" must be defined. Within this aspect, the required information consists of "projects", "project inputs" and "actors". First "actor adding" process is presented, and then necessary "project inputs" and their "adding" methods are provided. The section is completed by presenting the "project adding" and "project displaying" processes.

5.2.2.1. Actors

Actor database is developed in order to simplify "actor adding" process for the projects and lessons. In addition to that, since client data is used in similarity calculation, this system prevents miscalculation of similarities due to the misspell. Another advantage is the storing contact information to facilitate reaching the actor when it is needed. Entry of "person" and "corporation" type actors are done through the "add actor screen". The access button to this screen is located under actor's menu. (Figure 5.13 "label 1").

The necessary information required to add an actor was determined as the “name of the person” or “title of the company”, “phone number”, “address”, and “detailed information” about actor. After filling these four areas, user can select “individual or company” from the “toggle” button which is showed with the “area 2” in Figure 5.13.

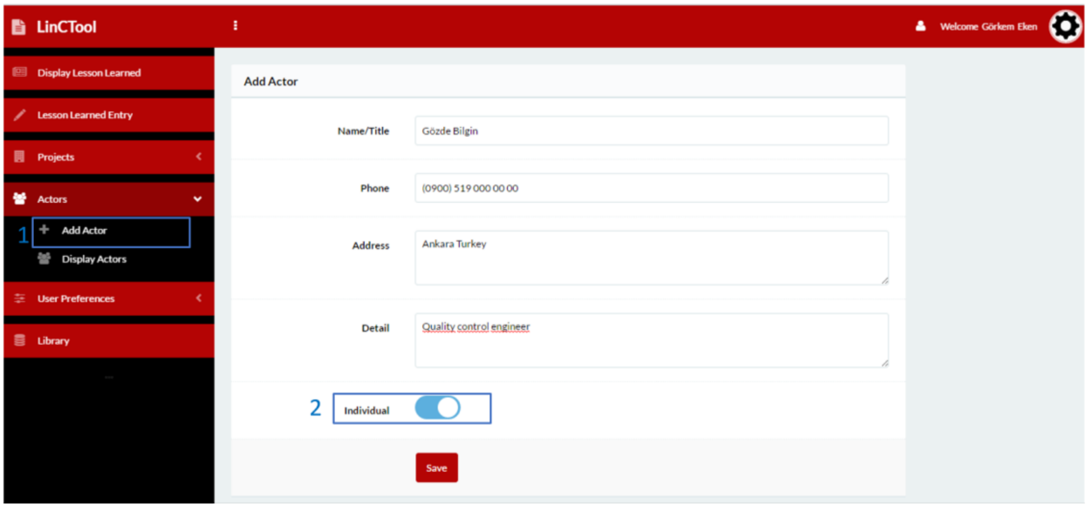


Figure 5.13: Actor Adding Screen

Since the information about actors is not static and can be changed over time, “actor management system” is developed for editing the actor information. This system contains a search option according to keyword to facilitate finding of an actor (Figure 5.14 “area 2”). After finding the searched actor, its previously entered information can be edited or it can be removed from the system through the buttons showed with “label 2” in Figure 5.14. Deleting operation is allowed only if the actor was not added to any project or any lesson. The access button to “actor management system” is located under “Actors” menu as showed in Figure 5.14 “area 1”.

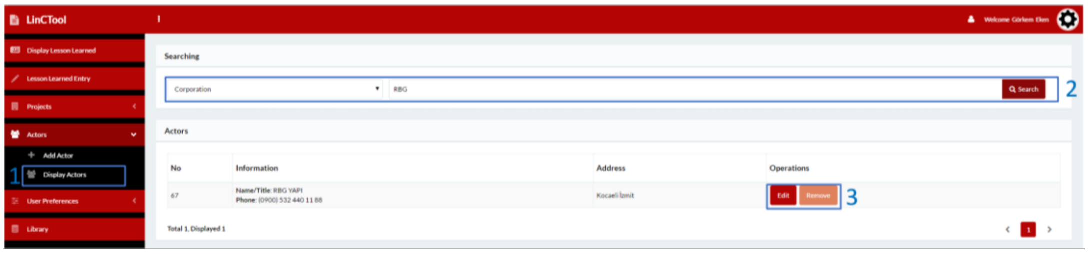


Figure 5.14: Actor Display Screen

5.2.2.2. Project Inputs

One of the lesson retrieval options is the “similarity search” for projects, and this “similarity search” is done according to “country”, “project type”, “employer”, “technology” and “contract type”. In project entry, user should select this information from the already defined data in order to prevent miscalculation due to misspell. “Employer” of a project is selected from the actors list as explained before. All the “country” names has been defined in the tool, and user should select the project location from these countries. Possible mismatching of the attributes in the “similarity search” due to misspelling of these two attributes is prevented by this method. On the other hand, information of “project type”, “technology” and “contract type” are not allowed to be entered to the system through predefined attributes like “country”, since these are differing attributes from company to company or country to country. In addition, adding this information to a project as a free text would also not be logical for the “similarity search” function. The database is developed for saving this information within a structured form in order to solve possible problems. Users are able to add new data to these areas when it is needed. In addition to these three input types, “partnership types” are saved to the system through project creation even though it is not used in the similarity calculation. Saving “partnership type” to a project is an important input for learning from projects. The system and the related screen are designed in the same way for these four inputs, and only one of them is presented in detail to demonstrate the system. Access links of entry screens for project inputs are located under “Project Inputs” menu as provided in Figure 5.15 “area 1”. This system is developed in a simple form to prevent misspell in the project adding procedure. For example, adding a new “project type” can be done by directly writing its name to the related area that is presented in Figure 5.15 “area 2”. In addition, all the entered data is listed in this screen to provide ability of editing and removing (Figure 5.15 “area 3”). The user is allowed to remove data only if it was not assigned to any project. This process is the same for all the project input types that are “project type”, “contract type”, “partnering type” and “technology”.

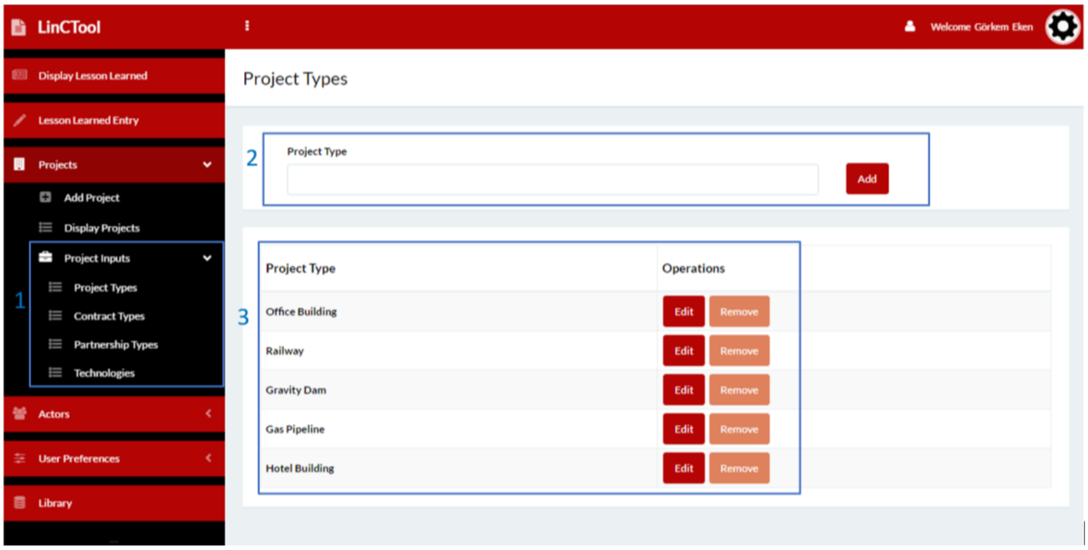


Figure 5.15: Example for Project Inputs Enter Screen

5.2.2.3. Project Entry and Management

Projects are entered through the project creation screen, which can be accessible from the "Add Project" menu link (Figure 5.16 "area 1"). Figure 5.16 "area 2" shows these information with an example project data. The required project information to define a project in the tool are listed and explained with the details presented in below.

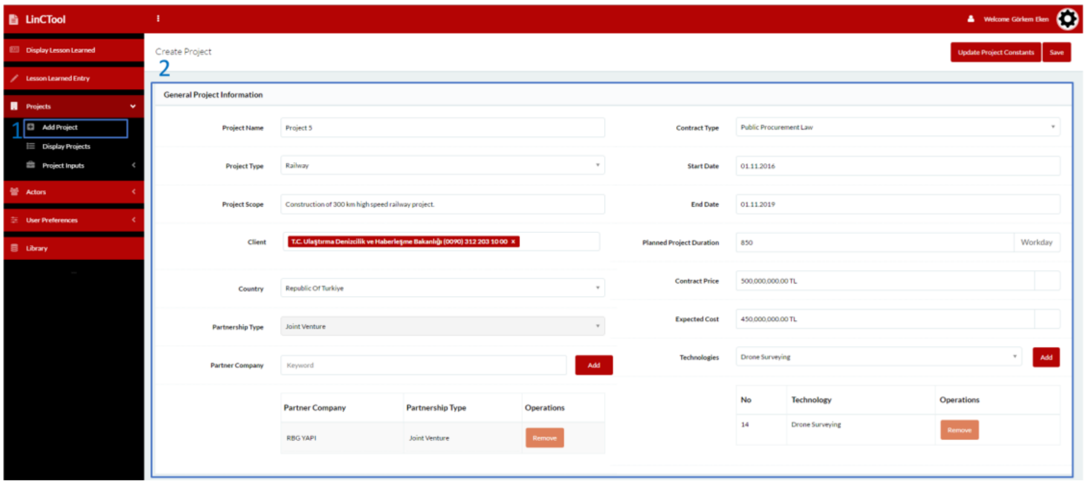


Figure 5.16: Project Creation Screen

Project Name: Project names must be entered in a unique and distinctive form in the system, since they are used to select projects in operations such as, lesson entry and similarity search. Free text area is used to capture this information.

Project Type: Project type is selected from the list of already identified types through the dropdown menu. This information is also used for similarity calculation. As mentioned before, project types can be added through the project inputs menu and in the project creation step. User can only select a type if it has been already added to the system.

Project Scope: Brief description and scope of the project should be entered to this area. This area is designed as a free text area and it is designed to get information about project's itself when it is needed.

Client: Client information is added from the defined actors in the system. When user writes a part of the client name, results are displayed automatically and then client information can be selected from the results list. Client information are also used in similarity calculation, so the system does not allow user to write a client name as text, so this should be selected from the database.

Country: Complete list of the countries are defined in the system and user can search a country name among this list. Search mechanism is integrated to the country dropdown menu to facilitate country selection. Users are forced to select the country name from list, because country information is one of the project attributes, which is used to assess similarities between projects.

Partnership Type: Partnership type is one of the project inputs, which must be defined before project creation, but it is not used in the similarity calculation directly. This area is used to label the agreement type with the partner company and if it is selected partner company name must also be selected. Similar to other selection areas, this area is also designed as dropdown menu, which shows the entered partnership types to the user.

Partner Company: Partner company name is added from the defined actors and same search mechanism with the client attribute is used. After selecting the partnership type and the partner company name, user have to use the "Add" button to enter this information to the project. Add button is used in partnership information since projects may have more than one partner companies unlike the project type or client. Each partner together with its type can be added through this system.

Contract Type: Contract type is entered to the project if a standard form of contract is used in project such as "FIDIC" or "public procurement law". It is important to relate the projects in terms of contract conditions and this is also used for determination of the similarity rates between projects in "similarity search" for lessons learned. As in other attributes, contract types also have to be entered to the system before selecting them in the project creation. Available contract types are listed through the dropdown menu in the project creation step and it can be selected from this list.

Start Date: Start date of the project should be selected by opening the calendar screen.

End Date: Contract end date of the project should be selected by opening the calendar screen.

Planned Project Duration: Planned project duration is different than the contractual duration. Estimated construction time is entered in terms of work days. The idea behind is that, guiding users about duration related lessons.

Contract Price: Value of the project, which is specified in the contract should be entered to this area.

Expected Cost: Estimated construction cost should be entered to this area. Contract price and expected cost are required in the project information to guide users about financial lessons.

Technologies: Special technologies are captured within the project information to use them in similarity calculations. This attribute is selected from the already added inputs. As mentioned before, technologies are entered from project inputs area to the system for keeping and editing easily. Users can use search option to find the related technology in the project creation step, and more than one technology can be added to one project.

Entered project information must be reachable and editable to review and change information when is needed. A screen was created to list all the projects in the tool in the purpose of meeting this requirement in the tool. This project list can be accessible through the "Display Projects" link that is located under the "Projects" menu (Figure 5.17 "area 1"). Search can be done through the "area 2" in Figure 5.17 according to project name through the project database. The "Project operations" button is for providing the user the ability to edit or remove a project in the list. The "Edit" button opens the same screen with the "Add Project" screen, differently it comes loaded with the project information of the project to be edited. By this way, project information can be updated without losing the links between the lessons and the projects.

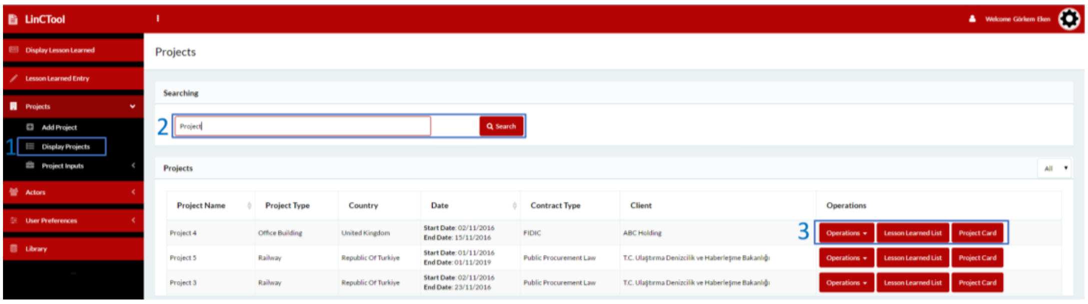


Figure 5.17: Project List Screen

Project card screen is developed to provide ability to review the projects easily. This screen does not contain any editable area so that it prevents changing information unintentionally. Project cards are accessible from the project list screen (Figure 5.17 "area 3"). This function is also necessary for authorization of the tool since it provides the ability to authorize users in terms of editing project and displaying project information. The project card access button is also placed to the lessons learned search screen and the details of this button is presented under the “5.2.4.4 Operations on Search Results“ section.

The “project card” contains information that is entered in the project adding section and an area for representation of calculated values. Information of “Project Name”, “Project Type”, “Project Scope”, “Client”, “Country”, “Partnership Information”, “Contract Type”, “Start Date”, “End Date”, “Planned Project Duration”, “Contract Price”, “Expected Cost” and “Technologies” is entered in the project creation step and displayed in the project card as it is, but a simple calculation is used to find the expected profit value (Figure 5.18).

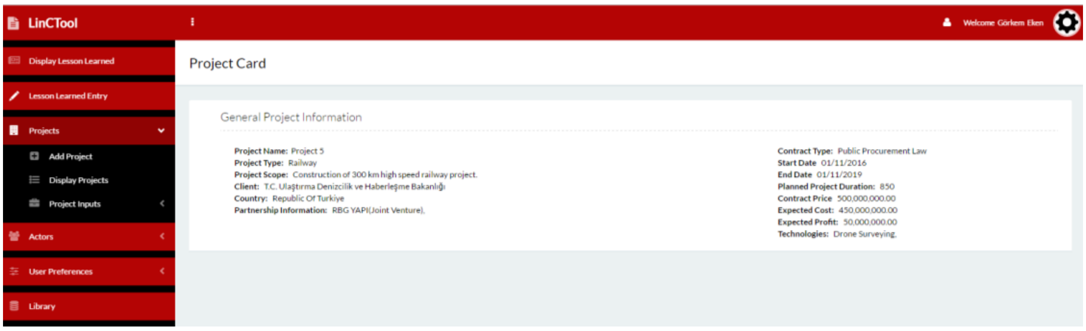


Figure 5.18: Project Card Screen

The “Lesson Learned List” button (Figure 5.17 “area 3”) is used for accessing and managing the lessons entered to the projects. This button opens the lessons learned screen of the selected project and in this screen, only the lessons of the selected project are listed (Figure 5.19 “area 2”). Search mechanism is developed in this screen in order to facilitate focusing an intended type of lessons. So that, listed lessons can be filtered according to “tag”, “effect on duration information”, “effect on project cost information”, “best practice or not” and “approval status”. In tag filter option, tags, which are assigned in the listed projects, are listed, and one of them can be selected through the drop down menu provided. “Effect on project” and “effect on cost” information can be selected from the drop down menu as “very low”, “low”, “middle”, “high”, and “very high”. “Approved” or “non-approved” lessons and “best practices” or “failures” can also be filtered through selecting the related areas (Figure

5.19 “area 1”). According to the user preferences lessons in the projects are filtered and users can use operations in the filtered results. Four operations can be done for the listed lessons. The “Detail/Edit” button is used for editing lesson learned and it opens the “lesson learned entry screen” with the information of the selected lesson. The “Lessons Learned Card” button is used for accessing the non-editable lesson learned information screen. Details of the “lessons learned entry screen” and “lessons learned card screen” are provided in the “5.2.3 Lesson Learned Entry“ section. The authorized users can change the approval status of the lessons through the “green” button presented in Figure 5.19 “area 3”. Deleting a lesson from the tool is done through the “Remove” button that is placed in this screen. Other operations and details related with the lessons learned operations are provided in the following two sections.

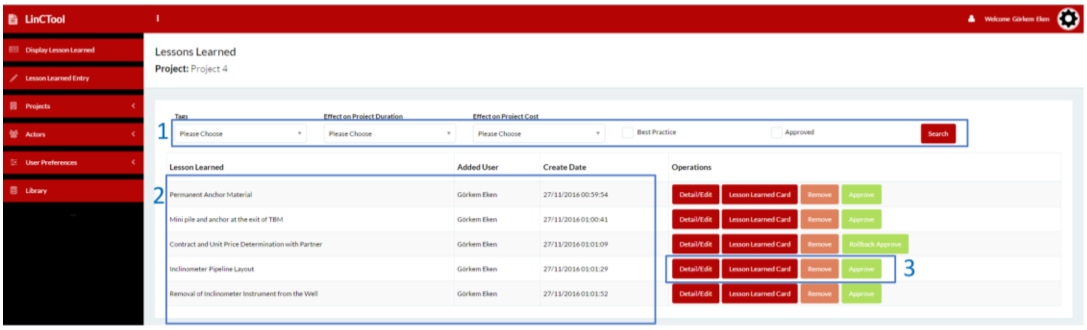


Figure 5.19: Lessons Learned List of Project

5.2.3. Lesson Learned Entry

The lesson learned entry screen is designed in a simple form as much as possible and it can be accessible from the “Lesson Learned Entry” menu link, which is shown in Figure 5.20 “area 1”. The necessary information for creating “lesson learned” are described in below;

Project: Each lesson must be related with one project that is defined earlier. Project name for lesson can be selected from the drop down menu, which presents project names from the tool database (Figure 5.20 “area 2”). This area is compulsory and without selecting a project name, lesson cannot be saved.

Lesson Learned Name: Lesson learned name is a brief introductory information for the lessons and this information is presented to the user when lessons are searched. Because of that, this information is also compulsory for creating lessons learned. This is entered through the provided free text area.

Best Practice: Lesson learned can be a “best practice” or a “failure” as mentioned in the literature review section; however, users may not be willing to select the “failure” option. In order to decrease the effect of this situation, tool is developed in a way that if lesson is not labelled as “best practice”, it implies the lesson is related with a “failure”. Therefore, in any screen of the tool, there is not any label related with the “failure”. In the lesson learned entry screen, only the “best practice” option is selectable and selecting this option is not compulsory. It means that lesson can be created without selecting the “best practice” option, and in this situation, lesson is treated as a “failure”. The statement of “Should be marked for the cases that are considered as a best practice” is provided in this screen to guide the user about usage of this area (Figure 5.20 “area 3”).

Event Description: “Event description” section is developed to capture the “best practice” or “failure” information in the text format. If the lesson is related with a “failure”, user can enter the reasons of problems, its consequences, unsuccessful actions taken to solve the problems, involved actors with their roles, etc. in the free text format. On the other hand, if lesson is related with a “best practice”, details of the event, why it is a best practice, its benefits, actions taken in the event, actors and their roles, etc. can be entered in the area. The “event description” area is used for understanding the event in detail and it is considered as the main area in terms of lessons learned capturing in the system. The system does not contain a “document upload and share system” since it may cause problems in terms of confidentiality of documents, but the related document names and their cloud links, photo and video links can be added to the event description area to provide extra information about the event. Sharing materials through cloud systems provides extra authorization options. Only authorized persons can access to the confidential documents by this way. In conclusion, the expected inputs for this area consist of detailed description of the event with all aspects and the necessary document links.

Recommendation: "Recommendation" area is also designed as a free text input. Similar to the "event description", input to this area changes according to the "lesson type" such as "failure" or "best practice". If the lesson is related with a best practice, expected recommendations can be summarized as possible ways to improve the process, important points for repeating it again, suggestions to make it a standard work process, critical points to pay attention in the process etc. On the other hand, if it is related with a "failure", possible prevention actions, ways to minimize effects of the consequences etc. can be entered.

Effect on Project Duration and Cost: This information is recorded separately to help categorizing lessons and improve the search capability. For example, by this way, user can only list the lessons, which have a high effect on duration or cost. To simplify this operation, degree of the effect can be entered in the system through "5-point scale" as well as real units. Each lesson may be labelled with one of the scales, which are "very low", "low", "medium", "high", and "very high". On the other hand, "real amounts" may not be entered if they are not known or difficult to calculate separately due to concurrent factors (Figure 5.20 "area 4").

Actor: "Actor" information is also not compulsory for creating a lesson, but it is necessary in terms of improving search capability and providing contact information of the involved actors. Actors are added from the actor database, which is explained in the "5.2.2.1 Actors" section. Search area, which is provided in Figure 5.16 "area 5" is used for finding actors from the database through keyword search. This means that in order to add an actor to a lesson it must be defined in the tool. This system does not provide any information about the roles of actors in the lesson, rather it gives in depth information about the actors which is mentioned in the "Event Description" part of the lesson. The developed system is capable of adding more than one actor to a lesson. The "Add" button is used to add an actor to a lesson and following that another search can be done to add another actor. This procedure is repeated until each actor that is mentioned in the “event description” part is added to the lesson.

Tags: Complete list of the lesson tags is provided in the lesson learned creation screen. Since number of the available tags is more than two thousand, “tag tree” comes to the screen with the tags at the outline level “1”; which means that it shows the only upper class tag groups. The user can expand these level tag groups to find the necessary tags manually, or developed search function can be used to find the intended tags. Search among tags is done through the “keyword search” and the results are displayed simultaneously, which means that no need to click any button to see the results, with their position in the hierarchy. For example, in order to add “Lost Productivity Cost” tag to a lesson, user can write some part of the word and results are listed simultaneously in the tree structure and this search option dramatically decreases the necessary effort needed to assign tags. Results are labelled with “red text” and in “italic form” to make them easily differentiable in the search results and results' upper level tags (Figure 5.20 “area 6”). Conservation of the tree structure is important in the search because upper level tags are also added to the lesson with the selected tag. So that, tag locations in the tree/hierarchy are shown with the results. Upper level tags are added automatically to the lesson to meet the requirements provided in detail in the “4.3.3.3 Tag Based Retrieval“ section. Following finding the intended tags in the tag tree, “right click” is used for relating it with the lesson. Added tags are listed through the assigned tags area, which is demonstrated in Figure 5.16 “area 7”. Tags constitute the main structure for grouping lessons and facilitating the retrieval procedure. Because of that, all the related tags should be assigned to a lesson.

When all the necessary information is filled in the “lesson learned add” screen, the “Save” button is used to create the lesson. More information about usage of the entered information in lesson learned creation is presented in the next section.

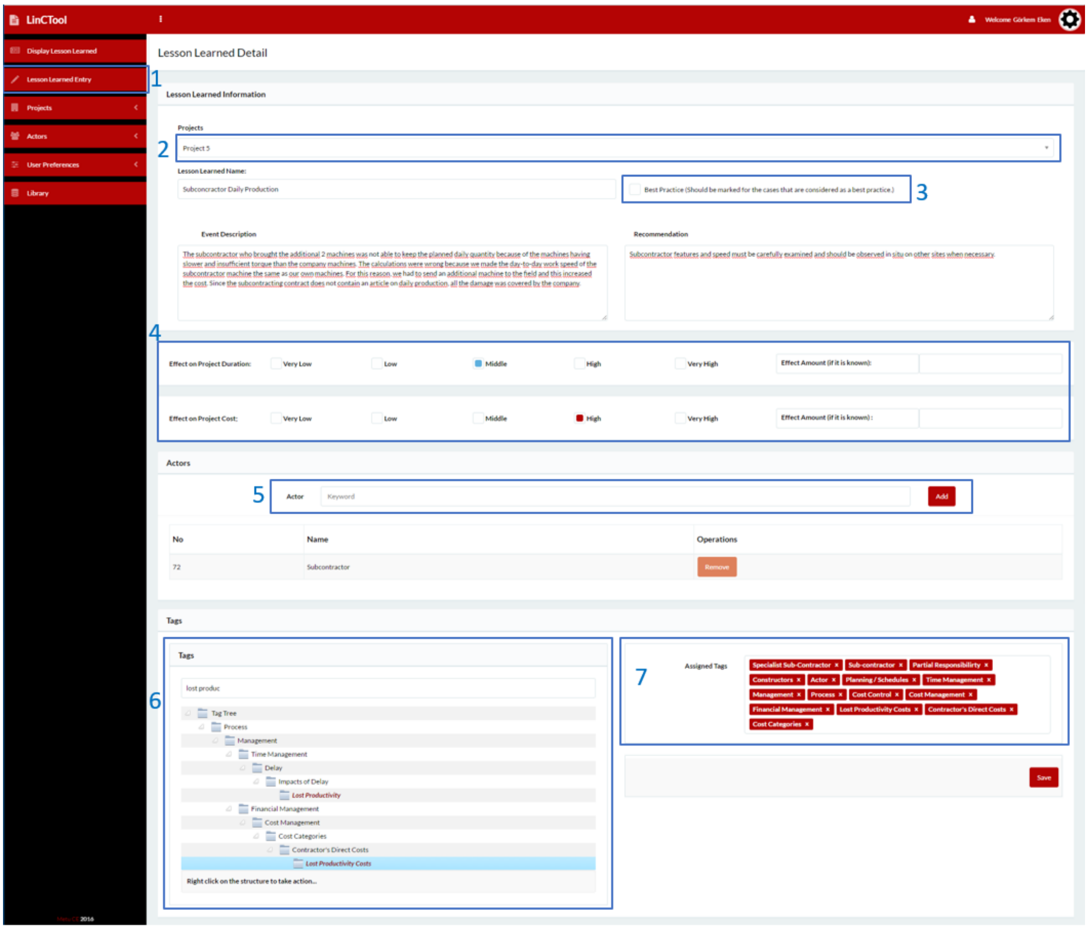


Figure 5.20: Lesson Learned Add Screen

5.2.4. Lesson Learned Retrieval

As mentioned before, to improve organizational learning, an effective search system is important as much as an effective capture mechanism in the lessons learned management systems. In the LinCTool, search mechanism is developed in three ways to provide flexibility to the user. All the search options is accessible through the "Display Lesson Learned" link, which is located in the main menu (Figure 5.21 "area 1"). The screen is opened with the "filtering search" option in default, but user can switch to the "similarity search" or "tag search" through the access buttons, which are shown in Figure 5.21 “area 2”. “Filtering”, “similarity” and “tag search” details are explained in the following sections.

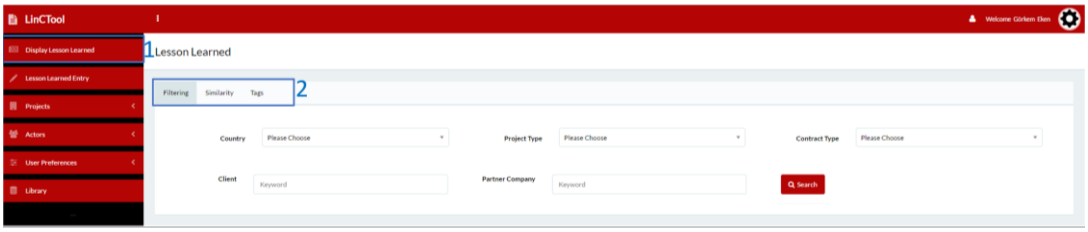


Figure 5.21: Lesson Learned Search Options

5.2.4.1. Search with Filter

Lesson retrieval through “Filtering” is done in two steps. In the first step, projects are filtered according to the entered attributes. Five attributes have been determined to filter projects among the project information entered in terms of attributes in the project creation phase. These are “Country”, “Project Type”, “Contract Type”, “Client”, and “Partner Company” information of projects (Figure 5.22 “area 1”). “Country”, “Project Type” and “Contract Type” information is selected from the dropdown menus that get data from the database. On the other hand, similarly, “Client” and “Partner Company” data come from the tool database, but their input areas are designed as “keyword search”. To list the lessons learned in the projects, not all the project attributes has to be filled. When more than one attribute is selected in each search, it narrows down the results because each attribute becomes related with each other with “and” function. This means that, when “Russia” and “Office Building” are selected for “country” and “project type” areas respectively, results will show the lessons which are only captured in “Office Building” projects constructed in “Russia”. When other attributes are also selected in one search, projects and their lessons are listed only if all the filtering attributes match with the project information. For example; “Office Building” projects executed in “Russia” under “FIDIC” contract.

After selecting interested attributes in the filtering, the “Search” button, which is located in “area 1” (Figure 5.18), is used to list the lessons. After search is done, “area 2” and “area 3” are opened as seen in Figure 5.18. “Area 2” contains the “secondary option” for filtering the results. This “secondary option” is designed based on the attributes, which are entered in the “lessons learned creation step”. This second phase can be used to filter the already listed lessons according to assigned “tags”, “effect on duration”, “effect on cost”, “approval status of lessons”, “creation date of lesson”, “related actors” and “best practice or not”. Details of these search options are provided as in below.

1. Tag selection area is designed in a way to list the only assigned tags in the lesson results. This means that the dropdown menu located next to the “Tags” header does not show all the “tags” in the “tag tree”. This area gets updated data for each search result. This facilitates selecting the tags to refine the lesson list and eliminates risk of obtaining an empty result.
2. “Effects on Project Duration” and “Effects on Project Cost” options can be used for focusing only on the important lessons, which have a high effect on projects' duration or cost. As explained in the lesson learned entry section, this information is entered to the lessons as “Very Low”, “Low”, “Medium”, “High” and “Very High”. The dropdown areas for these filters are used to select from the categories and search according to the selection.
3. “Approval status” option is mainly developed to facilitate finding and viewing newly created unapproved lessons by the authorized users, which are namely the “Knowledge Managers”. By this way, mismatched lessons are eliminated according to the selection, and only the “approved” or “unapproved” lessons can be examined easily.
4. “Creation date” of the lesson is automatically recorded and it is used as an option for lesson learned filtering. “Date” area, which is provided in Figure 5.22 “area 2” is used for this purpose. When a date is selected in this area, only the lessons are listed that are created after the selected date. This option is designed to ease periodical “lessons learned” search. New lessons can be

easily reviewed with this option, by selecting the last search date in some predefined periods.

5. "Best practice" label can be assigned to a lesson, if the lesson is considered as a "best practice". As mentioned before, "failure" labelling has not been used in the tool since the human behaviour is towards 'not willing to select a fail'. Therefor, "best practice" selection is used to list the best practices, or "non-best practices", which are mostly the "failures" or "problems".
6. "Actor" selection area is used to refine lessons according to the related actors. "Keyword search" is used to select an actor from the tool database. This is useful to find a lesson which is related with a specific actor such as, subcontractor, government agencies, employees, etc.

"Secondary search" area is optional and it can be used in order to decrease the volume of lessons listed if the scope of the search is clear. Second search option is also used in other two search and retrieval options that are similarity and tag based searches.

"Area 3" in Figure 5.18 shows the listed lessons according to search inputs. "Project" column in the list, shows the "project name" that the lesson is related. The "Detail" button, which is located next to the "project name" column can be used to open the "project card" in order to get detailed information about the project. Details of the "project card" is provided in Figure 5.18. The "Lessons learned" column contains names of the listed lessons.

The "Operations" column has four buttons, which are "Detail", "Edit", "Delete" and "Approve/Rollback Approve". Since these operations are common for each search option, details of these operations are provided separately in the section 5.2.4.4.

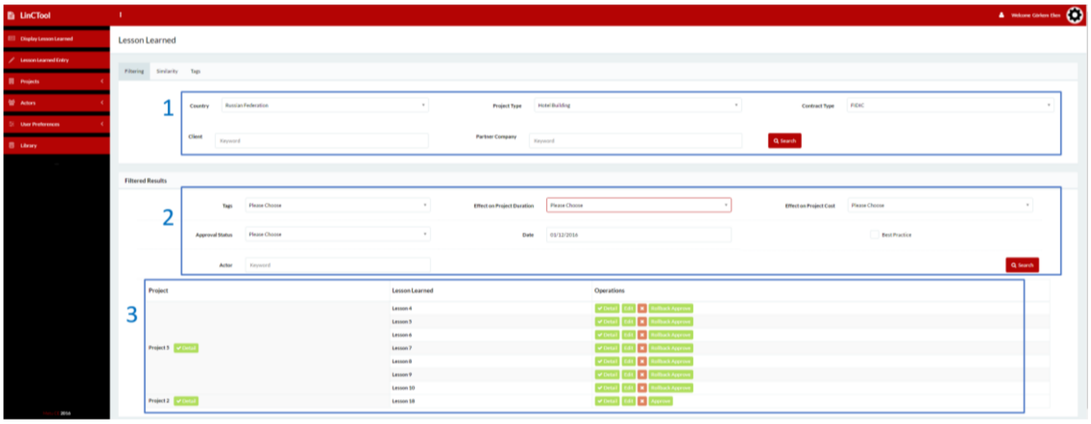


Figure 5.22: Search with Filter Screen

5.2.4.2. Search with Similarity

“Similarity search” is done according to “project similarity” rather than “lesson similarity”. As mentioned in the methodology section, similar projects have similar problems and similar procedures may be applied for finishing projects successfully. According to this logic, an alternative search option is developed for the lessons learned search. The “similarity search” screen can be opened through the “similarity tab” located in the upper side of the “Display Lesson Learned” screen (Figure 5.23 “area 1”). The interested project is selected from the dropdown menu that lists the defined projects in the tool (Figure 5.23 “area 2”). Project similarity is calculated according to the five project attributes. Weights of each attribute can be defined in tool as explained in the “5.2.1.2 Project Similarity Coefficients“ section. Details of the selection criteria and procedure for defining similarity attributes are presented in the “4.3.3.3 Tag Based Retrieval“ section; however, the selected attributes can be listed briefly as “country”, “project type”, “contract type”, “technology” and “client” information. The attributes are added to search by selection of the project from the dropdown menu which is provided as “area 2”; however, additional information can also be added through “area 3” in Figure 5.23. “Project 2” was selected as an example, from the dropdown menu and its attributes are listed below;

- Country: Russian Federation
- Client: ABC Holding
- Project Type: Motorway
- Technology: BIM
- Contract Type: FIDIC

Search can be done only according to the selected project's attributes automatically, and in addition to that, similar attributes can also be added such as "Turkey" as country, "Railway" as project type. Similar attributes are selected from the dropdown menus provided for "Country", "Project Type", "Technology" and "Contract Type"; on the other hand, addition of similar clients is done through the keyword search. When an additional attribute is added, it is listed in the area showed as "area 4" in Figure 5.23. In this area, the user defines the similarity rates for "Country", "Project Type" and "Client" types attributes; on the other hand, "Technology" and "Contract Type" attributes are coming with "100%" similarity and cannot be changed.

Simple calculation is done to find the similar projects. If selected project original attribute value is matching with other projects' attribute it takes full similarity rate which is defined in project similarity coefficients. Additionally, if an additional attribute is added, it is also considered in the calculation according to the similarity rate assigned. It means that, if a country is defined additionally as similar to the country in question and the similarity rate is defined as "50%", the country similarity is calculated as half of the main country similarity coefficient. Details of the calculation method is presented in the "4.3.3.2.2 Project Similarity Calculation" section.

Search results are listed at the bottom. "Project names" and total "similarity scores" are presented to the user with the similarity values (Figure 5.23 "area 6"). Lessons learned information of the projects is provided in the "area 7" of Figure 5.23 and the user can use the operation buttons to see the details, edit and delete the lessons learned and approve/rollback approve. Operation details is explained in detail at the "5.2.4.4 Operations on Search Results" section.

In order to filter the listed results according to the attributes of the lessons learned, “secondary search” area is provided as in the cases of “Filtering” and “Tag” search options (Figure 5.23 “area 5”). Details and usage of this second search area are explained in detail in the “5.2.4.1 Search with Filter“ section.

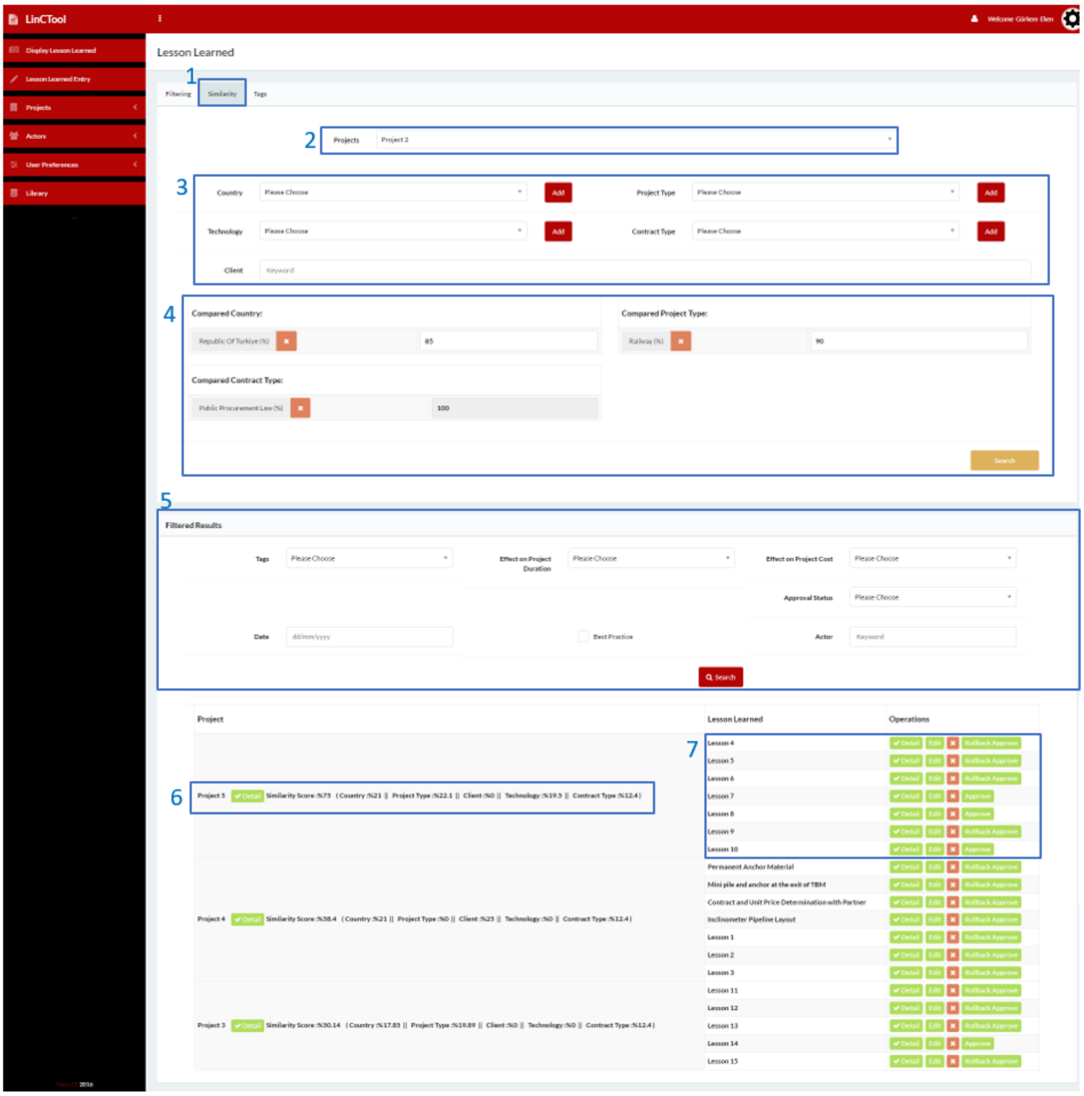


Figure 5.23: Search with Similarity

5.2.4.3. Search with Tag

Entered lessons learned can also be retrieved by “tag search” in addition to “filtering” and “similarity” searches. As mentioned before, each lesson is tagged from the “tag tree” according to its content. These tags can be used to narrow down the results in the “filtering” and “similarity” searches through the “secondary search” area. However, in the “tag search”, all the entered tags come within the tree structure to the screen, and the user is able to select the interested tags from this tree to retrieve the related lessons.

Search with tag area can be accessed through the tab located in the upper side of the “Display lessons learned” screen (Figure 5.24 “area 1”). In this screen, the “tag tree”, whose details are presented in the section “5.2.1.1 Tag Tree Modification“, is coming with a search mechanism. As mentioned before, since the default “tag tree” contains more than 2000 tags, the “tag tree” is not displayed as opened with all the tags. When it is opened, only the two level tags become visible; however, the user can expand the “tag tree” to all levels manually. In order to decrease the necessary effort for making the search, a search mechanism in the “tag tree” has been provided in this area. Finding the “intended tag” within the structure by manually expanding may be time consuming especially for the inexperienced users; however, the developed search mechanism helps to find a tag within seconds. The search area is positioned above the “tag tree” (Figure 5.24 “area 2”). A “keyword” is entered by the user and the corresponding results are displayed simultaneously even if the tag is not open/visible in the current outline level. The “intended tag” is assigned by the “Assign Tag” button that appears by the right click (Figure 5.24 “area 3”). The assigned tag is added to the right side with the upper level tags (Figure 5.24 “area 4”). This means that, when the “Cost Management” tag is assigned, “Financial Management” and “Management” tags are also added automatically. This provides capability of ensuring a broader view for the user in examining the results. When the user wants to narrow down the results through the “secondary search” area, which is also provided in the other search options, (s)he can select the specific tags from the list that contains only the “assigned tags” in the listed projects. Other options such as “actor” or “date” for filtering the results are also provided in this “secondary search” option (Figure 5.24 “area 5”).

The “results” area is exactly same with the results area in the “filter search” option. Lessons are listed with the related project names. As mentioned before, details for the buttons located in the search area is presented in the section “5.2.4.4 Operations on Search Results“.

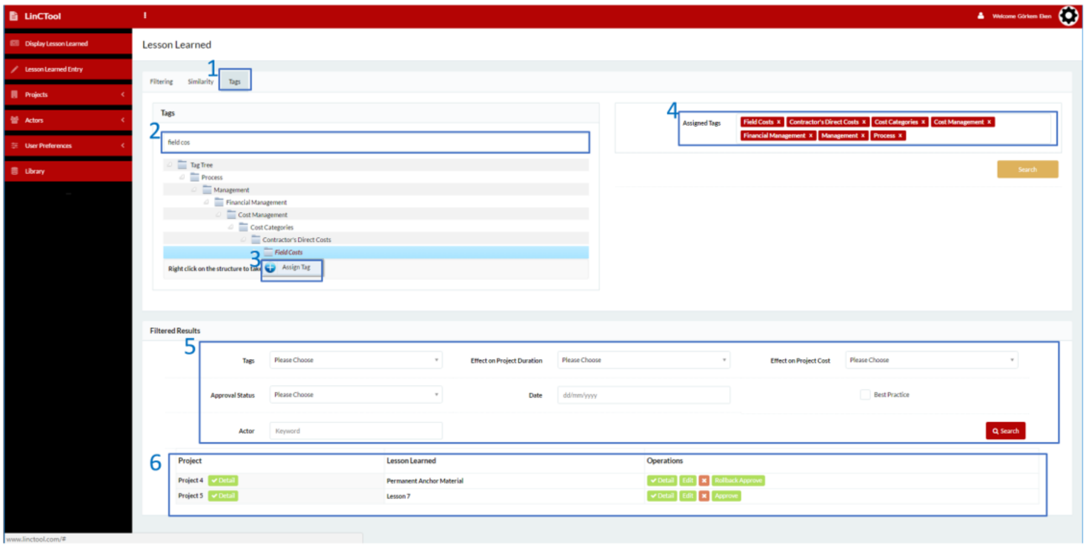
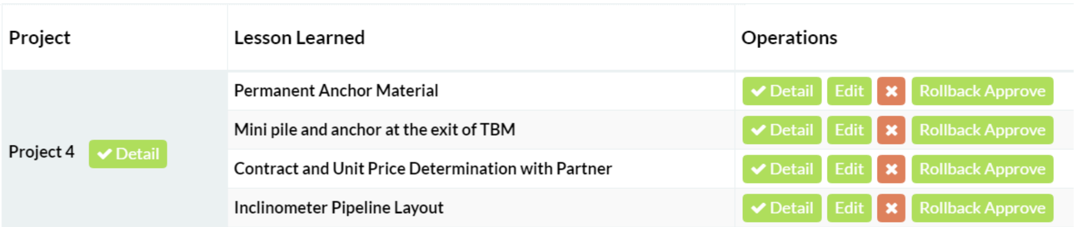


Figure 5.24: Search with Tag

5.2.4.4. Operations on Search Results

Users can use three different search mechanisms to list the relevant lessons as explained in the previous sections. Each search mechanism uses a different logic to list the relevant lessons; however, operations on the search results are the same for all of them. An example for the listed lessons is provided in Figure 5.25. Five buttons are located on the lesson learned list screens. As explained before, results are listed as grouped under projects. The first button “Detail” is located right to the “project name” and it redirects the user to the “project card” screen which is presented in Figure 5.18. With the help of this button, the user can easily access to the project information in order to review the project to assess its relevance with the interested project. Next to the "project" column, "lesson learned" column is located. In this column, the entered lessons to the project is listed with the names, which are entered in lesson creation step. Last column is the "operations" column and four more buttons are located in this column. The red "Cross" button is used to delete the lessons from this screen and it is only shown to the authorized users, which are defined as "knowledge managers" in the presented model. Similar to the "Delete" button, "Approve" and "Rollback approve" buttons are also shown to the authorized users and they are used to change the "approval status" of a lesson.

The "Edit" button is used to change the entered information for a lesson. This button opens almost the same screen with the lesson learned add screen, which is presented in Figure 5.20. Differently than the lesson add screen, the edit screen opens with the information entered previously for the lesson. The lesson is updated with new information, when the user makes a change and saves it.



Project	Lesson Learned	Operations
Project 4 ✔ Detail	Permanent Anchor Material	✔ Detail Edit ✖ Rollback Approve
	Mini pile and anchor at the exit of TBM	✔ Detail Edit ✖ Rollback Approve
	Contract and Unit Price Determination with Partner	✔ Detail Edit ✖ Rollback Approve
	Inclinometer Pipeline Layout	✔ Detail Edit ✖ Rollback Approve

Figure 5.25: Example for Lesson Learned Search Result and Operations

The last function, which is accessible from the "operations" column is used to access details of lessons learned. The "lesson detail" button redirects the users to the "lesson learned card", which is presented in Figure 5.26. This screen is designed mainly to inform the "Knowledge Seeker" roles about all aspects of the events. Knowledge transfer is actualized by reviewing the "lessons learned card". All the information, which is entered to the lessons, is provided and in addition to that the "account name" that indicates the individual that has added the lesson to the system together with the “creation dates” are presented. To summarize all the information that is shown in the “lesson learned card”, is listed as follows;

- **Project Name:** Project of which the learned lesson is belonging to.
- **Lessons Learned Name:** Brief informative title for the lesson, which is entered by the “knowledge source” or “knowledge manager”.
- **Best Practice:** Area provided for labelling the lessons as “best practice or not”. “Failure” is not provided as an option directly because of the reasons presented in the “5.2.3 Lesson Learned Entry” section; however, if the “best practice” option is not selected, it implies that the lesson is related with a “failure”.
- **Event Description:** Area provided for presenting the details of the events to inform the users. This section constitutes one of the main parts that transfer knowledge from person to person.
- **Recommendation:** Other main area provided for transferring knowledge. Main purpose of this area is transferring the implicit knowledge to explicit knowledge through sentences.
- **Added Actors:** This section presents the “actor names”, which are added by a “knowledge source” as relevant with the lesson. These actors can be companies as well as can be people.
- **Effect on Project Duration and Project Cost:** Areas provided for presenting information about “importance” and “severity levels” of the lessons.
- **Effect Amounts:** Areas provided for actual value changes in terms of “cost” and “duration”, if they are calculated and entered to the system.
- **Assigned Tags:** Constitute the list of the “tags” assigned to the lesson to label the content of the lesson and so to enable ‘indexing’ of the lesson.
- **User Name for the Saved Lesson:** Shows the “names” of the user accounts, who enters the lessons to the system, in order to facilitate getting ‘contact’ with them in case of an extra information is needed.
- **Create Date:** Creation date of the lesson in the system is provided for determining the lesson is ‘newsworthy’ or not.

- **Approve/Rollback Button:** Button is shown to the "knowledge managers" to make them change the "approval status" from the "lesson learned card" easily.

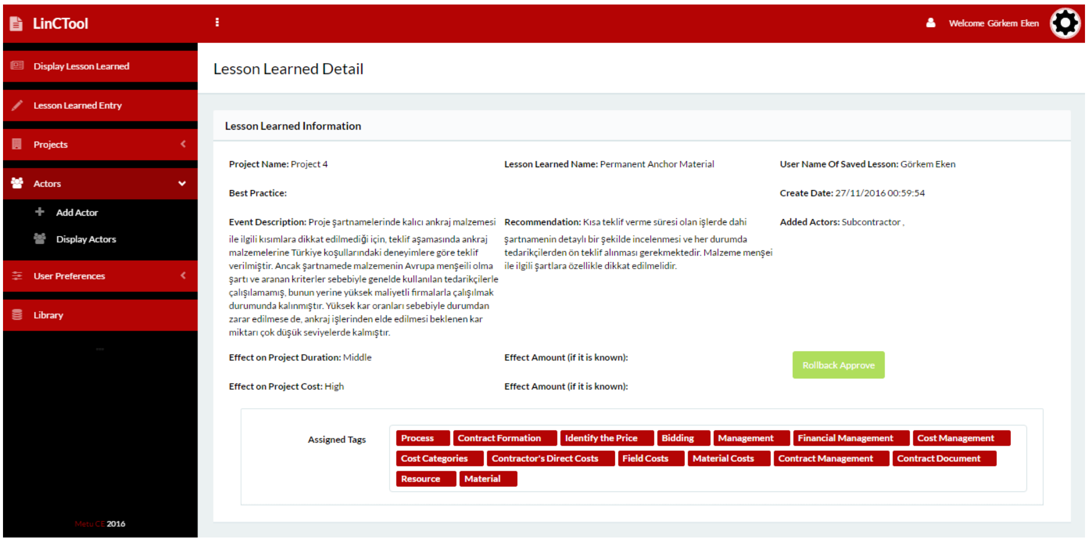


Figure 5.26: Lessons Learned Card

5.3. LinCTool Summary

As explained in previous sections, LinCTool is a web application and it can be accessible through the commonly used web browsers. All the operations are done through the web pages accessed from https://www.linctool.com. Left part of the web page is designed as static and all the links for different operation pages can be accessible from this static area. List of all operations provided in the system is given in Figure 5.27. 6 main menus are located in the left side. Visibility of these menus can be changed according to user privileges. For example, users who are not authorized to enter lessons learned, cannot access to lessons learned screen and also "Lessons Learned Entry" menu link is also invisible for them. This arrangement are done through "Admin Panel" and details are given in "5.2.1 Administrative Settings" section. Purpose of each screen and their usage is explained in previous sections in detail, however in this section, they are explained briefly to summarize.

1. Display Lessons Learned: This menu link is used to access lessons entered earlier with the help of three search mechanism. Filtering search, similarity search and tag based search are provided to retrieve lessons according to user needs.
2. Lessons Learned Entry: In second row, menu link is located to access lessons learned entry screen. Authorized users can select related project and enter lessons learned information through the accessed screen from the “Lessons Learned Entry” menu link. Lessons information composed of 2 main part which are lesson details and tags. Purpose of each information entered in this section is explained in “5.2.3 Lesson Learned Entry”
3. Projects: Projects menu link contains 3 different sub-menu link for 3 different screen. In the first row, “Add Project” button is located and authorized users, who are named as project coordinator in the proposed model, can access to project creation screen to define new project in the tool. Through second row button, screen, which provides ability to list projects that defined in the system, can be accessible. Additionally, project inputs are also defined from the sub-menus that can be accessible from “Project Inputs” menu link.
4. Actors: As mentioned before, LinCTool also contains a database for actor information. Actors are defined in the system and edited from the screens accessed through the “Actors” menu link. “Add Actor” screen is used to define actors in the system and “Display Actors” screen is used to list all the actors defined in the system. Details of them is presented in the 5.2.2.1 Actors section.
5. User Preferences: 3 sub-menu links are located under “User Preferences” menu link. First one is used to edit tag tree that is used to label lessons and retrieve them accordingly. Second one provide ability to change attribute coefficients that is used in similarity calculation. Admin panel contains user management and authorization system related functions.
6. Library: This menu link is used to access documents that provide information about system usage and special terms.

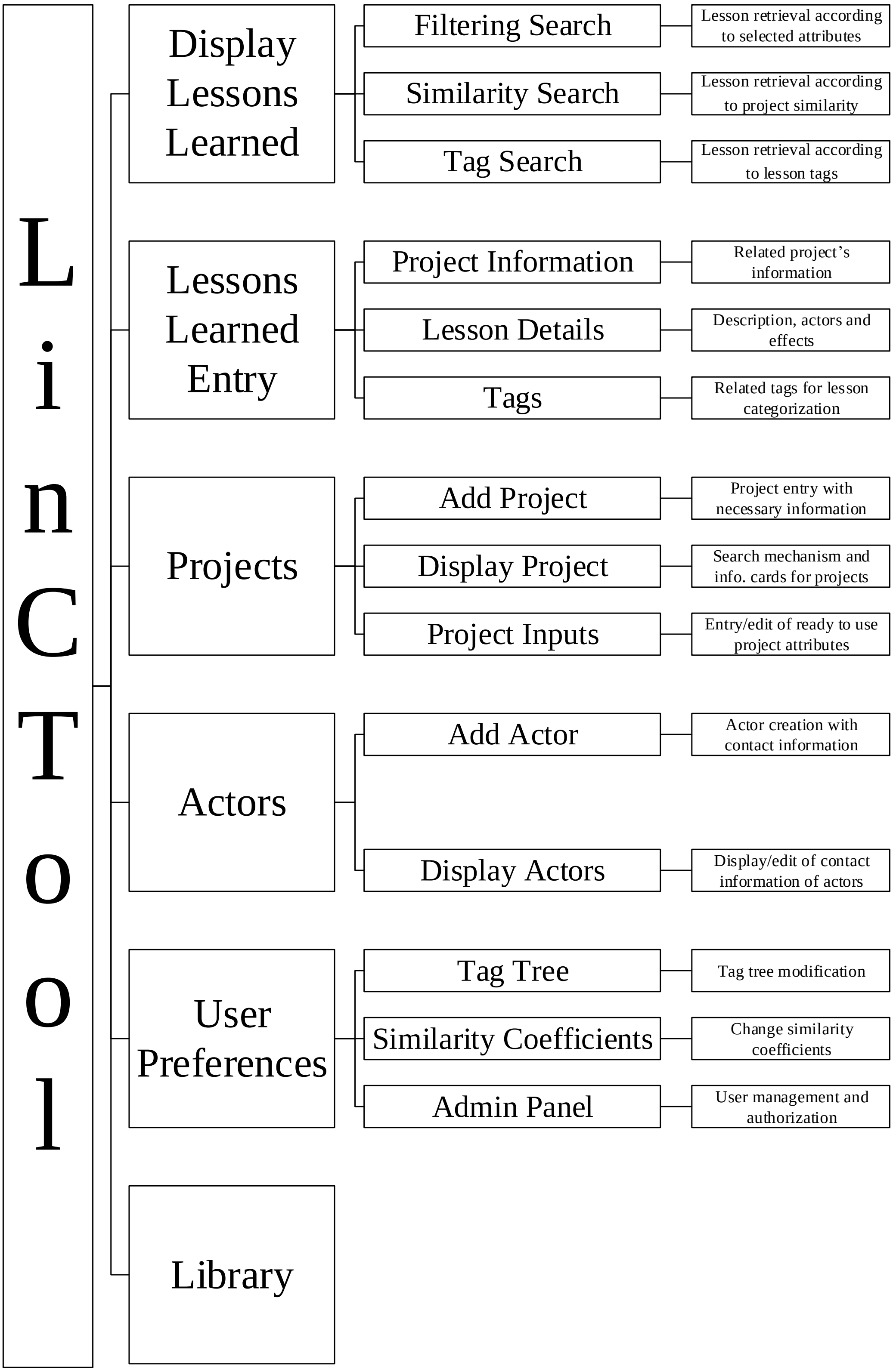


Figure 5.27: LinCTool Functions Summary

5.4. The Model and The Tool

In this research, objective is developing a lessons learned management model and a web based tool that have 11 features as explained before. Below some evaluations about how the study meets these features:

1. There have to be well-structured user responsibility definitions that would help to implement the model in a real company

4 different user types are defined in the LLMPM as "Knowledge Source", "Knowledge Seeker", "Knowledge Manager" and "Project Coordinator". Each user type has a unique privilege that defines them. Except the "Knowledge Manager" user role, roles are assigned to company employees with different titles; however, "Knowledge Manager" role is planned to be existing in a company separately. This type of authority distribution is expected to be helpful for implementing the system in a company by clear definition of user responsibilities.

2. A simple lessons learned capture method has to be developed to record tacit and explicit knowledge without omitting any parts of the lessons

In this research, lessons learned information is expected to be collectible from every phase of project and each topic that is related with construction. Since scope of the research has been kept as broad as possible, developing a strict input form, which only allows predefined input categories is found quite restrictive. To satisfy this objective, lessons are captured in two different free text areas, that one of them is used to enter details of an event and other one is used for entering recommendations about that. Free text area is also suitable to enter access links for the supplementary documents that is planned to be stored in a document management system.

3. A well-organized information flow shall be defined to easily manage lessons learned within the company

Assignment of the proposed user types to employees provides ability to design information flow within the company. With the proposed structure, lessons are collected from only employees who are competent at their jobs. In addition to that, "Knowledge Manager" role also adds secondary opinion about the value of the lessons. "Project Coordinator" role guarantees that project related data is entered by a person who knows what to do. With the help of these 3 user roles, correct and useful information is to be transferred within the company. As a result of this, "Knowledge Seekers" do not have to check correctness of the knowledge for each lesson.

4. A flexible tool has to be developed to support establishment of a company specific lessons learned management system

Developed tool, which is entitled as LinCTool, is open to changes and most of the features are designed to be editable according to company needs. First of all, user types and authorization system are proposed in the LLMPM in the scope of this research and these are defined in the LinCTool as default; however, new user types can be added through the developed user interfaces and privileges can be rearranged. In addition to that, project similarity coefficients, which are used in the calculation of project similarities are also editable. Weights of each project attribute are determined through the questionnaire; but it is considered that based on the company tradition, culture and management style, project similarity coefficients may be different then the survey results. As a result, attribute weights were not hard coded into the LinCTool, instead a user interface is developed to edit these default attribute weights according to company needs. Another feature that is open to change according to company preferences is the tag tree. As explained before, tag tree structure is developed in the scope of the research with the help of 30 different resources; however, it is appreciated that, companies may want to add new tags to this structure, especially related with use of specific software or equipment. For example, software can be added with their commercial name other than grouping them according to their functions. All these three editing options provide adequate flexibility to modify LinCTool according to company needs.

5. The tool has be online to ease accessibility of the users to lessons learned management system

One of the idea behind this research is capturing lessons as live with minimum effort. In this perspective, LinCTool is designed as a web application that client side does not need any extra software other than web browser. This makes system to be centralized and easy to access. Any computer or mobile device with internet or intranet connection is enough to fully access to the functions of the LinCTool and use them.

6. A method has to be found to interact with other IT-solutions to be able to access necessary documents

It is decided that developed tool does not necessarily have to store any supplementary documents such as contracts, photos or videos for two reasons. First reason is confidentiality of documents may be different from lessons that are entered. Second reason is that one of the scopes of this research is developing a lightweight software that can be deployed to any computer, which it can run Microsoft SQL server and Microsoft web server. So that, available document management systems like company specific cloud systems can be used to share documents by adding only access links to the lessons. Free text area in the lesson learned forms provides this chance to the users and this also provides ability to define different privileges in LinCTool and document sharing system.

7. A codification system has to be generated to ease entry of lessons learned to the database

Lessons learned information is captured through 8 different areas. 2 of them are free text areas to capture lesson details and these areas are not used to retrieve lessons. On the other hand, 6 of them are designed to capture specific data such as “related actor”, “project name” and “effect on project cost and durations”. Proposed system is capable to capture and categorize lessons in a structured form without limiting users in the process of knowledge transfer.

8. A tagging system has to be developed for effective classification and retrieval of lessons learned

A tag tree with more than 2000 predefined tags is developed and integrated to the proposed model. 30 different resources were used to develop the tag tree that would be used to label lessons according to their context. Same tag tree is embedded to search mechanisms to easily find desired lessons. Developed tagging system is also open to improvements according to company specific needs.

9. Different retrieval methods shall be available to increase reachability of the related lessons learned

3 different search methods are developed in the scope of this research to achieve this objective. "Filtering" search is used to find lessons according to project attributes that can be listed as "Country", "Project Type", "Client", "Contract Type" and "Partner Company". Second option also depends on the project attributes to find the related lessons. However, in this second option, project similarities are calculated by matching of project attributes and lessons that are entered to similar projects are listed. These two options may be very useful to find the related lessons for the specific project attributes or overall project. Another search method to retrieve lessons is tag-based search. In this method, users can find lessons according to its context rather than the project data. These three main methods are also supported by the second search area to combine the benefits of project-based search and lessons learned context based search.

10. An evaluation system is necessary to manage the lessons learned and to eliminate the useless knowledge

LLMPM proposes approval mechanism to be sure about the lesson quality. This approval mechanism is done by a special user role that is named as "Knowledge

Manager" in this research. LinCTool is developed to be suitable for defining user roles within the system. Functions that are related with approval of lessons are also integrated to the LinCTool, and their privileges are arranged accordingly to give access to only the authorized users.

11. A flexible tool that makes it possible to define different types of users provided in the developed model as well as adjustable to company specific requirements has to be developed.

Authorization system is integrated to the LinCTool in order to define different user types with different privileges. Authorization system gives ability to show/hide every button, menu and screens parallel with user definitions. This system is built according to user types that is proposed in the LLMPM; however, LinCTool has the necessary flexibility to define new user roles with new privileges or editing existing user roles according to company preferences.

CHAPTER 6

TESTING AND VERIFICATION

Verification and validation of this study have been carried out in two steps. In the first step, all functions of the tool are tested by black-box testing method. In the second step, interviews have been done with four professionals from three different companies to determine applicability of the system in the construction industry. Details of these two steps are given in the following sections.

6.1. Verification by Black-Box Testing

Before interviewing with the company professionals, LinCTool functions are tested by researchers. In this step, “Black-Box” testing method is chosen. In this method, inputs are entered by the user and outputs are monitored to determine the accuracy of the system. For this purpose, 11 projects and 39 lessons were created and defined in the system. Example for projects information and lessons learned that is used can be seen at Table 6.1 and Table 6.2 respectively. In addition to that, complete data set that used to verify the system can be seen in Appendix C. Similarities between projects and expected results for different search options have been determined before they are entered to LinCTool. When data entry step in the LinCTool is completed, LinCTool results are compared with the expected results. In addition to that, each feature of the tool is tested according to their intended work to be sure about system accuracy. Additionally, functionality of menu role relations and authorization system are tested with predefined user types. Each user type and their expected roles are defined in the system and controlled.

Table 6.1: Example Project Data with Lesson List

<table>
<tr><td colspan="2">Project Name:
Project 1</td><td colspan="4">Project Scope:
Construction of 30-storey office building and 50.000 m2 shopping mall</td></tr>
<tr><td colspan="2">Project Type:
Trade Center</td><td>Client:
Client 2</td><td>Country:
Russian Federation</td><td>Partnership Type:
Consortium</td><td>Partner Company:
Partner 1</td></tr>
<tr><td colspan="2">Contract Type:
FIDIC</td><td>Start Date:
01.01.2001</td><td>End Date:
01.06.2004</td><td>Planned Duration:
1024 Workday</td><td>Technologies:
Post-Tension Concrete
Tunnel Formwork</td></tr>
<tr><td colspan="6">Lesson List for Project 1</td></tr>
<tr><td>No</td><td colspan="4">Lessons Learned Title</td><td>Best practice or not</td></tr>
<tr><td>1</td><td colspan="4">Material procurement for permanent anchor</td><td></td></tr>
<tr><td>2</td><td colspan="4">Site accessibility problems</td><td></td></tr>
<tr><td>3</td><td colspan="4">Cold weather and productivity</td><td></td></tr>
<tr><td>4</td><td colspan="4">High productivity on tunnel formwork/communication</td><td>Best Practice</td></tr>
<tr><td>5</td><td colspan="4">Delays in progress payments</td><td></td></tr>
<tr><td>6</td><td colspan="4">Visa limitations</td><td></td></tr>
</table>

Table 6.2: Example Lessons Learned Data

<table>
<tr><td>Project Name:</td><td>Project 1</td></tr>
<tr><td>Lesson Learned Title:</td><td>Site accessibility problems</td></tr>
<tr><td>Event Description: The fact that the project was being carried out in the city center, made it difficult for work machines to enter and exit the site during busy hours. Especially for excavation works and concrete casting works, trucks and concrete mixers couldn't be entering to city center without special permission from the local government. This was tried to be solved by accelerating the job in the evening, but because of the low temperature at night, extra precautions such as using a heater were needed to some activities such as concrete casting and desired performance could not be achieved. Although the increase in night shifts and the measures taken resulted in an increase in cost, the desired efficiency could not be obtained and delay were occurred.</td><td>Recommendation: The project area should be considered while the work plan is being created. If there is a possibility of a problem in the field access, the duration of the related activities should be arranged considering possible problems. It should also be known in advance whether a permit is required from the local authorities for large tonnage vehicle entry and exit. The lack of awareness about the requirements of the necessary procedures for permits can completely stop access to the land from time to time. The appointment of a person with the necessary communication skills for this task by the project manager will reduce the problems. If the task is not given to a particular person within the field engineers, it can be result that nobody to undertake the task due to the lack of communication.</td></tr>
<tr><td>Effect on Project Duration: Middle</td><td>Effect on Project Cost: Very Low</td></tr>
<tr><td>Related Actor: -</td><td></td></tr>
<tr><td colspan="2">Tags:
Actor, Regulators, Local Authority, Development Control Authority, Staff, Construction Manager, Site Manager, Project Manager, Process, Connstruction, Construction Works, Earthwork, Concrete Works, Management, Time Management, Planning / Schedules, Activity Duration Estimating, Delay, Causes of Delay, External Causes, Rules and Regulations Related Causes, Types of Delay, Compensability of Delay, Excusable Compensable Delays, Impacts of Delay, Cost Overrun</td></tr>
</table>

Test results showed that only one function does not work as expected. In the tag search option, automatically adding the upper level tags prevents the users from focusing specific area. As explained in the related section, upper level tags are added automatically in the lessons learned entry step to label lessons with general topics as well as specific ones. However, adding upper level tags automatically in the tag search process, all the lessons related with the each added tags are listed. To solve this problem, LinCTool is modified in a way that only selected tags are added to search scope in the tag search option.

After black box testing of the LinCTool, tool functions and the proposed model are discussed with the company professionals who are interested with lesson learned and knowledge management systems in their companies. Details of this study can be seen in the next section.

6.2. Interview with Company Professionals

Four company professionals from three different companies are participated to validation study of the LinCTool. Participants were selected from professionals who are familiar to lessons learned concept. Validation work has been done in an oral discussion format. The proposed system, especially LinCTool with capture and search mechanisms, have been explained to participants at the beginning of the interview. After this informative introduction, specific functions have been discussed with the participants and this section is shaped according to participants' previous experiences that are faced at their companies. In addition to this discussion part, predefined questions that are prepared to determine LinCTool functionality were also asked to participants at the end of the interviews. Questions and participant responses can be seen in Table 6.3. Data that are entered at the black box testing process has also been used to demonstrate the system to the participants. LinCTool and its functions were demonstrated directly using the tool Discussion results are given in detail for each participant at the next section.

6.2.1. Participant 1

Participant 1 has 22 years' work experience and a PhD degree. He is currently working in a construction company that is listed in the ENR 250 list. His title in the company is Chief Sustainability Officer. In addition to that he has started some initiatives to develop a lessons learned management system in the company.

He focused on company culture that prevents successful implementation of knowledge management system in a company as well as IT functions of the proposed LLMPM. Drawbacks that are indicated by the participant in terms of company culture are presented first, then the tool functions are discussed.

According to the participant, most problematic part is the information flow from site or teams to company memory, which cannot be done without manager approvals. This may create very big problems for employees as well as managers. This indicates that company culture is forcing employees to keep unfavorable information to themselves. Each problem is tried to be solved within the unit itself without informing other units or upper levels. This issue may be solved by providing assurance that negative experiences won't be the reason for any sanction; however, in reality it is very hard to achieve this confidence for employees. In addition to that, construction team may also don't want to deal with extra work. Additionally, there may be complaints from construction sites like; "we are entering everything from our site but we couldn't find anything useful. If we continue to do that, other sites also have to enter their lessons." Employees and top managers' attitude to the system is an important factor for successful implementation of the system in a company, as explained before. According to the participant, a less transparent system, which hides user data that enters lessons, may be logical. User types that are defined in the LLMPM have been appreciated by the participant generally; however, real world implementation may cause some problems due to company dynamics according to the participant and some improvements may be needed according to real world implementation results.

Participant 1 also gave feedback about LinCTool. According to Participant 1, selecting project phase at the lessons learned entry step in addition to tags may provide valuable information for lesson categorization. This may be a simple list that shows project phases like project initiation, project closure, etc. This additional simple categorization may provide ability to retrieve lessons that are occurred in specific stages without using the tag tree. Tag tree is related with context of the lesson; however, phases may contain multiple lessons that are labeled with different tags.

Additionally, simple grouping that is proposed by the participant may be used for defining rules of restriction in the lessons learned retrieval step. According to the participant, financial lessons may not be useful for construction site and restriction for retrieving financial lessons according to users' department may be useful in terms of privacy.

In terms of LinCTool capabilities, participant states that report and printing options are not sufficient for using it in a company. Users mostly expect to have a print option after they find necessary information. Reporting engines that will be used to create custom templates to extract information from database were also proposed by the participant. Printing abilities that will be developed directly inside the LinCTool is also another option to get information to a paper or pdf file.

Another point that is proposed by the participant is search option that works on "event description" and "recommendation" parts of lessons. According to the participant, some users may find this option useful if it is used together with tags. In their experiences, free text search does not work as expected when it is the only option to retrieve lessons; however, in the proposed system, it may provide some benefits if it is combined with tag based categorization.

Functions that have been found useful by the participant are given in the section 6.2.4 Features Favored by Participants together with other participants' responses.

6.2.2. Participant 2 and 3

Participant 2 and Participant 3 work in the same construction company that is listed ENR top 250 construction companies list. A lessons learned management system that has similar objectives with the LinCTool is already being used within the company. Two interviews were done with the same company employees with different roles. Participant 2 is a Lead Planning Engineer who has a PhD degree. She has 11-year work experience and she is a user that has privileges to enter lessons and retrieve others in their system. Participant 3 is working as an Enterprise Systems Manager and she is responsible for managing lessons learned management system at the company. She has 11-year work experience and M.Sc. degree. Two participants gave two different perspectives in terms of user and developer to determine challenges and LinCTool function suitability.

Participants state that top management highly encourages activities related to lesson capture and there is not any problem related with information flow in their company. Company implements reward system to encourage employees to share their experiences. Gifts are given to employees who enter valuable lessons to the system in predefined periods. This company attitude mostly solves problems related with the lesson capture; however, reuse of these lessons and lesson quality are still problems in their systems. Responses to the LinCTool solutions for the lesson retrieval are given in the next section. In this section, suggestions to improve LinCTool are presented.

First thing that is suggested by the Participant 2 is adding document uploading option to the LinCTool itself. According to the participant, documents are mostly uploaded to show detailed calculation or photos that are used to visualize the situation. Mostly they are not confidential as it is suggested in the LinCTool. However, it is appreciated by the participant that LinCTool method can solve confidentiality problems related with the attachments to lessons. Improving LinCTool, in a way that making it capable to store documents in itself, and combining this function together with a cloud based document sharing as it is proposed in this research is appreciated to be the optimum solution. By this way, system can provide flexibility to users to select one of the options according to document type.

Participant 3 was focused on upper level categorization like Participant 1. According to Participant 3, users may skip tag assignment step without giving necessary attention. Selecting upper level categories at the lesson entry step may reduce negative effect of user behavior. In addition to that, upper level categorization may be used for determining a responsible person to approve lessons. In their systems, there has not been a single knowledge manager and all lessons are directed to team managers for investigation of values of the lessons. However, this creates some problems according to them. Automatic routing according to upper level categories may be resulted with sending lessons to unrelated person to approve. Rerouting the lesson to a new person may need extra effort in their system. However, our system, which proposes directly approving lessons by knowledge manager or with help of extra information from team managers, may be a solution to their problem according to the participant. At this point, their suggestion is that process of lesson sending from knowledge manager to related person, who are qualified to evaluate them, may be integrated to the system. In the current situation of the LinCTool, lessons are sent to related people by e-mail in case of knowledge manager needs extra information to approve or reject them. Participant 3 suggests that implementing routing mechanism inside the LinCTool may be useful in terms of usability perspective.

Participant 2 and Participant 3 also discussed the necessity of reporting functions to successfully operate system as Participant 1. According to them, search results should be printed to investigate easily. This function may be useful to discuss lessons in meetings. In their system, reports can be developed by exporting data to excel sheets; however, their problems are related with lesson retrieval options. In their system, categorization of lessons is not sufficient to retrieve related lessons in order to discuss at meetings. Participants state that, LinCTool can solve these retrieval problems with the help of the proposed search systems if it is improved in terms of reporting functions.

Retrieval options that are provided by the LinCTool are favored by the Participant 2 and Participant 3 in general and details are presented in the next section; however, they have two suggestions to improve lesson retrieval capabilities. One of them is that addition of “and”, “or” options to the tag based search mechanism. In the current situation, tag based search uses “or” conjunction to list lessons if two or more tags are added in the search. On the other hand, second search area can be used to add another tag to narrow down search results with “and” conjunction. According to participants, “and” option for tag based search can be useful function in terms of finding lessons related with two or more tags. Other suggestion is related to free text search among the “event description” and “recommendation” areas of lessons. This suggestion is also given by Participant 1. Participant 2 and Participant 3 states that their system only relies on free text search to retrieve lessons. However, they also complained that free text search is not a trustworthy system to retrieve all the related lessons. Problems related with the free text search are also discussed in the previous section of this research. However, participants argue that free text search can provide some advantages if it is used in second search area of the LinCTool. By this way benefits of “Filter”, “Similarity” and “Tag” searches can be combined with the benefits of “Free Text” search.

Last suggestion is about information asked at the lesson entry step. According to Participant 2, effect on quality can be useful information to group the lessons. According to participants some lessons may not have significant effect on project overall cost and duration, but they may be related with the quality of work. Similar with the cost and duration effect, quality can be captured in the 1-6 scale. Participant also states that LinCTool may be easier to use if it is improved in a way to provide ability to sort search results according to cost, duration and quality effects.

6.2.3. Participant 4

Participant 4 has 12 years' work experience and he is PhD candidate. He is currently working in a construction company that is listed in the ENR 250 Top International Contractor List. His title in the company is Planning Engineer. He has been involved in lessons learned management system development efforts in his company.

Participant 4 generally focused on the problems related with the lesson quality. Participant states that in their lessons learned system, lessons are collected by specified employees in each department and entered to a database. In this system, there is not any approval mechanism and this causes quality problems. However, he also states that this is the only way that his company have found to capture lessons. Employees are not willing to enter their experiences generally. According to him, tagging system also needs special effort to work properly because most probably users may not give necessary importance to tag assignment step. On the other hand, he also appreciates the LinCTool system for its solution to lessons capture and retrieval. He states that if employees are trained about lessons learned concept as well as system itself, proposed model may solve quality related problems. In addition to that, similar with other participants, knowledge manager may not be qualified to approve all lessons according to Participant 4 and team managers have to be involved to approval process. Moreover, similar to the other participants, Participant 4 suggested improving search capabilities with the free text search.

Participant 4 also mentioned that they suffer from lack of image uploading option in their system. Simple document uploading function may be useful to explain details of lesson to users. According to participant, some details may be explained easily by adding pictures than explaining it in narrative form.

6.2.4. Features Favored by Participants

In this section, LinCTool functions are presented, which are found useful by the participants to implement lesson learned management system in a company:

- Capturing lessons with project information is found very useful by all of the participants. Filtering search option is found sufficient in order to reveal lessons according to project attributes like country, project type or client etc. According to Participant 3, not all employees have enough knowledge to reach right persons to ask information about country or project type. Big construction companies work in very large geography with various project types. “Filter Search” that is presented by LinCTool has great potential to facilitate lesson retrievals according to project attributes.
- Similarity based search gets credit from Participant 1, Participant 2 and Participant 3. Using overall project similarity to determine possible problems and improvements in work process can be very useful and it may help to get overall idea about new projects. However, reporting options should be included to get full benefits of similarity search as mentioned earlier. On the other hand, Participant 4 argues that project similarity calculation could not be standardized and proposed system may not be very useful as expected.
- Moreover, tagging lessons according to its context is found very logical for retrieving process. Predefined tag tree and editable structure of tag tree that is used to modify it according to company needs is also appreciated by the participants. According to Participant 2 and Participant 3, some lessons may be related with very specific topics and new tags have to be added according to used materials, software, etc.
- Participant 2 and Participant 3, Participant 4 mentioned that their problems are mostly related with the lesson retrieval and quality of lessons. At this point, they accept that LinCTool search options may solve lesson retrieval problems. Participant 2 and Participant 3 also state that many lessons are entered to the system due to reward mechanism; however, quality of lessons

are not same for each entry. Discussion results about lesson quality reveals that different approvers at the different departments may be the reason of this quality differences. At this point, as proposed in this research, assigning one person as a knowledge manager that collects necessary information from related manager to approve or reject lessons may be solution for this quality problem.

- Lesson learned capture system in the LinCTool is found operative by all of the participants. Free text areas to capture event and personal opinions are found enough to capture details of lessons. In addition to that, related actor section that is proposed in this research is found very useful by Participant 2 and Participant 3. Also automatic adding of upper level tags is found useful in terms of giving necessary flexibility to users in the retrieval steps. Effect on duration and effect on cost areas in the 1-6 scale provide enough details according to all participants; however, participant 2 proposes to capture quality effect in the same way as mentioned before.
- Proposed user types and roles are found logical by all of the participants; however, common idea is performing this structure in a project to determine efficiency of it. Participant 1 has some doubts related with the company structure that limits information flow inside the company. On the other hand, Participant 2 and Participant 3 focus on "knowledge manager" role to see whether it would be capable to solve their quality problem related with lessons, or not.

In addition to the functions that are presented above, some other LinCTool features are also found suitable to implement this system in their companies. For example, online structure of the tool is defined to be essential for this type of systems. In addition to that, flexibility of the tool in terms of user definitions and their privileges together with editable tag tree and changeable similarity coefficients get credit from the participants. Overall evaluation results are given in the next section.

6.2.5. Summary of Interview Results and Recommendations

Interview results show that LinCTool has potential to solve some of the problems that have been faced by the participants in their companies. The proposed LLMPM may not solve all the problems as stated by Participant 1; however, retrieval options are found very useful if company culture allows employees to enter their experiences without any drawback. Company's enthusiasm about establishing lessons learned management system in order to create company memory plays the most important role to overcome the problems. All barriers that originated from employee attitude may be solved with in-house training and encouragement.

It is obvious that LinCTool has some points to be improved; however, these are mostly related with developing a more user-friendly tool adding some features. Further improvements may be done together with the participation of a company. Researchers also think that implementation of the tool in a company as a pilot study has great potential for both demonstration of the value of the LinCTool and improvement with further functions such as reporting abilities, etc.

Overall impression of the participants about LinCTool can be stated as positive. 9 expressions were read to participants that have been asked to grade these expressions according to their impressions about LinCTool. In the grading method, “1 point” refers to “strongly disagree” and “6 points” refers to “strongly agree”. Minimum point that is given to any expression by any participant is “3”. Overall point that is given by all of the participants is “5.34”. Lesson capture and search mechanisms are appreciated by the all participants and overall point for each expression is calculated as minimum “5.00”. Similarity calculation and search mechanism is found not very useful by Participant 4. All expressions and participant responses can be seen in Table 6.3.

Table 6.3: Participant Responses to Predefined Interview Questions

Expression	Participant				Average
	1	**2**	**3**	**4**	
1. Lessons learned entry form is suitable to capture them without information loss.	5	6	5	6	5.50
2. Entering Project name, actor information, effect levels and tags at the lessons entry step provide necessary information for categorizing lessons in the purpose of retrieving them.	5	5	5	5	5.00
3. Developed tag tree to label lessons according to their context is very functional.	5	6	5	6	5.50
4. Free text method is suitable for “Event Description” and “Recommendation” areas to capture details of the lessons.	6	6	5	6	5.75
5. Filtering method according to project attributes is very useful to retrieve lessons.	5	6	5	5	5.25
6. Retrieving lessons according to project similarities is very logical and useful.	6	6	5	3	5.00
7. Using tags to label lessons according to context and retrieve them is very useful.	5	5	5	6	5.33
8. LinCTool together with three search mechanisms provides ability to find related lessons easily.	5	5	5	6	5.25
9. My general opinion about proposed system is positive.	5	6	5	6	5.50
Overall	5.2	5.6	5	5.4	5.34

Validation study shows that LinCTool have potential to solve some problems that are faced during the implementation of lessons learned management system in a company. However, some improvements may be necessary to increase functionality of the tool. LinCTool benefits and shortcomings that are identified at the validation meetings can be summarized as presented in Table 6.4.

Table 6.4: Benefits and Shortcomings of LinCTool

Benefits of the Tool	Shortcomings of the Tool
• Flexible tool that provide ability to edit user roles according to company needs.	• Lack of lesson routing option inside the tool itself.
• Multiple search options that provides ability to retrieve lessons in different situations.	• Lack of reporting and saving search results options that may facilitate lesson review process.
• Simple but effective lessons learned capture mechanism.	• Lack of free text search option that may useful if scope of search is clear.
• Effective solution to categorize lessons according to their context.	• Lack of initial categorization of lessons according to project phases that may useful when user focuses specific phase.
• Web-based tool that makes it easy to access and manage.	

Validation results are checked according to necessary features that are defined as necessary features of a lessons learned management system in research objective section. Results can be seen in Figure 6.1.

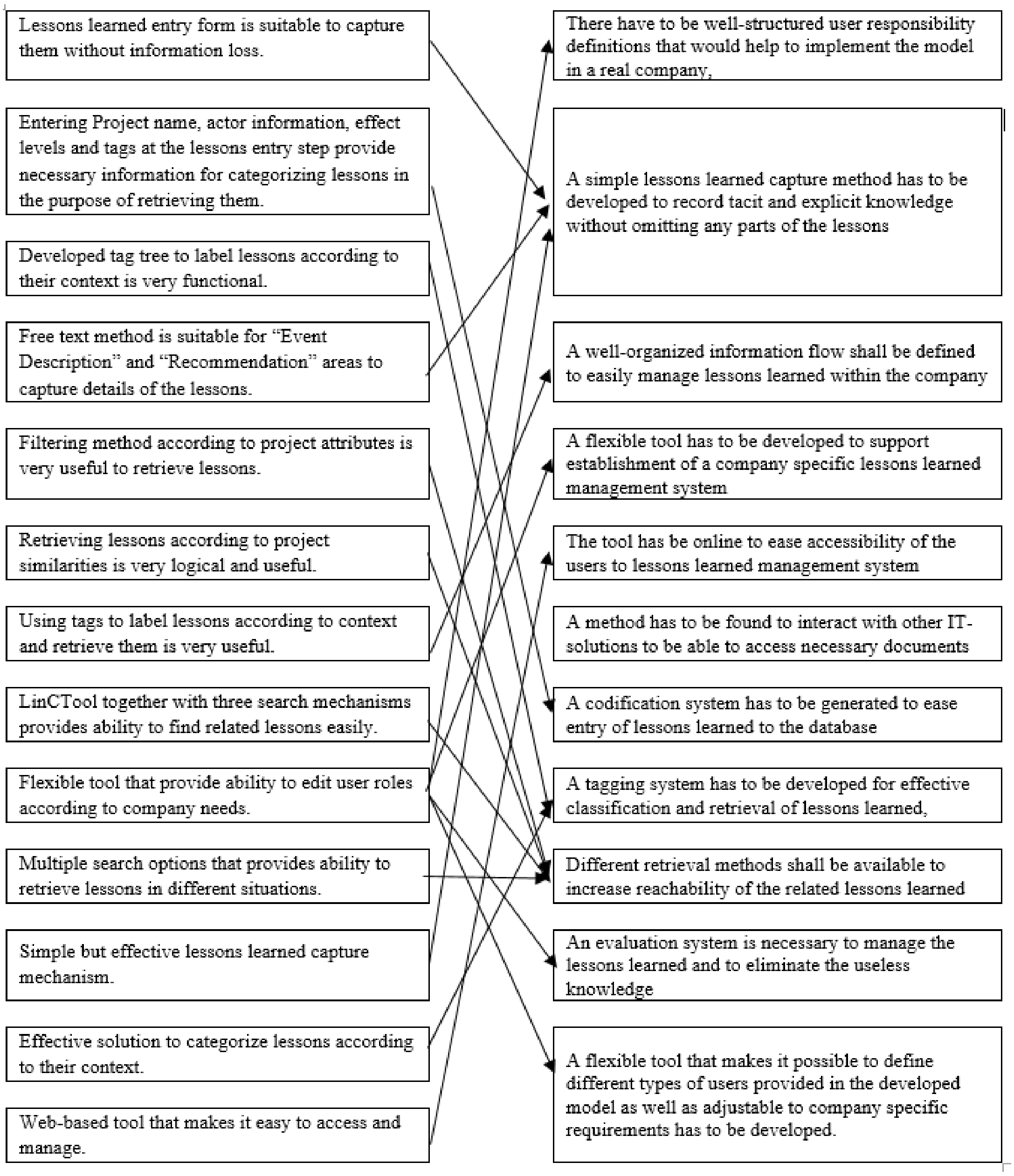


Figure 6.1: Comparison Between Interview Results and Predefined Features.

CHAPTER 7

RESULTS AND CONCLUSIONS

Experiences gained in the previous projects may contain valuable knowledge for the forthcoming projects. In order to take advantage of these past experiences, knowledge has to be captured and stored in a structured form to be ready to use when it is needed. At this point knowledge management term is emerged and various studies are conducted in the literature to capture both tacit and explicit knowledge to create organizational memory. Achieving these knowledge management objectives in the construction industry is a very challenging topic because of the nature of industry. The major aim is transferring the company to a learning organization in order to guarantee continuous learning through the whole life of the company, but it is hard to achieve this due to conservative structure of the industry as well as complexity of projects.

Construction projects are executed by contribution of various parties, such as contractors, suppliers, client, local authorities, etc., and also multiple works have to be done to complete a project successfully, such as design, construction feasibility, financing, etc. Parallel with the nature of the industry, there also have been various knowledge sources and each of them needs different approaches to be managed. In literature, two approaches are commonly accepted to achieve establishing a learning organization and managing knowledge. First approach argues that people have be the core of the strategy and human interaction is the best way to manage knowledge. In the second approach, strategy is built on IT tools. People based and IT based solutions does not replace one another; they are complementary to each other. To implement a successful system, company culture has to be developed and participants have to develop awareness about possible benefits of knowledge management and they have to be involved in the procedure, however; IT systems have also crucial importance to develop successful systems.

As mentioned before, different knowledge sources and their outputs require different approaches for their management. Explicit knowledge, which can be easily documented, may be captured through databases. Cost of projects can be given as an example for explicit knowledge. On the other hand, experiences gained during the project executions, which are examples of implicit knowledge, are hard to capture and disseminate. "Lessons Learned" term, which refers to failures and best practices that are faced in the project life cycle, constitutes the big part of the knowledge gained in a project. So that, capturing lessons in a structured form to use them as a guide in forthcoming projects has a potential to improve business performance and it may provide competitive advantage. Due to the high staff turnover, diversity of projects and time limitation, lessons learned management needs IT based solutions together with human participation. Lesson learned information is a valuable asset for companies to transform them to learning organizations; however, it is hard to collect this implicit knowledge and transform it to explicit knowledge.

This idea behind this study is to respond the needs of capturing and disseminating lessons learned from projects in the construction industry. As mentioned before, starting point of this research is based on satisfying the necessities of the project portfolio management system, however; it is appreciated that, benefits of the lessons learned management system cannot be limited with the project portfolio selection procedure. So that research is conducted as separate but also in parallel with the development of the portfolio management system. Developed solution provides suggestions and organizational structure to implement lessons learned management model as well as a structured computer program to provide ability for live capturing of lessons and organizing them to reuse when it necessary through the retrieval options. In order to achieve this, research objectives are defined in two categories. First one is related with "human participation" in the lessons learned management process model. From this perspective, user roles are tried to be defined in the process model. Defining a reliable way for the information flow within the company by neither limiting users nor decreasing system credibility has been one of the objectives in this research. Second one is focused on finding an IT solution for implementing the process model. Developing a form to capture lessons is the first step in developing the model but it is not enough to successfully store and disseminate lessons. Objectives in developing the tool have been defined as developing a flexible tool that can be modified according to different company needs as well as a solid tool that organizes lessons in a structured form. Codification system for the lessons and the retrieval options are the main parts of the tool as well as the usability of the tool.

7.1. Major Findings as a Result of Interviews

Outcome of the study demonstrates that digitization of information plays an important role in decreasing necessary effort to reach valuable information and increase project performance. IT solutions that are used for capturing and storing lessons learned have the potential to decrease these efforts On the other hand, company culture is a key factor for successful implementation of the system in a company. The major inferences obtained from this research can be summarized as follows:

- Hwang (2014), Fong and Yip (2006), and Carrillo et al. (2013) state that company culture and the level of importance that is given to the system by the upper management may be the main obstacles for successfully implementing lessons learned management system. In parallel, validation study of this research reveals that companies, which do not support lessons learned process or do not change company culture accordingly, may fail to collect lessons as mentioned by Participant 1. On the other hand, results of interviews with Participant 2 and Participant 3 show that proper company incentives can be a solution to overcome these barriers.

- Quality of lessons learned is a factor that affects value of lessons learned management systems. Validation results demonstrate that even if problems related with lessons learned capture step are solved successfully, value of the knowledge has to be checked. Approval mechanisms like the one proposed in this study, should be implemented in a lessons learned management system to solve this problem, which is also mentioned as a barrier by Carrillo et al. (2013), Paranagamage et al. (2012) and Shokri-Ghasabeh and Chileshe (2014)
- Lessons have to be captured in a way that facilitates lessons retrieval step. Three participants at the validation study argue that finding useful lessons within reasonable time is as important as capturing lessons for successful lessons learned management. Different search mechanisms that meet different requirements have to be integrated to IT solutions of the management systems in order to decrease necessary effort.
- Project similarities and project attributes may be used to facilitate lessons learned retrieval process as proposed in this study. According to validation meetings results of Participant 1, Participant 2 and Participant 3, project similarity may be useful option for companies that works in wide geography and execute different type of projects.
- Validation study results show that labeling lessons with the help of predefined structure that contains possible tags is useful option to retrieve lessons according the context. Problems related with "Free Text Search" explained in this research as well as are mentioned by the participants; on the other hand it is considered as complementary feature to find related lessons easily. Adding “Free Text Search” will be beneficial in such a system since other search options have potential to eliminate problems related with free text search.
- Success of lessons learned management system is dependent on IT solutions as well as company attitude. Participant 4’s company collects lessons in some way; however basic database to store lessons does not provide necessary functionality to find related lessons. Lack of proper IT structure causes

problems that decrease effectiveness of the system even though lessons are collected successfully.

- All lessons of a project which are learned in related stages from bidding to completion can be collected and stored in a tool through narratives; however, users' skills in writing and time spent to fill forms may affect usefulness of these narratives.
- Actor management system as a support system to find lessons can provide flexibility to a retrieval mechanism. In addition to that, document management system that is integrated inside the tool is expected as a feature that makes it possible to upload images and calculation documents which may enhance explanation capability of lessons learned.
- A lessons learned management system has to be capable of creating reports. Validation study reveals that possible users are expecting to create reports that contains related lessons in order to review them later.

7.2. LinCTool as a Module of COPPMAN

LinCTool is a standalone tool that is structured to be used to manage lessons learned. Necessity to develop the model and the tool has emerged from the requirements of the research project as mentioned before. Main objective of this research is developing a tool for construction companies that would support project portfolio management process. The project portfolio management tool, which is named as COPPMAN, is designed to use various features to provide suggestions about construction project portfolios. LinCTool features constitute a part of COPPMAN through providing the ability of managing lessons learned and reusing them as a supportive information in the project portfolio selection step. It can be stated that LinCTool constitutes the lessons learned management module of COPPMAN.

7.3. Limitations of the Study

Some of the limitations of the tool and the study are as follows:

- About lessons learned entry step: Developed lessons learned entry form can successfully capture all information related with an event and categorize them. However, quality of lessons highly depends on the user behavior and writing capabilities. It is appreciated that users can be guided by predefined questions during lessons learned entry step. On the other hand, each topic may necessitate different questions. For example, "Did any fatal accident occur or not?" question may be valid for health and safety related lessons, on the other hand, "What is the weather temperature?" is an important question for cast in place concrete lessons. In this research, it is assumed that knowledge sources are qualified to enter all the necessary information related with an event to the free text areas. The tool's performance can be improved by incorporating necessary explanations and questions for lessons learned entry.
- Another limitation of this study is interoperability capabilities of the LinCTool. LinCTool is designed to work as an online tool; however, data import and export capability is limiting its usability. This is also specified by the participants at the validation interviews. All of the participants mentioned that creating reports and exporting to excel sheet options are very important in terms of usability of such a system.
- Other limitation of the study is that LLMPM and LinCTool are validated through expert meetings and interviews respectively. However, workshops with the participation of all related staff within a company would provide better opinion and insight about the usability of the tool. Participation of more experts and testing of the tool in a higher number of companies with real cases would provide more valuable information about how to improve the tool and the model.
- Real implementation of the tool may provide better insights about the tool. However, as mentioned earlier, this study is a part of a research project that

aims to develop a tool that would support construction companies in the managing construction project portfolios. COPPMAN contains all features of LinCTool and validation studies of COPPMAN that is expected to be actual implementation, may provide chance to collect further information about LinCTool and LLMPM usability.

7.4. Recommendations for Future Works

The tool can be further improved. LinCTool may be modified according to the suggestions given by company professionals during the interviews. Interoperability capability and reporting options are the most significant deficiencies that affect usability of LinCTool. Thus, data export function to a commonly used software such as Microsoft Excel may be considered as well as adding printing option to the search results and lesson details screens. In addition to that, upper level grouping of the lessons in terms of project phases may be considered to improve LinCTool's lesson categorization capabilities.

Most importantly, developed system can be used in a construction company to evaluate its usability and performance. Implementation study may be held in 3 main steps. First step is entering lessons that a company already has. Most companies have project closure reports that contain significant lessons. In addition to these reports, managers can also enter their previous experiences. After entering some lessons to the tool successfully, step 2 and step 3 may be proceeded for further improvement. Step two is testing LinCTool user types and lesson capture mechanism by implementing it in a real construction project. Accounts may be created for each stakeholder of the pilot project and feedbacks can be collected regularly from them. Last step can be related to determining usability of the search capabilities. In this step, selected employees from the pilot project and the head office are requested to find lessons in the system according to their needs. In this step, head office personnel would be mostly responsible to evaluate filtering and similarity search options by trying to find related lessons for possible projects. On the other hand, site personnel may be responsible to evaluate the context based search option. Consequently, further efforts are necessary to better evaluate the model and the tool's performance by real life applications. However, it is believed that implementation of COPPMAN that is planned to be carried out within the context of TUBITAK funded research project will provide an important feedback for LLMPM and LinCTool.

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APPENDIX A

A: TAG TREE

Table A.1: Complete Taxonomy for Developed Tag Tree

Outline Code	Tag	Resource
1	Project	(El-Diraby et al. 2005)
1.1	Buildings	(EuroStat 1997)
1.1.1	Permanent Buildings	(Construction Project Information Committee 2013)
1.1.1.1	Residential buildings	(EuroStat 1997)
1.1.1.1.1	One-dwelling buildings	(EuroStat 1997)
1.1.1.1.2	Two- and more dwelling buildings	(EuroStat 1997)
1.1.1.1.2.1	Two-dwelling buildings	(EuroStat 1997)
1.1.1.1.2.2	Three- and more dwelling buildings	(EuroStat 1997)
1.1.1.1.3	Residences for communities	(EuroStat 1997)
1.1.1.2	Non-residential buildings	(EuroStat 1997)
1.1.1.2.1	Hotels and similar buildings	(EuroStat 1997)
1.1.1.2.1.1	Hotel buildings	(EuroStat 1997)
1.1.1.2.1.2	Other short-stay accommodation buildings	(EuroStat 1997)
1.1.1.2.2	Office buildings	(EuroStat 1997)
1.1.1.2.3	Wholesale and retail trade buildings	(EuroStat 1997)
1.1.1.2.4	Traffic and communication buildings	(EuroStat 1997)
1.1.1.2.4.1	Communication buildings	(EuroStat 1997)
1.1.1.2.4.2	Stations	(EuroStat 1997)
1.1.1.2.4.3	Terminals	(EuroStat 1997)
1.1.1.2.4.4	Garage buildings	(EuroStat 1997)
1.1.1.2.5	Industrial buildings and warehouses	(EuroStat 1997)
1.1.1.2.5.1	Industrial buildings	(EuroStat 1997)
1.1.1.2.5.2	Warehouses	(EuroStat 1997)
1.1.1.2.5.3	Containing Structures	(Construction Project Information Committee 2013)
1.1.1.2.5.3.1	Gasholders	(Construction Project Information Committee 2013)
1.1.1.2.5.3.1.1	Rigid Gasholders	(Construction Project Information Committee 2013)
1.1.1.2.5.3.1.2	Telescopic Gasholders	(Construction Project Information Committee 2013)
1.1.1.2.5.3.2	Ponds	(Construction Project Information Committee 2013)
1.1.1.2.5.3.3	Reservoirs	(Construction Project Information Committee 2013)
1.1.1.2.5.3.4	Silos	(Construction Project Information Committee 2013)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
1.1.1.2.5.3.5	Tanks	(Construction Project Information Committee 2013)
1.1.1.2.5.3.5.1	Enclosed Tanks	(Construction Project Information Committee 2013)
1.1.1.2.5.3.5.2	Open Tanks	(Construction Project Information Committee 2013)
1.1.1.2.6	Public entertainment, education, hospital or institutional care buildings	(EuroStat 1997)
1.1.1.2.6.1	Public entertainment buildings	(EuroStat 1997)
1.1.1.2.6.2	Museums and libraries	(EuroStat 1997)
1.1.1.2.6.3	School, university and research buildings	(EuroStat 1997)
1.1.1.2.6.4	Hospital or institutional care buildings	(EuroStat 1997)
1.1.1.2.6.5	Sports halls	(EuroStat 1997)
1.1.1.2.7	Other non-residential buildings	(EuroStat 1997)
1.1.1.2.7.1	Non-residential farm buildings	(EuroStat 1997)
1.1.1.2.7.2	Buildings used as places of worship and for religious activities	(EuroStat 1997)
1.1.1.2.7.3	Historic or protected monuments	(EuroStat 1997)
1.1.1.2.7.4	Other buildings not elsewhere classified	(EuroStat 1997)
1.1.2	Mobile And Temporary Buildings	(Construction Project Information Committee 2013)
1.1.2.1	Demountable Buildings	(Construction Project Information Committee 2013)
1.1.2.2	Mobile Buildings	(Construction Project Information Committee 2013)
1.1.2.3	Temporary Buildings	(Construction Project Information Committee 2013)
1.1.3	Underground Buildings	(Construction Project Information Committee 2013)
1.2	Civil engineering works	(EuroStat 1997)
1.2.1	Ground contouring	(Construction Project Information Committee 2013)
1.2.2	Transport infrastructures	(EuroStat 1997)
1.2.2.1	Highways, streets and roads	(EuroStat 1997)
1.2.2.1.1	Highways	(EuroStat 1997)
1.2.2.1.2	Streets and roads	(EuroStat 1997)
1.2.2.2	Railways	(EuroStat 1997), (International Organization for Standardization 2014a), (Construction Project Information Committee 2013)
1.2.2.2.1	Cable Car Railway	(EuroStat 1997), (Construction Project Information Committee 2013)
1.2.2.2.2	Guided Bus Way	(Construction Project Information Committee 2013)
1.2.2.2.3	Magnetic Levitation Railway	(Construction Project Information Committee 2013)
1.2.2.2.4	Monorail	(Construction Project Information Committee 2013), (International Organization for Standardization 2014a)
1.2.2.2.5	Rack Railway	(Construction Project Information Committee 2013)
1.2.2.2.6	Railway	(Construction Project Information Committee 2013)
1.2.2.2.7	High-Speed Railway	(Construction Project Information Committee 2013)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
1.2.2.2.8	Suspended Cableway	(Construction Project Information Committee 2013)
1.2.2.2.9	Tramways	(Construction Project Information Committee 2013), (International Organization for Standardization 2014a)
1.2.2.2.10	Subway	(EuroStat 1997), (International Organization for Standardization 2014a)
1.2.2.3	Aerial ropeway	(International Organization for Standardization 2014a)
1.2.2.4	Airfield runway	(EuroStat 1997)
1.2.2.5	Bridges, elevated highways, tunnels	(EuroStat 1997)
1.2.2.5.1	Bridges and elevated highways	(EuroStat 1997)
1.2.2.5.1.1	Arch bridge	(International Organization for Standardization 2014a), (Construction Project Information Committee 2013)
1.2.2.5.1.2	Bow string bridge	(International Organization for Standardization 2014a)
1.2.2.5.1.3	Cantilever bridge	(International Organization for Standardization 2014a), (Construction Project Information Committee 2013)
1.2.2.5.1.4	Cable stayed bridge	(International Organization for Standardization 2014a), (Construction Project Information Committee 2013)
1.2.2.5.1.5	Floating bridge	(International Organization for Standardization 2014a)
1.2.2.5.1.6	Movable bridge	(International Organization for Standardization 2014a), (Construction Project Information Committee 2013)
1.2.2.5.1.6.1	Bascule bridge	(International Organization for Standardization 2014a), (Construction Project Information Committee 2013)
1.2.2.5.1.6.2	Vertical lift bridge	(International Organization for Standardization 2014a), (Construction Project Information Committee 2013)
1.2.2.5.1.6.3	Swing bridge	(International Organization for Standardization 2014a), (Construction Project Information Committee 2013)
1.2.2.5.1.7	Simple Span Bridges	(Construction Project Information Committee 2013)
1.2.2.5.1.8	Viaduct	(International Organization for Standardization 2014a), (Construction Project Information Committee 2013)
1.2.2.5.1.9	Footbridge	(International Organization for Standardization 2014a)
1.2.2.5.1.10	Suspension Bridges	(Construction Project Information Committee 2013)
1.2.2.6	Tunnels	(EuroStat 1997)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
1.2.2.6.1	Bored Tunnels	(Construction Project Information Committee 2013)
1.2.2.6.2	Cut And Cover Tunnels	(Construction Project Information Committee 2013)
1.2.2.6.3	Immersed Tube Tunnels	(Construction Project Information Committee 2013)
1.2.3	Harbours, waterways, dams and other waterworks	(EuroStat 1997)
1.2.3.1	Harbours and navigable canals	(EuroStat 1997)
1.2.3.2	Dams	(EuroStat 1997)
1.2.3.2.1	Arch Dams	(Construction Project Information Committee 2013)
1.2.3.2.2	Buttress Dams	(Construction Project Information Committee 2013)
1.2.3.2.3	Embankment Dams	(Construction Project Information Committee 2013)
1.2.3.2.4	Gravity Arch Dams	(Construction Project Information Committee 2013)
1.2.3.2.5	Gravity Dams	(Construction Project Information Committee 2013)
1.2.3.3	Aqueducts, irrigation and cultivation waterworks	(EuroStat 1997), (Construction Project Information Committee 2013)
1.2.4	Pipelines, communication and electricity lines	(EuroStat 1997)
1.2.4.1	Long-distance	(EuroStat 1997)
1.2.4.1.1	Long-distance oil and gas pipelines	(EuroStat 1997)
1.2.4.1.1.1	Supported	(Construction Project Information Committee 2013)
1.2.4.1.1.2	Underground	(Construction Project Information Committee 2013)
1.2.4.1.2	Long-distance water pipelines	(EuroStat 1997)
1.2.4.1.2.1	Supported	(Construction Project Information Committee 2013)
1.2.4.1.2.2	Underground	(Construction Project Information Committee 2013)
1.2.4.1.3	Long-distance telecommunication lines, electricity lines	(EuroStat 1997)
1.2.4.1.3.1	Buried	(Construction Project Information Committee 2013)
1.2.4.1.3.2	Suspended	(Construction Project Information Committee 2013)
1.2.4.2	Local pipelines and cables	(EuroStat 1997)
1.2.4.2.1	Local gas supply lines	(EuroStat 1997)
1.2.4.2.2	Local water supply pipelines	(EuroStat 1997)
1.2.4.2.3	Local waste water pipelines	(EuroStat 1997)
1.2.4.2.4	Local electricity and telecommunication cables	(EuroStat 1997)
1.2.4.2.4.1	Buried	(Construction Project Information Committee 2013)
1.2.4.2.4.2	Suspended	(Construction Project Information Committee 2013)
1.2.5	Complex constructions on industrial sites	(EuroStat 1997)
1.2.5.1	Complex constructions on industrial sites	(EuroStat 1997)
1.2.5.1.1	Constructions for mining or extraction	(EuroStat 1997)
1.2.5.1.2	Power plant constructions	(EuroStat 1997)
1.2.5.1.3	Chemical plant constructions	(EuroStat 1997)
1.2.5.1.4	Heavy industrial plants, not elsewhere classified	(EuroStat 1997)
1.2.6	Other civil engineering works	(EuroStat 1997)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
1.2.6.1	Sport and recreation constructions	(EuroStat 1997)
1.2.6.1.1	Sports grounds	(EuroStat 1997)
1.2.6.1.2	Other sport and recreation constructions	(EuroStat 1997)
1.2.6.2	Other civil engineering works not elsewhere classified	(EuroStat 1997)
2	Actor	(El-Diraby et al. 2005)
2.1	Client	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.1.1	Project Sponsor, Funder	(Hughes and Murdoch 2001)
2.1.2	Client's Representative	(Hughes and Murdoch 2001)
2.1.3	Client liaison officer	(Hughes and Murdoch 2001)
2.2	Constructors	(Hughes and Murdoch 2001)
2.2.1	Main Contractor	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.2.2	Design Contractor	(Hughes and Murdoch 2001)
2.2.3	Management Contractor	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.2.4	Principal Contractor	(Hughes and Murdoch 2001)
2.2.5	Partial Responsibilirty	(Hughes and Murdoch 2001)
2.2.5.1	Sub-contractor	(Hughes and Murdoch 2001)
2.2.5.1.1	Domestic Sub-Contractor	(Hughes and Murdoch 2001)
2.2.5.1.2	Nominated sub-contractor	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.2.5.1.3	Labour-only Sub-contractor	(Hughes and Murdoch 2001)
2.2.5.1.4	Specialist Sub-Contractor	(Hughes and Murdoch 2001)
2.2.5.1.4.1	Process Contractor	(Hughes and Murdoch 2001)
2.2.5.1.4.2	Engineering Contractor	(Hughes and Murdoch 2001)
2.2.5.1.4.3	Specialist Trade Contractor	(Hughes and Murdoch 2001)
2.2.5.2	Supplier	(Hughes and Murdoch 2001)
2.2.5.2.1	Nominated Supplier	(Hughes and Murdoch 2001)
2.2.5.2.2	Specialist Supplier	(Hughes and Murdoch 2001)
2.2.6	Direct Contractor	(Hughes and Murdoch 2001)
2.3	Dispute Resolvers	(Hughes and Murdoch 2001)
2.3.1	Adjudicator	(Hughes and Murdoch 2001)
2.3.2	Arbitrator	(Hughes and Murdoch 2001)
2.3.3	Mediator	(Hughes and Murdoch 2001)
2.4	Regulators	(Hughes and Murdoch 2001)
2.4.1	Statuary Authorities	(Hughes and Murdoch 2001)
2.4.1.1	Utilities	(Hughes and Murdoch 2001)
2.4.1.2	Health and Safety Executive	(Hughes and Murdoch 2001)
2.4.2	Local Authority	(Hughes and Murdoch 2001)
2.4.2.1	Development Control Authority	(Hughes and Murdoch 2001)
2.4.2.2	Planning Manager	(Hughes and Murdoch 2001)
2.4.2.3	Building Control Officer	(Hughes and Murdoch 2001)
2.4.2.4	Environmental Health Officer	(Hughes and Murdoch 2001)
2.4.2.5	Fire Officer	(Hughes and Murdoch 2001)
2.5	Staff	
2.5.1	Feasibility Consultan	(Hughes and Murdoch 2001)
2.5.2	Construction Manager	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
2.5.2.1	Section Manager	(International Organization for Standardization 2014b)
2.5.2.2	Site Manager	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.5.2.3	Construction Planner	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.5.2.4	Contract Manager	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.5.2.5	Project Manager	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.5.3	Design	(Hughes and Murdoch 2001)
2.5.3.1	Leed Designer	(Hughes and Murdoch 2001)
2.5.3.2	Acoustic Consultant	(Hughes and Murdoch 2001)
2.5.3.3	Architect	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.5.3.4	Electrical Engineer	(Hughes and Murdoch 2001)
2.5.3.5	Mechanical Engineer	(Hughes and Murdoch 2001)
2.5.3.6	Enviromental Engineer	(Hughes and Murdoch 2001)
2.5.3.7	Structural Engineer	(Hughes and Murdoch 2001)
2.5.3.8	Fire Engineer	(Hughes and Murdoch 2001)
2.5.3.9	Geotechnical Engineer	(Hughes and Murdoch 2001)
2.5.3.10	Landscape Consultant	(Hughes and Murdoch 2001)
2.5.3.11	Materials Engineer	(Hughes and Murdoch 2001)
2.5.3.12	Traffic Consultant	(Hughes and Murdoch 2001)
2.5.4	Financial	(Hughes and Murdoch 2001)
2.5.4.1	Cost Consultant	(Hughes and Murdoch 2001)
2.5.4.2	Quantity Surveyor	(Hughes and Murdoch 2001)
2.5.4.3	Quantity Surveying Technician	(International Organization for Standardization 2014b)
2.5.5	Administration	(Hughes and Murdoch 2001)
2.5.5.1	Contract Administrator	(Hughes and Murdoch 2001)
2.5.5.2	Planning Supervisor	(Hughes and Murdoch 2001)
2.5.6	Site Inspector	(Hughes and Murdoch 2001)
2.5.6.1	Resident Engineer	(Hughes and Murdoch 2001)
2.5.6.2	Clerk of Works	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
2.5.7	Worker	(Hughes and Murdoch 2001)
2.5.7.1	Foreman	(International Organization for Standardization 2014b)
2.5.7.2	Labour	(International Organization for Standardization 2014b)
3	Process	(El-Diraby et al. 2005)
3.1	Feasibility	(Dykstra 2011)
3.2	Design	(El-Diraby et al. 2005), (Hughes and Murdoch 2001)
3.2.1	Stage	(Hughes and Murdoch 2001)
3.2.1.1	Outline Stage	(Hughes and Murdoch 2001)
3.2.1.2	Detailed Stage	(Hughes and Murdoch 2001)
3.2.1.3	Final Stage	(Hughes and Murdoch 2001)
3.2.1.4	Information for Construction	(Hughes and Murdoch 2001)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.2.1.4.1	Drawings	(Hughes and Murdoch 2001)
3.2.1.4.2	Specification	(Hughes and Murdoch 2001)
3.2.2	Design Branch	
3.2.2.1	Architectural Design	(Hughes and Murdoch 2001)
3.2.2.2	Structural Design	(Hughes and Murdoch 2001)
3.2.2.3	Electrical Design	(Hughes and Murdoch 2001)
3.2.2.4	Mechanical Design	(Hughes and Murdoch 2001)
3.2.2.5	Geotechnical Design	(Hughes and Murdoch 2001)
3.2.2.6	Other	
3.2.2.6.1	Acoustic Design	(Hughes and Murdoch 2001)
3.2.2.6.2	Traffic	(Hughes and Murdoch 2001)
3.2.2.6.3	Fire	(Hughes and Murdoch 2001)
3.3	Contract Formation	(Hughes and Murdoch 2001)
3.3.1	Define the work to be done	(Hughes and Murdoch 2001)
3.3.1.1	Bills of quantity	(Hughes and Murdoch 2001)
3.3.1.2	Contractor's Proposal	(Hughes and Murdoch 2001)
3.3.1.3	Employer's Requirements	(Hughes and Murdoch 2001)
3.3.1.4	Performance Specification	(Hughes and Murdoch 2001)
3.3.1.5	Tender Documentation	(Hughes and Murdoch 2001)
3.3.2	Agree Contractual Terms	(Hughes and Murdoch 2001)
3.3.2.1	Qualification	(Hughes and Murdoch 2001)
3.3.2.2	Drafting	(Hughes and Murdoch 2001)
3.3.2.3	Negotiation	(Hughes and Murdoch 2001)
3.3.3	Identify the Builder	(Hughes and Murdoch 2001)
3.3.3.1	Competition	(Hughes and Murdoch 2001)
3.3.3.2	Negotiation	(Hughes and Murdoch 2001)
3.3.3.3	Qualification	(Hughes and Murdoch 2001)
3.3.4	Identify the Price	(Hughes and Murdoch 2001)
3.3.4.1	Bidding	(Hughes and Murdoch 2001)
3.3.4.2	Competitive Tender	(Hughes and Murdoch 2001)
3.3.4.3	Negotiation	(Hughes and Murdoch 2001)
3.4	Construction	(Hughes and Murdoch 2001), (El-Diraby et al. 2005)
3.4.1	Site Works	(Chudley and Greeno 2010)
3.4.1.1	Site Survey	(Chudley and Greeno 2010), (CSI 2014)
3.4.1.1.1	Existing Conditions Assessment	(CSI 2014)
3.4.1.1.1.1	Movement and Vibration Assessment	(CSI 2014)
3.4.1.1.1.2	Acoustic Assessment	(CSI 2014)
3.4.1.1.1.3	Traffic Assessment	(CSI 2014)
3.4.1.1.1.4	Accessibility Assessment	(CSI 2014)
3.4.1.1.2	Environmental Assessment	(CSI 2014)
3.4.1.1.2.1	Protection orders for trees and structures	(Chudley and Greeno 2010)
3.4.1.1.3	Existing Material Assessment	(CSI 2014)
3.4.1.1.4	Hazardous Material Assessment	(CSI 2014)
3.4.1.2	Subsurface Investigation	(CSI 2014)
3.4.1.2.1	Geophysical Investigations	(CSI 2014)
3.4.1.2.1.1	Seismic Investigations	(CSI 2014)
3.4.1.2.1.2	Gravity Investigations	(CSI 2014)
3.4.1.2.1.3	Magnetic Investigations	(CSI 2014)
3.4.1.2.1.4	Electromagnetic Investigations	(CSI 2014)
3.4.1.2.1.5	Electrical Resistivity Investigations	(CSI 2014)
3.4.1.2.1.6	Magnetotelluric Investigations	(CSI 2014)
3.4.1.2.2	Geotechnical Investigations	(CSI 2014)
3.4.1.2.2.1	Subsurface Drilling and Sampling	(CSI 2014)
3.4.1.2.2.2	Material Testing	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	**Tag**	**Resource**
3.4.1.2.2.3	Exploratory Excavations	(CSI 2014)
3.4.1.2.2.4	Geotechnical Monitoring Before Construction	(CSI 2014)
3.4.1.3	Site Set Up	(Chudley and Greeno 2010)
3.4.1.3.1	Site layout considerations	(Chudley and Greeno 2010)
3.4.1.3.2	Site lighting and electrical supply	(Chudley and Greeno 2010)
3.4.1.3.3	Site office accommodation	(Chudley and Greeno 2010)
3.4.1.3.4	Site security	(Chudley and Greeno 2010)
3.4.1.3.5	Road construction	(Chudley and Greeno 2010)
3.4.1.3.6	Materials storage	(Chudley and Greeno 2010)
3.4.1.3.7	Locating public utility services	(Chudley and Greeno 2010)
3.4.1.4	Demolition and Structure Moving	(CSI 2014)
3.4.1.4.1	Demolition	(CSI 2014), (Chudley and Greeno 2010)
3.4.1.4.2	Structure Moving	(CSI 2014)
3.4.1.4.3	Removal and Salvage of Construction Materials	(CSI 2014)
3.4.1.5	Remediation	(CSI 2014)
3.4.1.5.1	Site Remediation	(CSI 2014)
3.4.1.5.2	Water Remediation	(CSI 2014)
3.4.1.5.3	Facility Remediation	(CSI 2014)
3.4.2	Construction Works	(CSI 2014)
3.4.2.1	Earthwork	(CSI 2014)
3.4.2.1.1	Site Clearing	(CSI 2014)
3.4.2.1.1.1	Clearing and Grubbing	(CSI 2014)
3.4.2.1.1.2	Selective Clearing	(CSI 2014)
3.4.2.1.1.3	Selective Tree and Shrub Removal and Trimming	(CSI 2014)
3.4.2.1.1.4	Earth Stripping and Stockpiling	(CSI 2014)
3.4.2.1.2	Earth Moving	(CSI 2014)
3.4.2.1.2.1	Off-Gassing Mitigation	(CSI 2014)
3.4.2.1.2.2	Grading	(CSI 2014)
3.4.2.1.2.3	Excavation and Fill	(CSI 2014)
3.4.2.1.2.4	Embankments	(CSI 2014)
3.4.2.1.2.5	Erosion and Sedimentation Controls	(CSI 2014)
3.4.2.1.3	Earthwork Methods	(CSI 2014)
3.4.2.1.3.1	Soil Treatment	(CSI 2014)
3.4.2.1.3.2	Soil Stabilization	(CSI 2014)
3.4.2.1.3.3	Rock Stabilization	(CSI 2014)
3.4.2.1.3.4	Soil Reinforcement	(CSI 2014)
3.4.2.1.3.5	Slope Protection	(CSI 2014)
3.4.2.1.3.6	Gabions	(CSI 2014)
3.4.2.1.3.7	Riprap	(CSI 2014)
3.4.2.1.4	Shoring and Underpinning	(CSI 2014)
3.4.2.1.4.1	Shoring	(CSI 2014)
3.4.2.1.4.2	Concrete Raising	(CSI 2014)
3.4.2.1.4.3	Vibroflotation and Densification	(CSI 2014)
3.4.2.1.4.4	Underpinning	(CSI 2014)
3.4.2.1.5	Excavation Support and Protection	(CSI 2014)
3.4.2.1.5.1	Anchor Tiebacks	(CSI 2014)
3.4.2.1.5.2	Cofferdams	(CSI 2014)
3.4.2.1.5.3	Cribbing and Walers	(CSI 2014)
3.4.2.1.5.4	Ground Freezing	(CSI 2014)
3.4.2.1.5.5	Slurry Walls	(CSI 2014)
3.4.2.1.6	Special Foundations and Load-Bearing Elements	(CSI 2014)
3.4.2.1.6.1	Driven Piles	(CSI 2014)
3.4.2.1.6.2	Bored Piles	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.2.1.6.3	Caissons	(CSI 2014)
3.4.2.1.6.4	Special Foundations	(CSI 2014)
3.4.2.1.6.5	Foundation Anchors	(CSI 2014)
3.4.2.1.7	Tunneling and Mining	(CSI 2014)
3.4.2.1.7.1	Tunnel Excavation	(CSI 2014)
3.4.2.1.7.2	Tunnel Support Systems	(CSI 2014)
3.4.2.1.7.3	Tunnel Grouting	(CSI 2014)
3.4.2.1.7.4	Tunnel Construction	(CSI 2014)
3.4.2.1.7.5	Shaft Construction	(CSI 2014)
3.4.2.1.7.6	Submersible Tube Tunnels	(CSI 2014)
3.4.2.2	Concrete Works	(CSI 2014)
3.4.2.2.1	Concrete Forming and Accessories	(CSI 2014)
3.4.2.2.1.1	Concrete Forming	(CSI 2014)
3.4.2.2.1.2	Concrete Accessories	(CSI 2014)
3.4.2.2.2	Concrete Reinforcing	(CSI 2014)
3.4.2.2.2.1	Reinforcement Bars	(CSI 2014)
3.4.2.2.2.2	Fabric and Grid Reinforcing	(CSI 2014)
3.4.2.2.2.3	Stressed Tendon Reinforcing	(CSI 2014)
3.4.2.2.2.4	Fibrous Reinforcing	(CSI 2014)
3.4.2.2.2.5	Composite Reinforcing	(CSI 2014)
3.4.2.2.3	Cast-in-Place Concrete	(CSI 2014)
3.4.2.2.3.1	Structural Concrete	(CSI 2014)
3.4.2.2.3.2	Architectural Concrete	(CSI 2014)
3.4.2.2.3.3	Low Density Concrete	(CSI 2014)
3.4.2.2.3.4	Concrete Finishing	(CSI 2014)
3.4.2.2.3.5	Specialty Placed Concrete	(CSI 2014)
3.4.2.2.3.5.1	Shotcrete	(CSI 2014)
3.4.2.2.3.5.2	Pumped Concrete	(CSI 2014)
3.4.2.2.3.5.3	Pneumatically Placed Concrete	(CSI 2014)
3.4.2.2.3.5.4	Roller-Compacted Concrete	(CSI 2014)
3.4.2.2.3.5.5	Underwater Placed Concrete	(CSI 2014)
3.4.2.2.3.6	Post-Tensioned Concrete	(CSI 2014)
3.4.2.2.3.7	Concrete Curing	(CSI 2014)
3.4.2.2.4	Precast Concrete	(CSI 2014)
3.4.2.2.4.1	Precast Structural Concrete	(CSI 2014)
3.4.2.2.4.1.1	Precast Concrete Hollow Core Planks	(CSI 2014)
3.4.2.2.4.1.2	Precast Concrete Slabs	(CSI 2014)
3.4.2.2.4.1.3	Precast Concrete Stairs	(CSI 2014)
3.4.2.2.4.1.4	Precast Structural Pretensioned Concrete	(CSI 2014)
3.4.2.2.4.1.5	Precast Structural Post-Tensioned Concrete	(CSI 2014)
3.4.2.2.4.2	Precast Architectural Concrete	(CSI 2014)
3.4.2.2.4.3	Site-Cast Concrete	(CSI 2014)
3.4.2.2.4.3.1	Tilt-Up Concrete	(CSI 2014)
3.4.2.2.4.3.2	Lift-Slab Concrete	(CSI 2014)
3.4.2.2.4.4	Precast Concrete Specialties	(CSI 2014)
3.4.2.2.4.5	Glass-Fiber-Reinforced Concrete	(CSI 2014)
3.4.2.2.5	Cast Decks and Underlayment	(CSI 2014)
3.4.2.2.5.1	Cast Roof Decks	(CSI 2014)
3.4.2.2.5.2	Lightweight Concrete Roof Insulation	(CSI 2014)
3.4.2.2.5.3	Concrete Topping	(CSI 2014)
3.4.2.2.5.4	Cast Underlayment	(CSI 2014)
3.4.2.2.6	Grouting	(CSI 2014)
3.4.2.2.6.1	Cementitious Grouting	(CSI 2014)
3.4.2.2.6.2	Non-Shrink Grouting	(CSI 2014)
3.4.2.2.6.3	Epoxy Grouting	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.2.2.6.4	Injection Grouting	(CSI 2014)
3.4.2.2.7	Mass Concrete	(CSI 2014)
3.4.2.2.7.1	Mass Concrete for Raft Foundations	(CSI 2014)
3.4.2.2.7.2	Mass Concrete for Dams	(CSI 2014)
3.4.2.2.8	Concrete Cutting and Boring	(CSI 2014)
3.4.2.2.8.1	Concrete Cutting	(CSI 2014)
3.4.2.2.8.2	Concrete Boring	(CSI 2014)
3.4.2.3	Masonry Works	(CSI 2014)
3.4.2.3.1	Unit Masonry	(CSI 2014)
3.4.2.3.1.1	Clay Unit Masonry	(CSI 2014)
3.4.2.3.1.2	Concrete Unit Masonry	(CSI 2014)
3.4.2.3.1.3	Glass Unit Masonry	(CSI 2014)
3.4.2.3.1.4	Adobe Unit Masonry	(CSI 2014)
3.4.2.3.1.5	Unit Masonry Panels	(CSI 2014)
3.4.2.3.1.6	Single-Wythe Unit Masonry	(CSI 2014)
3.4.2.3.1.7	Multiple-Wythe Unit Masonry	(CSI 2014)
3.4.2.3.1.8	Concrete Form Masonry Units	(CSI 2014)
3.4.2.3.1.9	Engineered Unit Masonry	(CSI 2014)
3.4.2.3.2	Stone Assemblies	(CSI 2014)
3.4.2.3.2.1	Dry-Placed Stone	(CSI 2014)
3.4.2.3.2.2	Exterior Stone Cladding	(CSI 2014)
3.4.2.3.2.3	Stone Masonry	(CSI 2014)
3.4.2.3.3	Refractory Masonry	(CSI 2014)
3.4.2.3.4	Corrosion-Resistant Masonry	(CSI 2014)
3.4.2.3.5	Manufactured Masonry	(CSI 2014)
3.4.2.3.5.1	Manufactured Brick Masonry	(CSI 2014)
3.4.2.3.5.2	Cast Stone Masonry	(CSI 2014)
3.4.2.3.5.3	Manufactured Stone Masonry	(CSI 2014)
3.4.2.4	Metal Works	(CSI 2014)
3.4.2.4.1	Structural Metal Framing	(CSI 2014)
3.4.2.4.1.1	Structural Steel Framing	(CSI 2014)
3.4.2.4.1.2	Structural Stainless-Steel Framing	(CSI 2014)
3.4.2.4.1.3	Structural Aluminum Framing	(CSI 2014)
3.4.2.4.1.4	Wire Rope Assemblies	(CSI 2014)
3.4.2.4.1.5	Structural Cabling	(CSI 2014)
3.4.2.4.1.6	Structural Rod Assemblies	(CSI 2014)
3.4.2.4.1.7	Tension Rod and Cable Truss Assemblies	(CSI 2014)
3.4.2.4.2	Metal Joists	(CSI 2014)
3.4.2.4.2.1	Steel Joist Framing	(CSI 2014)
3.4.2.4.2.2	Aluminum Joist Framing	(CSI 2014)
3.4.2.4.3	Metal Decking	(CSI 2014)
3.4.2.4.3.1	Steel Decking	(CSI 2014)
3.4.2.4.3.2	Aluminum Decking	(CSI 2014)
3.4.2.4.3.3	Acoustical Metal Decking	(CSI 2014)
3.4.2.4.3.4	Raceway Decking Assemblies	(CSI 2014)
3.4.2.4.3.5	Composite Metal Decking	(CSI 2014)
3.4.2.4.4	Cold-Formed Metal Framing	(CSI 2014)
3.4.2.4.4.1	Structural Metal Stud Framing	(CSI 2014)
3.4.2.4.4.2	Cold-Formed Metal Joist Framing	(CSI 2014)
3.4.2.4.4.3	Slotted Channel Framing	(CSI 2014)
3.4.2.4.4.4	Cold-Formed Metal Trusses	(CSI 2014)
3.4.2.4.4.5	Metal Support Assemblies	(CSI 2014)
3.4.2.4.5	Metal Fabrications	(CSI 2014)
3.4.2.4.5.1	Metal Stairs	(CSI 2014)
3.4.2.4.5.2	Metal Railings	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	**Tag**	**Resource**
3.4.2.4.5.3	Metal Gratings	(CSI 2014)
3.4.2.4.5.4	Metal Floor Plates	(CSI 2014)
3.4.2.4.5.5	Metal Stair Treads and Nosings	(CSI 2014)
3.4.2.4.5.6	Metal Castings	(CSI 2014)
3.4.2.4.5.7	Formed Metal Fabrications	(CSI 2014)
3.4.2.4.5.8	Metal Specialties	(CSI 2014)
3.4.2.4.6	Decorative Metal	(CSI 2014)
3.4.2.5	Wood, Plastic, and Composite Works	(CSI 2014)
3.4.2.5.1	Rough Carpentry	(CSI 2014)
3.4.2.5.1.1	Wood Framing	(CSI 2014)
3.4.2.5.1.2	Structural Panels	(CSI 2014)
3.4.2.5.1.3	Heavy Timber Construction	(CSI 2014)
3.4.2.5.1.4	Treated Wood Foundations	(CSI 2014)
3.4.2.5.1.5	Wood Decking	(CSI 2014)
3.4.2.5.1.6	Sheathing	(CSI 2014)
3.4.2.5.1.7	Shop-Fabricated Structural Wood	(CSI 2014)
3.4.2.5.1.8	Glued-Laminated Construction	(CSI 2014)
3.4.2.5.2	Finish Carpentry	(CSI 2014)
3.4.2.5.2.1	Millwork	(CSI 2014)
3.4.2.5.2.2	Prefinished Paneling	(CSI 2014)
3.4.2.5.2.3	Board Paneling	(CSI 2014)
3.4.2.5.3	Architectural Woodwork	(CSI 2014)
3.4.2.5.3.1	Architectural Wood Casework	(CSI 2014)
3.4.2.5.3.2	Wood Paneling	(CSI 2014)
3.4.2.5.3.3	Wood Stairs and Railings	(CSI 2014)
3.4.2.5.3.4	Ornamental Woodwork	(CSI 2014)
3.4.2.5.3.5	Wood Trim	(CSI 2014)
3.4.2.5.3.6	Wood Frames	(CSI 2014)
3.4.2.5.3.7	Wood Screens and Exterior Wood Shutters	(CSI 2014)
3.4.2.5.4	Structural Plastics	(CSI 2014)
3.4.2.5.4.1	Structural Plastic Shapes and Plates	(CSI 2014)
3.4.2.5.4.2	Plastic Structural Assemblies	(CSI 2014)
3.4.2.5.4.3	Plastic Decking	(CSI 2014)
3.4.2.5.5	Plastic Fabrications	(CSI 2014)
3.4.2.5.5.1	Cast Polymer Fabrications	(CSI 2014)
3.4.2.5.5.2	Plastic Railings	(CSI 2014)
3.4.2.5.5.3	Plastic Paneling	(CSI 2014)
3.4.2.5.5.4	Plastic Trim	(CSI 2014)
3.4.2.5.5.5	Custom Ornamental Simulated Woodwork	(CSI 2014)
3.4.2.5.6	Structural Composites	(CSI 2014)
3.4.2.5.6.1	Structural Composite Shapes and Plates	(CSI 2014)
3.4.2.5.6.2	Composite Structural Assemblies	(CSI 2014)
3.4.2.5.6.3	Composite Decking	(CSI 2014)
3.4.2.5.6.4	Composite Gratings	(CSI 2014)
3.4.2.5.7	Composite Fabrications	(CSI 2014)
3.4.2.5.7.1	Composite Railings	(CSI 2014)
3.4.2.5.7.2	Composite Trim	(CSI 2014)
3.4.2.5.7.3	Composite Paneling	(CSI 2014)
3.4.2.6	Thermal and Moisture Protection	(CSI 2014)
3.4.2.6.1	Dampproofing and Waterproofing	(CSI 2014)
3.4.2.6.1.1	Dampproofing	(CSI 2014)
3.4.2.6.1.2	Built-Up Bituminous Waterproofing	(CSI 2014)
3.4.2.6.1.3	Sheet Waterproofing	(CSI 2014)
3.4.2.6.1.4	Fluid-Applied Waterproofing	(CSI 2014)
3.4.2.6.1.5	Sheet Metal Waterproofing	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.2.6.1.6	Cementitious and Reactive Waterproofing	(CSI 2014)
3.4.2.6.1.7	Bentonite Waterproofing	(CSI 2014)
3.4.2.6.1.8	Traffic Coatings	(CSI 2014)
3.4.2.6.1.9	Water Repellents	(CSI 2014)
3.4.2.6.2	Thermal Protection	(CSI 2014)
3.4.2.6.2.1	Thermal Insulation	(CSI 2014)
3.4.2.6.2.1.1	Board Insulation	(CSI 2014)
3.4.2.6.2.1.1.1	Foam Board Insulation	(CSI 2014)
3.4.2.6.2.1.1.2	Fibrous Board Insulation	(CSI 2014)
3.4.2.6.2.1.1.3	Mineral Board Insulation	(CSI 2014)
3.4.2.6.2.1.2	Blanket Insulation	(CSI 2014)
3.4.2.6.2.1.3	Foamed-In-Place Insulation	(CSI 2014)
3.4.2.6.2.1.4	Loose-Fill Insulation	(CSI 2014)
3.4.2.6.2.1.5	Blown Insulation	(CSI 2014)
3.4.2.6.2.1.6	Sprayed Insulation	(CSI 2014)
3.4.2.6.2.1.7	Reflective Insulation	(CSI 2014)
3.4.2.6.2.2	Roof and Deck Insulation	(CSI 2014)
3.4.2.6.2.3	Exterior Insulation and Finish Systems	(CSI 2014)
3.4.2.6.2.3.1	Polymer-Based Exterior Insulation and Finish System	(CSI 2014)
3.4.2.6.2.3.2	Polymer-Modified Exterior Insulation and Finish System	(CSI 2014)
3.4.2.6.2.3.3	Water-Drainage Exterior Insulation and Finish System	(CSI 2014)
3.4.2.6.2.3.4	Direct-Applied Finish Systems	(CSI 2014)
3.4.2.6.3	Weather Barriers	(CSI 2014)
3.4.2.6.3.1	Vapor Retarders	(CSI 2014)
3.4.2.6.3.2	Air Barriers	(CSI 2014)
3.4.2.6.4	Steep Slope Roofing	(CSI 2014)
3.4.2.6.4.1	Shingles and Shakes	(CSI 2014)
3.4.2.6.4.2	Roof Tiles	(CSI 2014)
3.4.2.6.4.3	Natural Roof Coverings	(CSI 2014)
3.4.2.6.5	Roofing and Siding Panels	(CSI 2014)
3.4.2.6.5.1	Roof Panels	(CSI 2014)
3.4.2.6.5.2	Wall Panels	(CSI 2014)
3.4.2.6.5.3	Faced Panels	(CSI 2014)
3.4.2.6.5.4	Siding	(CSI 2014)
3.4.2.6.6	Membrane Roofing	(CSI 2014)
3.4.2.6.7	Flashing and Sheet Metal	(CSI 2014)
3.4.2.6.7.1	Sheet Metal Roofing	(CSI 2014)
3.4.2.6.7.2	Sheet Metal Flashing and Trim	(CSI 2014)
3.4.2.6.7.3	Sheet Metal Roofing Specialties	(CSI 2014)
3.4.2.6.7.4	Sheet Metal Wall Cladding	(CSI 2014)
3.4.2.6.7.5	Flexible Flashing	(CSI 2014)
3.4.2.6.8	Roof and Wall Specialties and Accessories	(CSI 2014)
3.4.2.6.8.1	Roof Specialties	(CSI 2014)
3.4.2.6.8.2	Roof Accessories	(CSI 2014)
3.4.2.6.8.3	Roof Pavers	(CSI 2014)
3.4.2.6.8.4	Wall Specialties	(CSI 2014)
3.4.2.6.9	Fire and Smoke Protection	(CSI 2014)
3.4.2.6.9.1	Applied Fireproofing	(CSI 2014)
3.4.2.6.9.2	Board Fireproofing	(CSI 2014)
3.4.2.6.9.3	Firestopping	(CSI 2014)
3.4.2.6.9.4	Smoke Seals	(CSI 2014)
3.4.2.6.9.5	Smoke Containment Barriers	(CSI 2014)
3.4.2.6.10	Joint Protection	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.2.6.10.1	Preformed Joint Seals	(CSI 2014)
3.4.2.6.10.2	Joint Sealants	(CSI 2014)
3.4.2.6.10.3	Expansion Control	(CSI 2014)
3.4.2.7	Openings	(CSI 2014)
3.4.2.7.1	Doors and Frames	(CSI 2014)
3.4.2.7.1.1	Metal Doors and Frames	(CSI 2014)
3.4.2.7.1.2	Metal Frames	(CSI 2014)
3.4.2.7.1.3	Metal Doors	(CSI 2014)
3.4.2.7.1.4	Wood Doors	(CSI 2014)
3.4.2.7.1.5	Plastic Doors	(CSI 2014)
3.4.2.7.1.6	Composite Doors	(CSI 2014)
3.4.2.7.1.7	Integrated Door Opening Assemblies	(CSI 2014)
3.4.2.7.2	Specialty Doors and Frames	(CSI 2014)
3.4.2.7.2.1	Access Doors and Panels	(CSI 2014)
3.4.2.7.2.2	Sliding Glass Doors	(CSI 2014)
3.4.2.7.2.3	Coiling Doors and Grilles	(CSI 2014)
3.4.2.7.2.4	Special Function Doors	(CSI 2014)
3.4.2.7.2.5	Folding Doors and Grilles	(CSI 2014)
3.4.2.7.2.6	Panel Doors	(CSI 2014)
3.4.2.7.2.7	Traffic Doors	(CSI 2014)
3.4.2.7.2.8	Pressure-Resistant Doors	(CSI 2014)
3.4.2.7.3	Entrances, Storefronts, and Curtain Walls	(CSI 2014)
3.4.2.7.3.1	Entrances and Storefronts	(CSI 2014)
3.4.2.7.3.2	Entrances	(CSI 2014)
3.4.2.7.3.3	Storefronts	(CSI 2014)
3.4.2.7.3.4	Curtain Wall and Glazed Assemblies	(CSI 2014)
3.4.2.7.3.5	Translucent Wall and Roof Assemblies	(CSI 2014)
3.4.2.7.4	Windows	(CSI 2014)
3.4.2.7.4.1	Metal Windows	(CSI 2014)
3.4.2.7.4.2	Wood Windows	(CSI 2014)
3.4.2.7.4.3	Plastic Windows	(CSI 2014)
3.4.2.7.4.4	Composite Windows	(CSI 2014)
3.4.2.7.4.5	Pressure-Resistant Windows	(CSI 2014)
3.4.2.7.4.6	Special Function Windows	(CSI 2014)
3.4.2.7.5	Roof Windows and Skylights	(CSI 2014)
3.4.2.7.5.1	Roof Windows	(CSI 2014)
3.4.2.7.5.2	Unit Skylights	(CSI 2014)
3.4.2.7.5.3	Metal-Framed Skylights	(CSI 2014)
3.4.2.7.5.4	Plastic-Framed Skylights	(CSI 2014)
3.4.2.7.5.5	Skylight Protection and Screens	(CSI 2014)
3.4.2.7.6	Hardware	(CSI 2014)
3.4.2.7.6.1	Door Hardware	(CSI 2014)
3.4.2.7.6.2	Access Control Hardware	(CSI 2014)
3.4.2.7.6.3	Window Hardware	(CSI 2014)
3.4.2.7.6.4	Special Function Hardware	(CSI 2014)
3.4.2.7.6.5	Hardware Accessories	(CSI 2014)
3.4.2.7.7	Glazing	(CSI 2014)
3.4.2.7.7.1	Glass Glazing	(CSI 2014)
3.4.2.7.7.2	Mirrors	(CSI 2014)
3.4.2.7.7.3	Plastic Glazing	(CSI 2014)
3.4.2.7.7.4	Glazing Accessories	(CSI 2014)
3.4.2.7.7.5	Glazing Surface Films	(CSI 2014)
3.4.2.7.7.6	Special Function Glazing	(CSI 2014)
3.4.2.7.8	Louvers and Vents	(CSI 2014)
3.4.2.7.8.1	Louvers	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.2.7.8.2	Louvered Equipment Enclosures	(CSI 2014)
3.4.2.7.8.3	Vents	(CSI 2014)
3.4.2.8	Finishes	(CSI 2014)
3.4.2.8.1	Plaster and Gypsum Board	(CSI 2014)
3.4.2.8.1.1	Plaster and Gypsum Board Assemblies	(CSI 2014)
3.4.2.8.1.2	Supports for Plaster and Gypsum Board	(CSI 2014)
3.4.2.8.1.3	Gypsum Plastering	(CSI 2014)
3.4.2.8.1.4	Cement Plastering	(CSI 2014)
3.4.2.8.1.5	Other Plastering	(CSI 2014)
3.4.2.8.1.6	Veneer Plastering	(CSI 2014)
3.4.2.8.1.7	Plaster Fabrications	(CSI 2014)
3.4.2.8.1.8	Backing Boards and Underlayments	(CSI 2014)
3.4.2.8.1.9	Gypsum Board	(CSI 2014)
3.4.2.8.2	Tiling	(CSI 2014)
3.4.2.8.2.1	Thin-Set Tiling	(CSI 2014)
3.4.2.8.2.2	Mortar-Bed Tiling	(CSI 2014)
3.4.2.8.2.3	Conductive Tiling	(CSI 2014)
3.4.2.8.2.4	Waterproofing-Membrane Tiling	(CSI 2014)
3.4.2.8.2.5	Chemical-Resistant Tiling	(CSI 2014)
3.4.2.8.3	Ceilings	(CSI 2014)
3.4.2.8.3.1	Acoustical Ceilings	(CSI 2014)
3.4.2.8.3.2	Acoustical Ceiling Suspension Assemblies	(CSI 2014)
3.4.2.8.3.3	Specialty Ceilings	(CSI 2014)
3.4.2.8.3.4	Textured Ceilings	(CSI 2014)
3.4.2.8.3.5	Special Function Ceilings	(CSI 2014)
3.4.2.8.3.6	Integrated Ceiling Assemblies	(CSI 2014)
3.4.2.8.4	Flooring	(CSI 2014)
3.4.2.8.4.1	Flooring Treatment	(CSI 2014)
3.4.2.8.4.2	Specialty Flooring	(CSI 2014)
3.4.2.8.4.3	Masonry Flooring	(CSI 2014)
3.4.2.8.4.4	Wood Flooring	(CSI 2014)
3.4.2.8.4.5	Resilient Flooring	(CSI 2014)
3.4.2.8.4.6	Terrazzo Flooring	(CSI 2014)
3.4.2.8.4.7	Fluid-Applied Flooring	(CSI 2014)
3.4.2.8.4.8	Carpeting	(CSI 2014)
3.4.2.8.4.9	Access Flooring	(CSI 2014)
3.4.2.8.5	Wall Finishes	(CSI 2014)
3.4.2.8.5.1	Wall Coverings	(CSI 2014)
3.4.2.8.5.2	Wall Carpeting	(CSI 2014)
3.4.2.8.5.3	Flexible Wood Sheets	(CSI 2014)
3.4.2.8.5.4	Stone Facing	(CSI 2014)
3.4.2.8.5.5	Plastic Blocks	(CSI 2014)
3.4.2.8.5.6	Special Wall Surfacing	(CSI 2014)
3.4.2.8.5.7	Interior Wall Paneling	(CSI 2014)
3.4.2.8.6	Acoustic Treatment	(CSI 2014)
3.4.2.8.6.1	Acoustic Insulation	(CSI 2014)
3.4.2.8.6.2	Acoustic Finishes	(CSI 2014)
3.4.2.8.6.3	Acoustic Room Components	(CSI 2014)
3.4.2.8.7	Painting and Coating	(CSI 2014)
3.4.2.8.7.1	Painting	(CSI 2014)
3.4.2.8.7.2	Staining and Transparent Finishing	(CSI 2014)
3.4.2.8.7.3	Decorative Finishing	(CSI 2014)
3.4.2.8.7.4	High-Performance Coatings	(CSI 2014)
3.4.2.8.7.5	Special Coatings	(CSI 2014)
3.4.2.9	Special Construction	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	**Tag**	**Resource**
3.4.2.9.1	Special Facility Components	(CSI 2014)
3.4.2.9.1.1	Swimming Pools	(CSI 2014)
3.4.2.9.1.2	Fountains	(CSI 2014)
3.4.2.9.1.3	Aquariums	(CSI 2014)
3.4.2.9.1.4	Amusement Park Structures and Equipment	(CSI 2014)
3.4.2.9.1.5	Specialty Element Construction	(CSI 2014)
3.4.2.9.1.6	Tubs and Pools	(CSI 2014)
3.4.2.9.1.7	Ice Rinks	(CSI 2014)
3.4.2.9.1.8	Kennels and Animal Shelters	(CSI 2014)
3.4.2.9.2	Special Purpose Rooms	(CSI 2014)
3.4.2.9.2.1	Controlled Environment Rooms	(CSI 2014)
3.4.2.9.2.2	Office Shelters and Booths	(CSI 2014)
3.4.2.9.2.3	Planetariums	(CSI 2014)
3.4.2.9.2.4	Special Activity Rooms	(CSI 2014)
3.4.2.9.2.4.1	Saunas	(CSI 2014)
3.4.2.9.2.4.2	Steam Baths	(CSI 2014)
3.4.2.9.2.4.3	Athletic Rooms	(CSI 2014)
3.4.2.9.2.5	Fabricated Rooms	(CSI 2014)
3.4.2.9.2.5.1	Storm Shelter Rooms	(CSI 2014)
3.4.2.9.2.6	Vaults	(CSI 2014)
3.4.2.9.2.7	Athletic and Recreational Special Construction	(CSI 2014)
3.4.2.9.3	Special Structures	(CSI 2014)
3.4.2.9.3.1	Fabric Structures	(CSI 2014)
3.4.2.9.3.2	Space Frames	(CSI 2014)
3.4.2.9.3.3	Geodesic Structures	(CSI 2014)
3.4.2.9.3.4	Fabricated Engineered Structures	(CSI 2014)
3.4.2.9.3.5	Rammed Earth Construction	(CSI 2014)
3.4.2.9.3.6	Towers	(CSI 2014)
3.4.2.9.4	Integrated Construction	(CSI 2014)
3.4.2.9.4.1	Building Modules	(CSI 2014)
3.4.2.9.4.2	Modular Mezzanines	(CSI 2014)
3.4.2.9.4.3	Facility Protection	(CSI 2014)
3.4.2.9.4.4	Sound, Vibration, and Seismic Control	(CSI 2014)
3.4.2.9.4.5	Radiation Protection	(CSI 2014)
3.4.2.9.5	Special Instrumentation	(CSI 2014)
3.4.2.9.5.1	Stress Instrumentation	(CSI 2014)
3.4.2.9.5.2	Seismic Instrumentation	(CSI 2014)
3.4.2.9.5.3	Meteorological Instrumentation	(CSI 2014)
3.4.2.10	Exterior Improvements	(CSI 2014)
3.4.2.10.1	Bases, Ballasts, and Paving	(CSI 2014)
3.4.2.10.1.1	Base Courses	(CSI 2014)
3.4.2.10.1.2	Flexible Paving	(CSI 2014)
3.4.2.10.1.3	Rigid Paving	(CSI 2014)
3.4.2.10.1.4	Unit Paving	(CSI 2014)
3.4.2.10.1.5	Aggregate Surfacing	(CSI 2014)
3.4.2.10.1.6	Curbs, Gutters, Sidewalks, and Driveways	(CSI 2014)
3.4.2.10.1.7	Paving Specialties	(CSI 2014)
3.4.2.10.1.8	Athletic and Recreational Surfacing	(CSI 2014)
3.4.2.10.2	Site Improvements	(CSI 2014)
3.4.2.10.2.1	Fences and Gates	(CSI 2014)
3.4.2.10.2.2	Retaining Walls	(CSI 2014)
3.4.2.10.2.3	Site Furnishings	(CSI 2014)
3.4.2.10.2.4	Fabricated Bridges	(CSI 2014)
3.4.2.10.2.5	Screening Devices	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.2.10.2.6	Manufactured Site Specialties	(CSI 2014)
3.4.2.10.3	Wetlands	(CSI 2014)
3.4.2.10.3.1	Constructed Wetlands	(CSI 2014)
3.4.2.10.3.2	Wetlands Restoration	(CSI 2014)
3.4.2.10.4	Irrigation	(CSI 2014)
3.4.2.10.4.1	Irrigation Components	(CSI 2014)
3.4.2.10.4.2	Irrigation Pumps	(CSI 2014)
3.4.2.10.4.3	Planting Irrigation	(CSI 2014)
3.4.2.10.4.4	Agricultural Irrigation	(CSI 2014)
3.4.2.10.5	Planting	(CSI 2014)
3.4.2.10.5.1	Planting Preparation	(CSI 2014)
3.4.2.10.5.2	Turf and Grasses	(CSI 2014)
3.4.2.10.5.3	Plants	(CSI 2014)
3.4.2.10.5.4	Planting Accessories	(CSI 2014)
3.4.2.10.5.5	Exterior Planting Support Structures	(CSI 2014)
3.4.2.10.5.6	Transplanting	(CSI 2014)
3.4.2.11	Specialities and Equipment	(CSI 2014)
3.4.2.11.1	Specialties	(CSI 2014)
3.4.2.11.1.1	Information Specialties	(CSI 2014)
3.4.2.11.1.1.1	Visual Display Units	(CSI 2014)
3.4.2.11.1.1.2	Display Cases	(CSI 2014)
3.4.2.11.1.1.3	Directories	(CSI 2014)
3.4.2.11.1.1.4	Signage	(CSI 2014)
3.4.2.11.1.1.5	Telephone Specialties	(CSI 2014)
3.4.2.11.1.1.6	Informational Kiosks	(CSI 2014)
3.4.2.11.1.2	Interior Specialties	(CSI 2014)
3.4.2.11.1.2.1	Compartments and Cubicles	(CSI 2014)
3.4.2.11.1.2.2	Partitions	(CSI 2014)
3.4.2.11.1.2.3	Service Walls	(CSI 2014)
3.4.2.11.1.2.4	Wall and Door Protection	(CSI 2014)
3.4.2.11.1.2.5	Toilet, Bath, and Laundry Accessories	(CSI 2014)
3.4.2.11.1.3	Fireplaces and Stoves	(CSI 2014)
3.4.2.11.1.3.1	Manufactured Fireplaces	(CSI 2014)
3.4.2.11.1.3.2	Fireplace Specialties	(CSI 2014)
3.4.2.11.1.3.3	Stoves	(CSI 2014)
3.4.2.11.1.4	Safety Specialties	(CSI 2014)
3.4.2.11.1.4.1	Emergency Access and Information Cabinets	(CSI 2014)
3.4.2.11.1.4.2	Emergency Aid Specialties	(CSI 2014)
3.4.2.11.1.4.3	Fire Protection Specialties	(CSI 2014)
3.4.2.11.1.4.4	Photoluminescent Exit Specialties	(CSI 2014)
3.4.2.11.1.5	Storage Specialties	(CSI 2014)
3.4.2.11.1.5.1	Lockers	(CSI 2014)
3.4.2.11.1.5.2	Postal Specialties	(CSI 2014)
3.4.2.11.1.5.3	Storage Assemblies	(CSI 2014)
3.4.2.11.1.5.4	Wardrobe and Closet Specialties	(CSI 2014)
3.4.2.11.1.6	Exterior Specialties	(CSI 2014)
3.4.2.11.1.6.1	Exterior Protection	(CSI 2014)
3.4.2.11.1.6.2	Protective Covers	(CSI 2014)
3.4.2.11.1.6.3	Manufactured Exterior Specialties	(CSI 2014)
3.4.2.11.1.6.4	Flagpoles	(CSI 2014)
3.4.2.11.1.7	Other Specialties	(CSI 2014)
3.4.2.11.1.7.1	Pest Control Devices	(CSI 2014)
3.4.2.11.1.7.2	Grilles and Screens	(CSI 2014)
3.4.2.11.1.7.3	Flags and Banners	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.2.11.1.7.4	Gas Lighting	(CSI 2014)
3.4.2.11.1.7.5	Security Mirrors and Domes	(CSI 2014)
3.4.2.11.1.7.6	Scales	(CSI 2014)
3.4.2.11.2	Equipment	(CSI 2014)
3.4.2.11.2.1	Vehicle and Pedestrian Equipment	(CSI 2014)
3.4.2.11.2.1.1	Vehicle Service Equipment	(CSI 2014)
3.4.2.11.2.1.2	Parking Control Equipment	(CSI 2014)
3.4.2.11.2.1.3	Loading Dock Equipment	(CSI 2014)
3.4.2.11.2.1.4	Pedestrian Control Equipment	(CSI 2014)
3.4.2.11.2.2	Commercial Equipment	(CSI 2014)
3.4.2.11.2.2.1	Retail and Service Equipment	(CSI 2014)
3.4.2.11.2.2.2	Banking Equipment	(CSI 2014)
3.4.2.11.2.2.3	Hospitality Equipment	(CSI 2014)
3.4.2.11.2.2.4	Office Equipment	(CSI 2014)
3.4.2.11.2.2.5	Postal, Packaging, and Shipping Equipment	(CSI 2014)
3.4.2.11.2.3	Residential Equipment	(CSI 2014)
3.4.2.11.2.3.1	Unit Kitchens	(CSI 2014)
3.4.2.11.2.4	Foodservice Equipment	(CSI 2014)
3.4.2.11.2.4.1	Foodservice Storage Equipment	(CSI 2014)
3.4.2.11.2.4.2	Food Preparation Equipment	(CSI 2014)
3.4.2.11.2.4.3	Food Delivery Carts and Conveyors	(CSI 2014)
3.4.2.11.2.4.4	Food Cooking Equipment	(CSI 2014)
3.4.2.11.2.4.5	Food Dispensing Equipment	(CSI 2014)
3.4.2.11.2.4.6	Foodservice Cleaning and Disposal Equipment	(CSI 2014)
3.4.2.11.2.5	Educational and Scientific Equipment	(CSI 2014)
3.4.2.11.2.5.1	Library Equipment	(CSI 2014)
3.4.2.11.2.5.2	Audio-Visual Equipment	(CSI 2014)
3.4.2.11.2.5.3	Laboratory Equipment	(CSI 2014)
3.4.2.11.2.5.4	Planetarium Equipment	(CSI 2014)
3.4.2.11.2.5.5	Observatory Equipment	(CSI 2014)
3.4.2.11.2.5.6	Vocational Shop Equipment	(CSI 2014)
3.4.2.11.2.5.7	Exhibit Equipment	(CSI 2014)
3.4.2.11.2.6	Entertainment and Recreation Equipment	(CSI 2014)
3.4.2.11.2.6.1	Broadcast, Theater, and Stage Equipment	(CSI 2014)
3.4.2.11.2.6.2	Musical Equipment	(CSI 2014)
3.4.2.11.2.6.3	Athletic Equipment	(CSI 2014)
3.4.2.11.2.6.4	Recreational Equipment	(CSI 2014)
3.4.2.11.2.6.5	Play Field Equipment and Structures	(CSI 2014)
3.4.2.11.2.7	Healthcare Equipment	(CSI 2014)
3.4.2.11.2.7.1	Medical Sterilizing Equipment	(CSI 2014)
3.4.2.11.2.7.2	Examination and Treatment Equipment	(CSI 2014)
3.4.2.11.2.7.3	Patient Care Equipment	(CSI 2014)
3.4.2.11.2.7.4	Dental Equipment	(CSI 2014)
3.4.2.11.2.7.5	Optical Equipment	(CSI 2014)
3.4.2.11.2.7.6	Operating Room Equipment	(CSI 2014)
3.4.2.11.2.7.7	Radiology Equipment	(CSI 2014)
3.4.2.11.2.7.8	Mortuary Equipment	(CSI 2014)
3.4.2.11.2.7.9	Therapy Equipment	(CSI 2014)
3.4.2.11.2.8	Facility Maintenance and Operation Equipment	(CSI 2014)
3.4.2.11.2.8.1	Facility Maintenance Equipment	(CSI 2014)
3.4.2.11.2.8.2	Facility Solid Waste Handling Equipment	(CSI 2014)
3.4.2.11.2.9	Other Equipment	(CSI 2014)
3.4.2.11.2.9.1	Religious Equipment	(CSI 2014)
3.4.2.11.2.9.2	Agricultural Equipment	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.2.11.2.9.3	Horticultural Equipment	(CSI 2014)
3.4.2.11.2.9.4	Veterinary Equipment	(CSI 2014)
3.4.2.11.2.9.5	Arts and Crafts Equipment	(CSI 2014)
3.4.2.11.2.9.6	Security Equipment	(CSI 2014)
3.4.2.11.2.9.7	Detention Equipment	(CSI 2014)
3.4.2.12	Furnishings	(CSI 2014)
3.4.2.12.1	Art	(CSI 2014)
3.4.2.12.1.1	Murals	(CSI 2014)
3.4.2.12.1.2	Wall Decorations	(CSI 2014)
3.4.2.12.1.3	Sculptures	(CSI 2014)
3.4.2.12.1.4	Art Glass	(CSI 2014)
3.4.2.12.1.5	Religious Art	(CSI 2014)
3.4.2.12.2	Window Treatments	(CSI 2014)
3.4.2.12.2.1	Window Blinds	(CSI 2014)
3.4.2.12.2.2	Curtains and Drapes	(CSI 2014)
3.4.2.12.2.3	Interior Shutters	(CSI 2014)
3.4.2.12.2.4	Window Shades	(CSI 2014)
3.4.2.12.2.5	Window Treatment Operating Hardware	(CSI 2014)
3.4.2.12.2.6	Interior Daylighting Devices	(CSI 2014)
3.4.2.12.3	Casework	(CSI 2014)
3.4.2.12.3.1	Manufactured Metal Casework	(CSI 2014)
3.4.2.12.3.2	Manufactured Wood Casework	(CSI 2014)
3.4.2.12.3.3	Manufactured Plastic Casework	(CSI 2014)
3.4.2.12.3.4	Specialty Casework	(CSI 2014)
3.4.2.12.3.5	Countertops	(CSI 2014)
3.4.2.12.3.6	Furnishings and Accessories	(CSI 2014)
3.4.2.12.3.7	Office Accessories	(CSI 2014)
3.4.2.12.3.8	Table Accessories	(CSI 2014)
3.4.2.12.3.9	Portable Lamps	(CSI 2014)
3.4.2.12.3.10	Bath Furnishings	(CSI 2014)
3.4.2.12.3.11	Bedroom Furnishings	(CSI 2014)
3.4.2.12.3.12	Furnishing Accessories	(CSI 2014)
3.4.2.12.3.13	Rugs and Mats	(CSI 2014)
3.4.2.12.4	Furniture	(CSI 2014)
3.4.2.12.4.1	Office Furniture	(CSI 2014)
3.4.2.12.4.2	Seating	(CSI 2014)
3.4.2.12.4.3	Retail Furniture	(CSI 2014)
3.4.2.12.4.4	Hospitality Furniture	(CSI 2014)
3.4.2.12.4.5	Detention Furniture	(CSI 2014)
3.4.2.12.4.6	Institutional Furniture	(CSI 2014)
3.4.2.12.4.7	Industrial Furniture	(CSI 2014)
3.4.2.12.4.8	Residential Furniture	(CSI 2014)
3.4.2.12.4.9	Systems Furniture	(CSI 2014)
3.4.2.12.5	Multiple Seating	(CSI 2014)
3.4.2.12.5.1	Fixed Audience Seating	(CSI 2014)
3.4.2.12.5.2	Portable Audience Seating	(CSI 2014)
3.4.2.12.5.3	Stadium and Arena Seating	(CSI 2014)
3.4.2.12.5.4	Booths and Tables	(CSI 2014)
3.4.2.12.5.5	Multiple-Use Fixed Seating	(CSI 2014)
3.4.2.12.5.6	Telescoping Stands	(CSI 2014)
3.4.2.12.5.7	Pews and Benches	(CSI 2014)
3.4.2.12.5.8	Seat and Table Assemblies	(CSI 2014)
3.4.2.12.6	Other Furnishings	(CSI 2014)
3.4.2.12.6.1	Interior Planters and Artificial Plants	(CSI 2014)
3.4.2.12.6.2	Interior Public Space Furnishings	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.3	Conveying Equipment	(CSI 2014)
3.4.3.1	Dumbwaiters	(CSI 2014)
3.4.3.1.1	Manual Dumbwaiters	(CSI 2014)
3.4.3.1.2	Electric Dumbwaiters	(CSI 2014)
3.4.3.1.3	Hydraulic Dumbwaiters	(CSI 2014)
3.4.3.2	Elevators	(CSI 2014)
3.4.3.2.1	Electric Traction Elevators	(CSI 2014)
3.4.3.2.2	Hydraulic Elevators	(CSI 2014)
3.4.3.2.3	Limited-Use/Limited-Application Elevators	(CSI 2014)
3.4.3.2.4	Custom Elevator Cabs and Doors	(CSI 2014)
3.4.3.2.5	Elevator Equipment and Controls	(CSI 2014)
3.4.3.3	Escalators and Moving Walks	(CSI 2014)
3.4.3.3.1	Escalators	(CSI 2014)
3.4.3.3.2	Moving Walks	(CSI 2014)
3.4.3.3.3	Moving Ramps	(CSI 2014)
3.4.3.4	Lifts	(CSI 2014)
3.4.3.4.1	People Lifts	(CSI 2014)
3.4.3.4.2	Wheelchair Lifts	(CSI 2014)
3.4.3.4.3	Platform Lifts	(CSI 2014)
3.4.3.4.4	Sidewalk Lifts	(CSI 2014)
3.4.3.4.5	Vehicle Lifts	(CSI 2014)
3.4.3.5	Turntables	(CSI 2014)
3.4.3.5.1	Industrial Turntables	(CSI 2014)
3.4.3.5.2	Hospitality Turntables	(CSI 2014)
3.4.3.5.3	Exhibit Turntables	(CSI 2014)
3.4.3.5.4	Entertainment Turntables	(CSI 2014)
3.4.3.6	Scaffolding	(CSI 2014)
3.4.3.6.1	Suspended Scaffolding	(CSI 2014)
3.4.3.6.2	Rope Climbers	(CSI 2014)
3.4.3.6.3	Elevating Platforms	(CSI 2014)
3.4.3.6.4	Powered Scaffolding	(CSI 2014)
3.4.3.7	Other Conveying Equipment	(CSI 2014)
3.4.3.7.1	Facility Chutes	(CSI 2014)
3.4.3.7.2	Pneumatic Tube Systems	(CSI 2014)
3.4.3.7.3	Slide Pole Systems	(CSI 2014)
3.4.4	Mechanical Systems	(CSI 2014)
3.4.4.1	Fire Suppression	(CSI 2014)
3.4.4.1.1	Fire Suppression Systems Insulation	(CSI 2014)
3.4.4.1.2	Instrumentation and Control for Fire-Suppression Systems	(CSI 2014)
3.4.4.1.3	Water-Based Fire-Suppression Systems	(CSI 2014)
3.4.4.1.3.1	Facility Fire-Suppression Water-Service Piping	(CSI 2014)
3.4.4.1.3.2	Fire-Suppression Standpipes	(CSI 2014)
3.4.4.1.3.3	Fire-Suppression Sprinkler Systems	(CSI 2014)
3.4.4.1.3.4	Fire-Suppression Pressure Maintenance Pumps	(CSI 2014)
3.4.4.1.4	Fire-Extinguishing Systems	(CSI 2014)
3.4.4.1.4.1	Carbon-Dioxide Fire-Extinguishing Systems	(CSI 2014)
3.4.4.1.4.2	Clean-Agent Fire-Extinguishing Systems	(CSI 2014)
3.4.4.1.4.3	Wet-Chemical Fire-Extinguishing Systems	(CSI 2014)
3.4.4.1.4.4	Dry-Chemical Fire-Extinguishing Systems	(CSI 2014)
3.4.4.1.5	Fire Pumps	(CSI 2014)
3.4.4.1.5.1	Centrifugal Fire Pumps	(CSI 2014)
3.4.4.1.5.2	Vertical-Turbine Fire Pumps	(CSI 2014)
3.4.4.1.5.3	Positive-Displacement Fire Pumps	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	**Tag**	**Resource**
3.4.4.1.6	Fire-Suppression Water Storage	(CSI 2014)
3.4.4.1.6.1	Storage Tanks for Fire-Suppression Water	(CSI 2014)
3.4.4.2	Plumbing	(CSI 2014)
3.4.4.2.1	Plumbing Insulation	(CSI 2014)
3.4.4.2.2	Instrumentation and Control for Plumbing	(CSI 2014)
3.4.4.2.3	Plumbing Piping	(CSI 2014)
3.4.4.2.4	Facility Water Distribution	(CSI 2014)
3.4.4.2.4.1	Facility Potable-Water Storage Tanks	(CSI 2014)
3.4.4.2.4.2	Facility Sanitary Sewerage	(CSI 2014)
3.4.4.2.4.3	Facility Storm Drainage	(CSI 2014)
3.4.4.2.4.4	General Service Compressed-Air Systems	(CSI 2014)
3.4.4.2.5	Plumbing Equipment	(CSI 2014)
3.4.4.2.5.1	Domestic Water Softeners	(CSI 2014)
3.4.4.2.5.2	Domestic Water Filtration Equipment	(CSI 2014)
3.4.4.2.5.3	Electric Domestic Water Heaters	(CSI 2014)
3.4.4.2.5.4	Fuel-Fired Domestic Water Heaters	(CSI 2014)
3.4.4.2.5.5	Domestic Water Heat Exchangers	(CSI 2014)
3.4.4.2.5.6	Domestic Water Preheaters	(CSI 2014)
3.4.4.2.6	Plumbing Fixtures	(CSI 2014)
3.4.4.2.6.1	Residential Plumbing Fixtures	(CSI 2014)
3.4.4.2.6.2	Commercial Plumbing Fixtures	(CSI 2014)
3.4.4.2.6.3	Healthcare Plumbing Fixtures	(CSI 2014)
3.4.4.2.6.4	Emergency Plumbing Fixtures	(CSI 2014)
3.4.4.2.6.5	Security Plumbing Fixtures	(CSI 2014)
3.4.4.2.6.6	Drinking Fountains and Water Coolers	(CSI 2014)
3.4.4.2.7	Pool and Fountain Plumbing Systems	(CSI 2014)
3.4.4.2.7.1	Swimming Pool Plumbing Systems	(CSI 2014)
3.4.4.2.7.2	Fountain Plumbing Systems	(CSI 2014)
3.4.4.2.8	Gas and Vacuum Systems for Laboratory and Healthcare Facilities	(CSI 2014)
3.4.4.2.8.1	Compressed-Air Systems for Laboratory and Healthcare Facilities	(CSI 2014)
3.4.4.2.8.2	Vacuum Systems for Laboratory and Healthcare Facilities	(CSI 2014)
3.4.4.2.8.3	Gas Systems for Laboratory and Healthcare Facilities	(CSI 2014)
3.4.4.2.8.4	Chemical-Waste Systems for Laboratory and Healthcare Facilities	(CSI 2014)
3.4.4.2.8.5	Processed Water Systems for Laboratory and Healthcare Facilities	(CSI 2014)
3.4.4.3	Heating, Ventilating, and Air Conditioning (HVAC)	(CSI 2014)
3.4.4.3.1	HVAC Insulation	(CSI 2014)
3.4.4.3.2	Instrumentation and Control for HVAC	(CSI 2014)
3.4.4.3.3	Facility Fuel Systems	(CSI 2014)
3.4.4.3.3.1	Facility Fuel Piping	(CSI 2014)
3.4.4.3.3.2	Facility Fuel Pumps	(CSI 2014)
3.4.4.3.3.3	Facility Fuel-Storage Tanks	(CSI 2014)
3.4.4.3.4	HVAC Piping and Pumps	(CSI 2014)
3.4.4.3.4.1	Hydronic Piping and Pumps	(CSI 2014)
3.4.4.3.4.2	Steam and Condensate Piping and Pumps	(CSI 2014)
3.4.4.3.4.3	Refrigerant Piping	(CSI 2014)
3.4.4.3.4.4	Internal-Combustion Engine Piping	(CSI 2014)
3.4.4.3.4.5	HVAC Water Treatment	(CSI 2014)
3.4.4.3.5	HVAC Air Distribution	(CSI 2014)
3.4.4.3.5.1	HVAC Ducts and Casings	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.4.3.5.2	Air Plenums and Chases	(CSI 2014)
3.4.4.3.5.3	Air Duct Accessories	(CSI 2014)
3.4.4.3.5.4	HVAC Fans	(CSI 2014)
3.4.4.3.5.5	Special Exhaust Systems	(CSI 2014)
3.4.4.3.5.6	Air Terminal Units	(CSI 2014)
3.4.4.3.5.7	Air Outlets and Inlets	(CSI 2014)
3.4.4.3.5.8	Ventilation Hoods	(CSI 2014)
3.4.4.3.6	HVAC Air Cleaning Devices	(CSI 2014)
3.4.4.3.6.1	Particulate Air Filtration	(CSI 2014)
3.4.4.3.6.2	Gas-Phase Air Filtration	(CSI 2014)
3.4.4.3.6.3	Electronic Air Cleaners	(CSI 2014)
3.4.4.3.7	Central Heating Equipment	(CSI 2014)
3.4.4.3.7.1	Breechings, Chimneys, and Stacks	(CSI 2014)
3.4.4.3.7.2	Heating Boilers	(CSI 2014)
3.4.4.3.7.3	Heating Boiler Feedwater Equipment	(CSI 2014)
3.4.4.3.7.4	Furnaces	(CSI 2014)
3.4.4.3.7.5	Fuel-Fired Heaters	(CSI 2014)
3.4.4.3.7.6	Solar Energy Heating Equipment	(CSI 2014)
3.4.4.3.7.7	Heat Exchangers for HVAC	(CSI 2014)
3.4.4.3.8	Central Cooling Equipment	(CSI 2014)
3.4.4.3.8.1	Refrigerant Compressors	(CSI 2014)
3.4.4.3.8.2	Packaged Compressor and Condenser Units	(CSI 2014)
3.4.4.3.8.3	Refrigerant Condensers	(CSI 2014)
3.4.4.3.8.4	Packaged Water Chillers	(CSI 2014)
3.4.4.3.8.5	Cooling Towers	(CSI 2014)
3.4.4.3.9	Central HVAC Equipment	(CSI 2014)
3.4.4.3.9.1	Thermal Storage	(CSI 2014)
3.4.4.3.9.2	Air-to-Air Energy Recovery Equipment	(CSI 2014)
3.4.4.3.9.3	Indoor Central-Station Air-Handling Units	(CSI 2014)
3.4.4.3.9.4	Packaged Outdoor HVAC Equipment	(CSI 2014)
3.4.4.3.9.5	Custom-Packaged Outdoor HVAC Equipment	(CSI 2014)
3.4.4.3.9.6	Evaporative Air-Cooling Equipment	(CSI 2014)
3.4.4.3.10	Decentralized HVAC Equipment	(CSI 2014)
3.4.4.3.10.1	Decentralized Unitary HVAC Equipment	(CSI 2014)
3.4.4.3.10.2	Convection Heating and Cooling Units	(CSI 2014)
3.4.4.3.10.3	Radiant Heating Units	(CSI 2014)
3.4.4.3.10.4	Humidity Control Equipment	(CSI 2014)
3.4.4.4	Process Interconnections	(CSI 2014)
3.4.4.4.1	Gas and Vapor Process Piping and Ductwork	(CSI 2014)
3.4.4.4.1.1	Steam Process Piping	(CSI 2014)
3.4.4.4.1.2	Compressed Air Process Piping	(CSI 2014)
3.4.4.4.1.3	Process Ductwork	(CSI 2014)
3.4.4.4.1.4	Combustion System Gas Piping	(CSI 2014)
3.4.4.4.1.5	Specialty and High-Purity Gases Piping	(CSI 2014)
3.4.4.4.1.6	Welding and Cutting Gases Piping	(CSI 2014)
3.4.4.4.1.7	Vacuum Systems Process Piping	(CSI 2014)
3.4.4.4.2	Liquids Process Piping	(CSI 2014)
3.4.4.4.2.1	Liquid Fuel Process Piping	(CSI 2014)
3.4.4.4.2.2	Petroleum Products Piping	(CSI 2014)
3.4.4.4.2.3	Water and Wastewater Process Piping	(CSI 2014)
3.4.4.4.2.4	Specialty Liquid Chemicals Piping	(CSI 2014)
3.4.4.4.2.5	Liquid Acids and Bases Piping	(CSI 2014)
3.4.4.4.2.6	Liquid Polymer Piping	(CSI 2014)
3.4.4.4.3	Solid and Mixed Materials Piping and Chutes	(CSI 2014)
3.4.4.4.3.1	Bulk Materials Piping and Chutes	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.4.4.3.2	Bulk Materials Valves	(CSI 2014)
3.4.4.4.3.3	Pneumatic Conveying Lines	(CSI 2014)
3.4.4.4.4	Process Piping and Equipment Protection	(CSI 2014)
3.4.4.4.4.1	Process Piping and Equipment Heat Tracing	(CSI 2014)
3.4.4.4.4.2	Process Piping and Equipment Insulation	(CSI 2014)
3.4.4.4.4.3	Process Corrosion Protection	(CSI 2014)
3.4.4.4.4.4	Refractories	(CSI 2014)
3.4.4.4.5	Process Control and Enterprise Management Systems	(CSI 2014)
3.4.4.4.5.1	Process Control and Enterprise Management Systems General Provisions	(CSI 2014)
3.4.4.4.5.2	Computer System Hardware and Ancillaries	(CSI 2014)
3.4.4.4.5.3	Control System Equipment	(CSI 2014)
3.4.4.4.5.4	Network and Communication Equipment	(CSI 2014)
3.4.4.4.5.5	Control System Equipment Panels and Racks	(CSI 2014)
3.4.4.4.5.6	Process Control Software	(CSI 2014)
3.4.4.4.5.7	Packaged Control Systems	(CSI 2014)
3.4.4.4.6	Instrumentation for Process Systems	(CSI 2014)
3.4.4.4.6.1	Flow Measurement	(CSI 2014)
3.4.4.4.6.2	Level Measurement	(CSI 2014)
3.4.4.4.6.3	Pressure, Strain, and Force Measurement	(CSI 2014)
3.4.4.4.6.4	Temperature Measurement	(CSI 2014)
3.4.4.4.6.5	Process Liquid Analytical Measurement	(CSI 2014)
3.4.4.4.6.6	Process Gas Analytical Measurement	(CSI 2014)
3.4.4.4.6.7	Position and Motion Measurement	(CSI 2014)
3.4.4.4.6.8	Panel Mounted Instruments	(CSI 2014)
3.4.4.4.6.9	Miscellaneous Instruments, Calibration Equipment, Instrument Valves, and Fittings	(CSI 2014)
3.4.4.4.7	Commissioning of Process Systems	(CSI 2014)
3.4.4.4.8	Primary Control Devices	(CSI 2014)
3.4.4.4.8.1	Primary Control Valves	(CSI 2014)
3.4.4.4.8.2	Self-Contained Flow Controllers	(CSI 2014)
3.4.4.4.8.3	Linear Actuators and Positioners	(CSI 2014)
3.4.4.4.8.4	Self-Contained Pressure Regulators	(CSI 2014)
3.4.4.4.8.5	Rotary Actuators	(CSI 2014)
3.4.4.4.8.6	Saturable Core Reactors	(CSI 2014)
3.4.4.4.8.7	Variable Frequency Drives	(CSI 2014)
3.4.5	Electrical, Communication and Automation Systems	(CSI 2014)
3.4.5.1	Integrated Automation	(CSI 2014)
3.4.5.1.1	Integrated Automation Network Equipment	(CSI 2014)
3.4.5.1.1.1	Integrated Automation Network Devices	(CSI 2014)
3.4.5.1.1.2	Integrated Automation Network Gateways	(CSI 2014)
3.4.5.1.1.3	Integrated Automation Control and Monitoring Network	(CSI 2014)
3.4.5.1.1.4	Integrated Automation Local Control Units	(CSI 2014)
3.4.5.1.1.5	Integrated Automation Software	(CSI 2014)
3.4.5.1.2	Integrated Automation Instrumentation and Terminal Devices	(CSI 2014)
3.4.5.1.2.1	Integrated Automation Instrumentation and Terminal Devices for Facility Equipment	(CSI 2014)
3.4.5.1.2.2	Integrated Automation Instrumentation and Terminal Devices for Conveying Equipment	(CSI 2014)
3.4.5.1.2.3	Integrated Automation Instrumentation and Terminal Devices for Fire-Suppression Systems	(CSI 2014)
3.4.5.1.2.4	Integrated Automation Instrumentation and Terminal Devices for Plumbing	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.5.1.2.5	Integrated Automation Instrumentation and Terminal Devices for HVAC	(CSI 2014)
3.4.5.1.2.6	Integrated Automation Instrumentation and Terminal Devices for Electrical Systems	(CSI 2014)
3.4.5.1.2.7	Integrated Automation Instrumentation and Terminal Devices for Communications Systems	(CSI 2014)
3.4.5.1.2.8	Integrated Automation Instrumentation and Terminal Devices for Electronic Safety and Security Systems	(CSI 2014)
3.4.5.1.3	Integrated Automation Facility Controls	(CSI 2014)
3.4.5.1.3.1	Integrated Automation Control of Facility Equipment	(CSI 2014)
3.4.5.1.3.2	Integrated Automation Control of Conveying Equipment	(CSI 2014)
3.4.5.1.3.3	Integrated Automation Control of Fire-Suppression Systems	(CSI 2014)
3.4.5.1.3.4	Integrated Automation Control of Plumbing	(CSI 2014)
3.4.5.1.3.5	Integrated Automation Control of HVAC	(CSI 2014)
3.4.5.1.3.6	Integrated Automation Control of Electrical Systems	(CSI 2014)
3.4.5.1.3.7	Integrated Automation Control of Communications Systems	(CSI 2014)
3.4.5.1.3.8	Integrated Automation Control of Electronic Safety and Security Systems	(CSI 2014)
3.4.5.1.4	Integrated Automation Control Sequences	(CSI 2014)
3.4.5.1.4.1	Integrated Automation Control Sequences for Facility Equipment	(CSI 2014)
3.4.5.1.4.2	Integrated Automation Control Sequences for Conveying Equipment	(CSI 2014)
3.4.5.1.4.3	Integrated Automation Control Sequences for Fire- Suppression Systems	(CSI 2014)
3.4.5.1.4.4	Integrated Automation Control Sequences for Plumbing	(CSI 2014)
3.4.5.1.4.5	Integrated Automation Control Sequences for HVAC	(CSI 2014)
3.4.5.1.4.6	Integrated Automation Control Sequences for Electrical Systems	(CSI 2014)
3.4.5.1.4.7	Integrated Automation Control Sequences for Communications Systems	(CSI 2014)
3.4.5.1.4.8	Integrated Automation Control Sequences for Electronic Safety and Security Systems	(CSI 2014)
3.4.5.2	Electrical	(CSI 2014)
3.4.5.2.1	Medium-Voltage Electrical Distribution	(CSI 2014)
3.4.5.2.1.1	Substations	(CSI 2014)
3.4.5.2.1.2	Medium-Voltage Transformers	(CSI 2014)
3.4.5.2.1.3	Medium-Voltage Switchgear	(CSI 2014)
3.4.5.2.1.4	Medium-Voltage Metering	(CSI 2014)
3.4.5.2.1.5	Medium-Voltage Circuit Protection Devices	(CSI 2014)
3.4.5.2.2	Low-Voltage Electrical Transmission	(CSI 2014)
3.4.5.2.2.1	Low-Voltage Electrical Service Entrance	(CSI 2014)
3.4.5.2.2.2	Low-Voltage Transformers	(CSI 2014)
3.4.5.2.2.3	Low-Voltage Switchgear	(CSI 2014)
3.4.5.2.2.4	Switchboards and Panelboards	(CSI 2014)
3.4.5.2.2.5	Enclosed Bus Assemblies	(CSI 2014)
3.4.5.2.2.6	Power Distribution Units	(CSI 2014)
3.4.5.2.2.7	Low-Voltage Distribution Equipment	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.5.2.2.8	Low-Voltage Circuit Protective Devices	(CSI 2014)
3.4.5.2.2.9	Low-Voltage Controllers	(CSI 2014)
3.4.5.2.3	Facility Electrical Power Generating and Storing Equipment	(CSI 2014)
3.4.5.2.3.1	Photovoltaic Collectors	(CSI 2014)
3.4.5.2.3.2	Packaged Generator Assemblies	(CSI 2014)
3.4.5.2.3.3	Battery Equipment	(CSI 2014)
3.4.5.2.3.4	Power Filters and Conditioners	(CSI 2014)
3.4.5.2.3.5	Transfer Switches	(CSI 2014)
3.4.5.2.4	Electrical Protection	(CSI 2014)
3.4.5.2.4.1	Facility Lightning Protection	(CSI 2014)
3.4.5.2.4.2	Surge Protective Devices	(CSI 2014)
3.4.5.2.5	Lighting	(CSI 2014)
3.4.5.2.5.1	Interior Lighting	(CSI 2014)
3.4.5.2.5.2	Emergency Lighting	(CSI 2014)
3.4.5.2.5.3	Exit Signs	(CSI 2014)
3.4.5.2.5.4	Classified Location Lighting	(CSI 2014)
3.4.5.2.5.5	Special Purpose Lighting	(CSI 2014)
3.4.5.2.5.6	Exterior Lighting	(CSI 2014)
3.4.5.3	Communications	(CSI 2014)
3.4.5.3.1	Structured Cabling	(CSI 2014)
3.4.5.3.1.1	Communications Equipment Room Fittings	(CSI 2014)
3.4.5.3.1.2	Communications Backbone Cabling	(CSI 2014)
3.4.5.3.1.3	Communications Horizontal Cabling	(CSI 2014)
3.4.5.3.1.4	Communications Connecting Cords, Devices, and Adapters	(CSI 2014)
3.4.5.3.2	Data Communications	(CSI 2014)
3.4.5.3.2.1	Data Communications Network Equipment	(CSI 2014)
3.4.5.3.2.2	Data Communications Hardware	(CSI 2014)
3.4.5.3.2.3	Data Communications Peripheral Data Equipment	(CSI 2014)
3.4.5.3.2.4	Data Communications Software	(CSI 2014)
3.4.5.3.2.5	Data Communications Programming and Integration Services	(CSI 2014)
3.4.5.3.3	Voice Communications	(CSI 2014)
3.4.5.3.3.1	Voice Communications Switching and Routing Equipment	(CSI 2014)
3.4.5.3.3.2	Voice Communications Terminal Equipment	(CSI 2014)
3.4.5.3.3.3	Voice Communications Messaging	(CSI 2014)
3.4.5.3.3.4	Call Accounting	(CSI 2014)
3.4.5.3.3.5	Call Management	(CSI 2014)
3.4.5.3.4	Audio-Video Communications	(CSI 2014)
3.4.5.3.4.1	Audio-Video Systems	(CSI 2014)
3.4.5.3.4.2	Electronic Digital Systems	(CSI 2014)
3.4.5.3.5	Distributed Communications and Monitoring Systems	(CSI 2014)
3.4.5.3.5.1	Distributed Audio-Video Communications Systems	(CSI 2014)
3.4.5.3.5.2	Healthcare Communications and Monitoring Systems	(CSI 2014)
3.4.5.3.5.3	Distributed Systems	(CSI 2014)
3.4.5.4	Electronic Safety and Security	(CSI 2014)
3.4.5.4.1	Electronic Access Control and Intrusion Detection	(CSI 2014)
3.4.5.4.1.1	Access Control	(CSI 2014)
3.4.5.4.1.2	Intrusion Detection	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.5.4.2	Electronic Surveillance	(CSI 2014)
3.4.5.4.2.1	Video Surveillance	(CSI 2014)
3.4.5.4.2.2	Electronic Personal Protection Systems	(CSI 2014)
3.4.5.4.3	Electronic Detection and Alarm	(CSI 2014)
3.4.5.4.3.1	Fire Detection and Alarm	(CSI 2014)
3.4.5.4.3.2	Radiation Detection and Alarm	(CSI 2014)
3.4.5.4.3.3	Gas Detection and Alarm	(CSI 2014)
3.4.5.4.3.4	Fuel-Oil Detection and Alarm	(CSI 2014)
3.4.5.4.3.5	Refrigerant Detection and Alarm	(CSI 2014)
3.4.5.4.3.6	Water Detection and Alarm	(CSI 2014)
3.4.5.4.3.7	Mass Notification Systems	(CSI 2014)
3.4.5.4.4	Electronic Monitoring and Control	(CSI 2014)
3.4.5.4.4.1	Electronic Structural Monitoring Systems	(CSI 2014)
3.4.5.4.4.2	Electronic Detention Monitoring and Control Systems	(CSI 2014)
3.4.6	Utilities	(CSI 2014)
3.4.6.1	Water Utilities	(CSI 2014)
3.4.6.1.1	Water Utility Distribution Piping	(CSI 2014)
3.4.6.1.2	Water Utility Distribution Equipment	(CSI 2014)
3.4.6.1.3	Disinfecting of Water Utility Distribution	(CSI 2014)
3.4.6.1.4	Water Utility Storage Tanks	(CSI 2014)
3.4.6.2	Wells	(CSI 2014)
3.4.6.2.1	Water Supply Wells	(CSI 2014)
3.4.6.2.2	Test Wells	(CSI 2014)
3.4.6.2.3	Extraction Wells	(CSI 2014)
3.4.6.2.4	Monitoring Wells	(CSI 2014)
3.4.6.2.5	Recharge Wells	(CSI 2014)
3.4.6.2.6	Relief Wells	(CSI 2014)
3.4.6.2.7	Well Abandonment	(CSI 2014)
3.4.6.3	Sanitary Sewerage Utilities	(CSI 2014)
3.4.6.3.1	Sanitary Utility Sewerage Piping	(CSI 2014)
3.4.6.3.2	Wastewater Utility Pumping Stations	(CSI 2014)
3.4.6.3.3	Low Pressure Utility Sewerage	(CSI 2014)
3.4.6.3.4	Sanitary Utility Sewerage Force Mains	(CSI 2014)
3.4.6.3.5	Utility Septic Tanks	(CSI 2014)
3.4.6.3.6	Overflow Control	(CSI 2014)
3.4.6.3.7	Treatment Lagoons	(CSI 2014)
3.4.6.3.8	Sanitary Utility Sewerage Structures	(CSI 2014)
3.4.6.4	Storm Drainage Utilities	(CSI 2014)
3.4.6.4.1	Storm Utility Drainage Piping	(CSI 2014)
3.4.6.4.2	Culverts	(CSI 2014)
3.4.6.4.3	Storm Utility Water Drains	(CSI 2014)
3.4.6.4.4	Storm Utility Drainage Pumps	(CSI 2014)
3.4.6.4.5	Subdrainage	(CSI 2014)
3.4.6.4.6	Ponds and Reservoirs	(CSI 2014)
3.4.6.4.7	Storm Drainage Structures	(CSI 2014)
3.4.6.5	Fuel Distribution Utilities	(CSI 2014)
3.4.6.5.1	Natural-Gas Distribution	(CSI 2014)
3.4.6.5.2	Liquid Fuel Distribution	(CSI 2014)
3.4.6.5.3	Fuel-Storage Tanks	(CSI 2014)
3.4.6.6	Hydronic and Steam Energy Utilities	(CSI 2014)
3.4.6.6.1	Hydronic Energy Distribution	(CSI 2014)
3.4.6.6.2	Steam Energy Distribution	(CSI 2014)
3.4.6.6.3	Electrical Utilities	(CSI 2014)
3.4.6.6.4	Electrical Utility Transmission and Distribution	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.6.6.5	Utility Substations	(CSI 2014)
3.4.6.6.6	Utility Transformers	(CSI 2014)
3.4.6.6.7	High-Voltage Switchgear and Protection Devices	(CSI 2014)
3.4.6.6.8	Medium-Voltage Utility Switchgear and Protection Devices	(CSI 2014)
3.4.6.6.9	Site Grounding	(CSI 2014)
3.4.6.7	Communications Utilities	(CSI 2014)
3.4.6.7.1	Communications Structures	(CSI 2014)
3.4.6.7.2	Communications Distribution	(CSI 2014)
3.4.6.7.3	Wireless Communications Distribution	(CSI 2014)
3.4.7	Transportation	(CSI 2014)
3.4.7.1	Guideways/Railways	(CSI 2014)
3.4.7.1.1	Rail Tracks	(CSI 2014)
3.4.7.1.2	Monorails	(CSI 2014)
3.4.7.1.3	Funiculars	(CSI 2014)
3.4.7.1.4	Cable Transportation	(CSI 2014)
3.4.7.2	Traction Power	(CSI 2014)
3.4.7.2.1	Traction Power Distribution	(CSI 2014)
3.4.7.2.2	Overhead Traction Power	(CSI 2014)
3.4.7.2.3	Third Rail Traction Power	(CSI 2014)
3.4.7.3	Transportation Signaling and Control Equipment	(CSI 2014)
3.4.7.3.1	Roadway Signaling and Control Equipment	(CSI 2014)
3.4.7.3.2	Railway Signaling and Control Equipment	(CSI 2014)
3.4.7.3.3	Airfield Signaling and Control Equipment	(CSI 2014)
3.4.7.3.4	Bridge Signaling and Control Equipment	(CSI 2014)
3.4.7.4	Transportation Fare Collection Equipment	(CSI 2014)
3.4.7.4.1	Vehicle Fare Collection	(CSI 2014)
3.4.7.4.2	Passenger Fare Collection	(CSI 2014)
3.4.7.5	Transportation Construction and Equipment	(CSI 2014)
3.4.7.5.1	Roadway Construction	(CSI 2014)
3.4.7.5.2	Railway Construction	(CSI 2014)
3.4.7.5.3	Airfield Construction	(CSI 2014)
3.4.7.5.4	Roadway Equipment	(CSI 2014)
3.4.7.5.5	Railway Equipment	(CSI 2014)
3.4.7.5.6	Transportation Equipment	(CSI 2014)
3.4.7.5.7	Weighing Equipment	(CSI 2014)
3.4.7.6	Bridges	(CSI 2014)
3.4.7.6.1	Bridge Machinery	(CSI 2014)
3.4.7.6.2	Bridge Specialties	(CSI 2014)
3.4.8	Waterway and Marine Construction	(CSI 2014)
3.4.8.1	Waterway and Marine Signaling and Control Equipment	(CSI 2014)
3.4.8.1.1	Signaling and Control Equipment for Waterways	(CSI 2014)
3.4.8.1.2	Marine Signaling and Control Equipment	(CSI 2014)
3.4.8.1.3	Signaling and Control Equipment for Dams	(CSI 2014)
3.4.8.2	Waterway and Marine Construction and Equipment	(CSI 2014)
3.4.8.2.1	Hydraulic Fabrications	(CSI 2014)
3.4.8.2.2	Hydraulic Gates	(CSI 2014)
3.4.8.2.3	Hydraulic Valves	(CSI 2014)
3.4.8.2.4	Dredging	(CSI 2014)
3.4.8.2.5	Waterway Construction and Equipment	(CSI 2014)
3.4.8.2.5.1	Levees	(CSI 2014)
3.4.8.2.5.2	Waterway Bank Protection	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.8.2.5.3	Waterway Scour Protection	(CSI 2014)
3.4.8.2.5.4	Waterway Structures	(CSI 2014)
3.4.8.2.6	Marine Construction and Equipment	(CSI 2014)
3.4.8.2.6.1	Floating Construction	(CSI 2014)
3.4.8.2.6.2	Offshore Platform Construction	(CSI 2014)
3.4.8.2.6.3	Underwater Construction	(CSI 2014)
3.4.8.2.6.4	Marine Specialties	(CSI 2014)
3.4.8.3	Dam Construction and Equipment	(CSI 2014)
3.4.8.3.1	Gravity Dams	(CSI 2014)
3.4.8.3.2	Arch Dams	(CSI 2014)
3.4.8.3.3	Embankment Dams	(CSI 2014)
3.4.8.3.4	Buttress Dams	(CSI 2014)
3.4.8.3.5	Auxiliary Dam Structures	(CSI 2014)
3.4.8.4	Coastal Construction	(CSI 2014)
3.4.8.4.1	Shoreline Protection	(CSI 2014)
3.4.8.4.1.1	Seawalls	(CSI 2014)
3.4.8.4.1.2	Revetments	(CSI 2014)
3.4.8.4.1.3	Breakwaters	(CSI 2014)
3.4.8.4.1.4	Jetties	(CSI 2014)
3.4.8.4.1.5	Groins	(CSI 2014)
3.4.8.4.2	Artificial Reefs	(CSI 2014)
3.4.9	Plant Equipment	(CSI 2014)
3.4.9.1	Material Processing and Handling Equipment	(CSI 2014)
3.4.9.1.1	Bulk Material Processing Equipment	(CSI 2014)
3.4.9.1.1.1	Bulk Material Sizing Equipment	(CSI 2014)
3.4.9.1.1.2	Bulk Material Conveying Equipment	(CSI 2014)
3.4.9.1.1.3	Bulk Material Feeders	(CSI 2014)
3.4.9.1.1.4	Batching Equipment	(CSI 2014)
3.4.9.1.2	Piece Material Handling Equipment	(CSI 2014)
3.4.9.1.2.1	Conveyors	(CSI 2014)
3.4.9.1.2.2	Cranes and Hoists	(CSI 2014)
3.4.9.1.2.3	Lifting Devices	(CSI 2014)
3.4.9.1.2.4	Specialty Material Handling Equipment	(CSI 2014)
3.4.9.1.3	Manufacturing Equipment	(CSI 2014)
3.4.9.1.3.1	Manufacturing Lines and Equipment	(CSI 2014)
3.4.9.1.3.2	Forming Equipment	(CSI 2014)
3.4.9.1.3.3	Machining Equipment	(CSI 2014)
3.4.9.1.3.4	Finishing Equipment	(CSI 2014)
3.4.9.1.3.5	Dies and Molds	(CSI 2014)
3.4.9.1.3.6	Assembly and Testing Equipment	(CSI 2014)
3.4.9.1.4	Container Processing and Packaging	(CSI 2014)
3.4.9.1.4.1	Container Filling and Sealing	(CSI 2014)
3.4.9.1.4.2	Container Packing Equipment	(CSI 2014)
3.4.9.1.4.3	Shipping Packaging	(CSI 2014)
3.4.9.1.5	Material Storage	(CSI 2014)
3.4.9.1.5.1	Automatic Material Storage	(CSI 2014)
3.4.9.1.5.2	Bulk Material Storage	(CSI 2014)
3.4.9.1.5.3	Storage Equipment and Systems	(CSI 2014)
3.4.9.1.6	Mobile Plant Equipment	(CSI 2014)
3.4.9.1.6.1	Mobile Earth Moving Equipment	(CSI 2014)
3.4.9.1.6.2	Trucks	(CSI 2014)
3.4.9.1.6.3	General Vehicles	(CSI 2014)
3.4.9.1.6.4	Rail Vehicles	(CSI 2014)
3.4.9.1.6.5	Mobile Support Equipment	(CSI 2014)
3.4.9.1.6.6	Miscellaneous Mobile Equipment	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	**Tag**	**Resource**
3.4.9.1.6.7	Plant Maintenance Equipment	(CSI 2014)
3.4.9.2	Process Heating, Cooling, and Drying Equipment	(CSI 2014)
3.4.9.2.1	Process Heating Equipment	(CSI 2014)
3.4.9.2.1.1	Process Boilers	(CSI 2014)
3.4.9.2.1.2	Process Heaters	(CSI 2014)
3.4.9.2.1.3	Industrial Heat Exchangers and Recuperators	(CSI 2014)
3.4.9.2.1.4	Industrial Furnaces	(CSI 2014)
3.4.9.2.1.5	Industrial Ovens	(CSI 2014)
3.4.9.2.2	Process Cooling Equipment	(CSI 2014)
3.4.9.2.2.1	Process Cooling Towers	(CSI 2014)
3.4.9.2.2.2	Process Chillers and Coolers	(CSI 2014)
3.4.9.2.2.3	Process Condensers and Evaporators	(CSI 2014)
3.4.9.2.3	Process Drying Equipment	(CSI 2014)
3.4.9.2.3.1	Gas Dryers and Dehumidifiers	(CSI 2014)
3.4.9.2.3.2	Material Dryers	(CSI 2014)
3.4.9.3	Process Gas and Liquid Handling, Purification, and Storage Equipment	(CSI 2014)
3.4.9.3.1	Gas Handling Equipment	(CSI 2014)
3.4.9.3.1.1	Gas Fans, Blowers, Pumps and Boosters	(CSI 2014)
3.4.9.3.1.2	Gas Compressors	(CSI 2014)
3.4.9.3.1.3	Gas Process Equipment	(CSI 2014)
3.4.9.3.1.4	Process Air and Gas Filters	(CSI 2014)
3.4.9.3.2	Liquid Handling Equipment	(CSI 2014)
3.4.9.3.2.1	Liquid Process Equipment	(CSI 2014)
3.4.9.3.2.2	Dry Location Liquid Pumps	(CSI 2014)
3.4.9.3.2.3	Suspended Liquid Pumps	(CSI 2014)
3.4.9.3.2.4	Submersible/Immersible Liquid Pumps	(CSI 2014)
3.4.9.3.2.5	Specialized Liquid Pumps	(CSI 2014)
3.4.9.3.2.6	Process Liquid Filters	(CSI 2014)
3.4.9.3.3	Gas and Liquid Purification Equipment	(CSI 2014)
3.4.9.3.3.1	Gas and Liquid Purification Filtration Equipment	(CSI 2014)
3.4.9.3.3.2	Gas and Liquid Purification Process Equipment	(CSI 2014)
3.4.9.3.4	Gas and Liquid Storage	(CSI 2014)
3.4.9.3.4.1	Non-pressurized Tanks and Vessels	(CSI 2014)
3.4.9.3.4.2	Pressurized Tanks and Vessels	(CSI 2014)
3.4.9.4	Pollution and Waste Control Equipment	(CSI 2014)
3.4.9.4.1	Air Pollution Control	(CSI 2014)
3.4.9.4.1.1	Particulate Control Equipment	(CSI 2014)
3.4.9.4.1.2	Gaseous Air Pollution Control Equipment	(CSI 2014)
3.4.9.4.2	Noise Pollution Control	(CSI 2014)
3.4.9.4.2.1	Noise Pollution Control Equipment	(CSI 2014)
3.4.9.4.3	Odor Control	(CSI 2014)
3.4.9.4.3.1	Odor Treatment Equipment	(CSI 2014)
3.4.9.4.3.2	Odor Dispersing and Masking/Counteracting Equipment	(CSI 2014)
3.4.9.4.4	Water Pollution Control Equipment	(CSI 2014)
3.4.9.4.4.1	Water Pollution Containment and Cleanup Equipment	(CSI 2014)
3.4.9.4.5	Solid Waste Control and Reuse	(CSI 2014)
3.4.9.4.5.1	Solid Waste Collection, Transfer, and Hauling Equipment	(CSI 2014)
3.4.9.4.5.2	Solid Waste Processing Equipment	(CSI 2014)
3.4.9.4.5.3	Composting Equipment	(CSI 2014)
3.4.9.4.6	Waste Thermal Processing Equipment	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.4.9.4.6.1	Waste-to-Energy Plants	(CSI 2014)
3.4.9.4.6.2	Fluidized Bed Combustion Equipment	(CSI 2014)
3.4.9.4.6.3	Rotary Kiln Incinerators	(CSI 2014)
3.4.9.4.6.4	Gasification Equipment	(CSI 2014)
3.4.9.4.6.5	Pyrolysis Equipment	(CSI 2014)
3.4.9.4.6.6	Hazardous Waste and Medical Waste Incinerators	(CSI 2014)
3.4.9.4.6.7	Heat Recovery Equipment for Waste Thermal Processing	(CSI 2014)
3.4.9.4.6.8	Synthesis Gas Cleanup and Handling Equipment	(CSI 2014)
3.4.9.5	Industry-Specific Manufacturing Equipment	(CSI 2014)
3.4.9.5.1	Oil and Gas Extraction Equipment	(CSI 2014)
3.4.9.5.2	Mining Machinery and Equipment	(CSI 2014)
3.4.9.5.3	Food Manufacturing Equipment	(CSI 2014)
3.4.9.5.4	Beverage and Tobacco Manufacturing Equipment	(CSI 2014)
3.4.9.5.5	Textiles and Apparel Manufacturing Equipment	(CSI 2014)
3.4.9.5.6	Leather and Allied Product Manufacturing Equipment	(CSI 2014)
3.4.9.5.7	Wood Product Manufacturing Equipment	(CSI 2014)
3.4.9.5.8	Paper Manufacturing Equipment	(CSI 2014)
3.4.9.5.9	Printing and Related Manufacturing Equipment	(CSI 2014)
3.4.9.5.10	Petroleum and Coal Products Manufacturing Equipment	(CSI 2014)
3.4.9.5.11	Chemical Manufacturing Equipment	(CSI 2014)
3.4.9.5.12	Plastics and Rubber Manufacturing Equipment	(CSI 2014)
3.4.9.5.13	Nonmetallic Mineral Product Manufacturing Equipment	(CSI 2014)
3.4.9.5.14	Primary Metal Manufacturing Equipment	(CSI 2014)
3.4.9.5.15	Fabricated Metal Product Manufacturing Equipment	(CSI 2014)
3.4.9.5.16	Machinery Manufacturing Equipment	(CSI 2014)
3.4.9.5.17	Computer and Electronic Product Manufacturing Equipment	(CSI 2014)
3.4.9.5.18	Electrical Equipment, Appliance, and Component Manufacturing Equipment	(CSI 2014)
3.4.9.5.19	Transportation Manufacturing Equipment	(CSI 2014)
3.4.9.5.20	Furniture and Related Product Manufacturing Equipment	(CSI 2014)
3.4.9.5.21	Other Manufacturing Equipment	(CSI 2014)
3.4.9.6	Water and Wastewater Equipment	(CSI 2014)
3.4.9.6.1	Water and Wastewater Preliminary Treatment Equipment	(CSI 2014)
3.4.9.6.1.1	Screening Equipment	(CSI 2014)
3.4.9.6.1.2	Grit Removal and Handling Equipment	(CSI 2014)
3.4.9.6.1.3	Grinding and Shredding Equipment	(CSI 2014)
3.4.9.6.1.4	Oil and Grease Separation and Removal Equipment	(CSI 2014)
3.4.9.6.2	Water and Wastewater Chemical Feed Equipment	(CSI 2014)
3.4.9.6.2.1	Gas Chemical Feed Equipment	(CSI 2014)
3.4.9.6.2.2	Liquid Chemical Feed Equipment	(CSI 2014)
3.4.9.6.2.3	Dry Chemical Feed Equipment	(CSI 2014)
3.4.9.6.3	Water and Wastewater Clarification and Mixing Equipment	(CSI 2014)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	**Tag**	**Resource**
3.4.9.6.3.1	Mixing Equipment	(CSI 2014)
3.4.9.6.3.2	Clarifier Equipment	(CSI 2014)
3.4.9.6.3.3	Sediment Removal Equipment	(CSI 2014)
3.4.9.6.4	Water and Wastewater Secondary Treatment Equipment	(CSI 2014)
3.4.9.6.4.1	Air and Gas Diffusion Equipment	(CSI 2014)
3.4.9.6.4.2	Biological Treatment Systems	(CSI 2014)
3.4.9.6.5	Water and Wastewater Advanced Treatment Equipment	(CSI 2014)
3.4.9.6.5.1	Filtration Equipment	(CSI 2014)
3.4.9.6.5.2	Demineralization Equipment	(CSI 2014)
3.4.9.6.5.3	Ultraviolet Equipment	(CSI 2014)
3.4.9.6.6	Water and Wastewater Residuals Handling and Treatment	(CSI 2014)
3.4.9.6.6.1	Residuals Thickening Equipment	(CSI 2014)
3.4.9.6.6.2	Residuals Stabilization	(CSI 2014)
3.4.9.6.6.3	Residuals Dewatering Equipment	(CSI 2014)
3.4.9.6.6.4	Thermal Treatment of Residuals	(CSI 2014)
3.4.9.7	Electrical Power Generation	(CSI 2014)
3.4.9.7.1	Electrical Power Generation Equipment	(CSI 2014)
3.4.9.7.1.1	Fossil Fuel Plant Electrical Power Generation Equipment	(CSI 2014)
3.4.9.7.1.2	Nuclear Fuel Plant Electrical Power Generation Equipment	(CSI 2014)
3.4.9.7.1.3	Hydroelectric Plant Electrical Power Generation Equipment	(CSI 2014)
3.4.9.7.1.4	Solar Energy Electrical Power Generation Equipment	(CSI 2014)
3.4.9.7.1.5	Wind Energy Electrical Power Generation Equipment	(CSI 2014)
3.4.9.7.1.6	Geothermal Energy Electrical Power Generation Equipment	(CSI 2014)
3.4.9.7.1.7	Electrochemical Energy Electrical Power Generation Equipment	(CSI 2014)
3.4.9.7.1.8	Fuel Cell Electrical Power Generation Equipment	(CSI 2014)
3.4.9.7.1.9	Electrical Power Control Equipment	(CSI 2014)
3.4.9.7.2	Electrical Power Generation Testing	(CSI 2014)
3.4.9.7.2.1	Electrical Power Generation Test Equipment	(CSI 2014)
3.5	Management	
3.5.1	Time Management	(PMI 2000a), (Kerzner 2003), (Sears et al. 2008)
3.5.1.1	Schedule Techniques	(Kerzner 2003), (Sears et al. 2008), (Hendrickson 2000), (Arditi et al. 2010)
3.5.1.1.1	Critical Path Method (CPM)	(Arditi et al. 2010), (Nicholas 2004)
3.5.1.1.2	Program Evaluation and Review Technique (PERT)	(Arditi et al. 2010), (Nicholas 2004)
3.5.1.1.3	Graphical Evaluation and Review Technique (GERT)	(Nicholas 2004)
3.5.1.1.4	Gantt Chart	(Arditi et al. 2010)
3.5.1.1.5	Monte Carlo Simulation	(Arditi et al. 2010)
3.5.1.1.6	Linear Scheduling Technique	(Hinze 2004)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	**Tag**	**Resource**
3.5.1.2	Planning / Schedules	(Kerzner 2003), (Sears et al. 2008), (Hendrickson 2000), (Dykstra 2011)
3.5.1.2.1	WBS	(Kerzner 2003)
3.5.1.2.2	Activity Sequencing	(PMI 2000a)
3.5.1.2.3	Activity Duration Estimating	(PMI 2000a)
3.5.1.2.4	Schedule Development	(PMI 2000a)
3.5.1.2.5	Activity Weights Definition	(PMI 2000a)
3.5.1.3	Schedule Control	(PMI 2000a), (Kerzner 2003), (Fewings 2012), (PMI 2000b)
3.5.1.3.1	Acceleration (Fast tracking)	(Kerzner 2003), (Sears et al. 2008)
3.5.1.3.2	Progress Monitoring	(PMI 2000a), (Sears et al. 2008)
3.5.1.3.2.1	Weekly Schedule Report	(Sears et al. 2008)
3.5.1.3.2.2	Monthly Schedule Report	(Sears et al. 2008)
3.5.1.4	Delay	(Bilgin 2011)
3.5.1.4.1	Causes of Delay	(Bilgin 2011)
3.5.1.4.1.1	Owner Causes	(Bilgin 2011)
3.5.1.4.1.1.1	Design Related Causes	(Bilgin 2011)
3.5.1.4.1.1.2	Consultant Causes	(Bilgin 2011)
3.5.1.4.1.1.3	Owner's Financial Causes	(Bilgin 2011)
3.5.1.4.1.1.4	Owner Generated Causes	(Bilgin 2011)
3.5.1.4.1.1.5	Contract Related Causes	(Bilgin 2011)
3.5.1.4.1.1.6	Contractual Relationship Related Causes	(Bilgin 2011)
3.5.1.4.1.2	Contractor Causes	(Bilgin 2011)
3.5.1.4.1.2.1	Material Related Causes	(Bilgin 2011)
3.5.1.4.1.2.2	Equipment Related Causes	(Bilgin 2011)
3.5.1.4.1.2.3	Labor Related Causes	(Bilgin 2011)
3.5.1.4.1.2.4	Contractor's Financial Causes	(Bilgin 2011)
3.5.1.4.1.2.5	Subcontractor Causes	(Bilgin 2011)
3.5.1.4.1.2.6	Health and Safety Related Causes	(Bilgin 2011)
3.5.1.4.1.2.7	Scheduling and Controlling Related Causes	(Bilgin 2011)
3.5.1.4.1.2.8	Contractor Generated Causes	(Bilgin 2011)
3.5.1.4.1.3	External Causes	(Bilgin 2011)
3.5.1.4.1.3.1	Inclement Weather Causes	(Bilgin 2011)
3.5.1.4.1.3.2	Environmental Causes	(Bilgin 2011)
3.5.1.4.1.3.3	Force Majeure Causes	(Bilgin 2011)
3.5.1.4.1.3.4	Rules and Regulations Related Causes	(Bilgin 2011)
3.5.1.4.1.3.5	Economical Causes	(Bilgin 2011)
3.5.1.4.1.3.6	Political Causes	(Bilgin 2011)
3.5.1.4.1.3.7	Social Causes	(Bilgin 2011)
3.5.1.4.1.3.8	Technological Causes	(Bilgin 2011)
3.5.1.4.2	Types of Delay	(Bilgin 2011)
3.5.1.4.2.1	Compensability of Delay	(Bilgin 2011)
3.5.1.4.2.1.1	Excusable compensable delays	(Bilgin 2011)
3.5.1.4.2.1.2	Excusable non-compensable delays	(Bilgin 2011)
3.5.1.4.2.1.3	Non-excusable delays	(Bilgin 2011)
3.5.1.4.2.2	Criticality of Delay	(Bilgin 2011)
3.5.1.4.2.2.1	Critical delays: Delay to completion	(Bilgin 2011)
3.5.1.4.2.2.2	Non-critical delays: Delay to progress	(Bilgin 2011)
3.5.1.4.3	Impacts of Delay	(Bilgin 2011)
3.5.1.4.3.1	Time Overrun	(Bilgin 2011)
3.5.1.4.3.2	Cost Overrun	(Bilgin 2011)
3.5.1.4.3.3	Disruption	(Bilgin 2011)
3.5.1.4.3.4	Lost Productivity	(Bilgin 2011)
3.5.1.4.3.5	Acceleration	(Bilgin 2011)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.5.1.4.3.5.1	Constructive Acceleration	(Bilgin 2011)
3.5.1.4.3.5.2	Directive Acceleration	(Bilgin 2011)
3.5.1.4.3.6	Dispute	(Bilgin 2011)
3.5.1.4.3.7	Total Abandonment	(Bilgin 2011)
3.5.1.4.3.8	Contract Termination	(Bilgin 2011)
3.5.1.4.4	Mitigation of Delay	(Bilgin 2011)
3.5.1.4.4.1	Changing the Work Sequence	(Bilgin 2011)
3.5.1.4.4.1.1	Deleting some work items	(Bilgin 2011)
3.5.1.4.4.1.2	Allowing more of the critical work to occur at the same time	(Bilgin 2011)
3.5.1.4.4.2	Accelerating the Work	(Bilgin 2011)
3.5.1.4.4.2.1	Increasing manpower	(Bilgin 2011)
3.5.1.4.4.2.2	Adding equipment	(Bilgin 2011)
3.5.1.4.4.2.3	Expediting the delivery of materials	(Bilgin 2011)
3.5.1.4.4.2.4	Working outside planned working hours	(Bilgin 2011)
3.5.1.4.4.2.5	Extra shifting	(Bilgin 2011)
3.5.1.4.4.2.6	Improving conditions e.g. providing temporary heat	(Bilgin 2011)
3.5.1.4.4.3	Changing the Contract	(Bilgin 2011)
3.5.1.4.4.3.1	Changing the materials used	(Bilgin 2011)
3.5.1.4.4.3.2	Changing the method of construction	(Bilgin 2011)
3.5.1.4.4.3.3	Relaxing the contract restrictions	(Bilgin 2011)
3.5.1.4.4.3.4	Asking for a change in design	(Bilgin 2011)
3.5.1.4.4.4	Making Improvements	(Bilgin 2011)
3.5.1.4.4.4.1	Improvement of productivity	(Bilgin 2011)
3.5.1.4.4.4.2	Improvement of communications between parties	(Bilgin 2011)
3.5.1.4.4.4.3	Conducting work methods improvement studies	(Bilgin 2011)
3.5.1.4.4.4.4	Asking for more site meetings with all functional groups	(Bilgin 2011)
3.5.1.4.4.4.5	Asking top management for more executive authorities to project manager	(Bilgin 2011)
3.5.1.4.4.4.6	Protection of uncompleted work	(Bilgin 2011)
3.5.1.4.4.4.7	Timely and reasonable reprocurement	(Bilgin 2011)
3.5.1.4.4.4.8	Timely changing or cancellation of purchase orders	(Bilgin 2011)
3.5.1.4.5	Delay Analysis	(Bilgin 2011)
3.5.2	Financial Management	(PMI 2000a), (Sears et al. 2008), (PMI 2000b), (Hendrickson 2000)
3.5.2.1	Accounting Transactions	(Peterson 2010)
3.5.2.1.1	Invoice Charged to a Job	(Peterson 2010)
3.5.2.1.2	Invoice Charged to a Job without Retention	(Peterson 2010)
3.5.2.1.3	Invoice Charged to a Job with Retention	(Peterson 2010)
3.5.2.1.4	Paying Invoices	(Peterson 2010)
3.5.2.1.5	Labor Charged to a Job	(Peterson 2010)
3.5.2.1.6	Labor Charged to General Overhead	(Peterson 2010)
3.5.2.1.7	Paying an Employee's Wages	(Peterson 2010)
3.5.2.1.8	Paying Payroll Taxes	(Peterson 2010)
3.5.2.1.9	Recording Office Rent	(Peterson 2010)
3.5.2.1.10	Recording Office Depreciation	(Peterson 2010)
3.5.2.1.11	Recording General Overhead Invoices	(Peterson 2010)
3.5.2.1.12	Billing a Client	(Peterson 2010)
3.5.2.1.13	Billing for Retention	(Peterson 2010)
3.5.2.1.14	Receiving Payment from a Client	(Peterson 2010)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	**Tag**	**Resource**
3.5.2.1.15	Purchase of Equipment with a Loan	(Peterson 2010)
3.5.2.1.16	Equipment Depreciatio	(Peterson 2010)
3.5.2.1.17	Loan Payment	(Peterson 2010)
3.5.2.1.18	Leased Equipment with an Operating Lease	(Peterson 2010)
3.5.2.1.19	Leased Equipment with a Capital Lease	(Peterson 2010)
3.5.2.1.20	Lease Payments on a Capital Lease	(Peterson 2010)
3.5.2.1.21	Amortization of a Capital Lease	(Peterson 2010)
3.5.2.1.22	Invoice for Equipment Repairs	(Peterson 2010)
3.5.2.1.23	Equipment Charged to a Job	(Peterson 2010)
3.5.2.1.24	Equipment Charged to an Employee	(Peterson 2010)
3.5.2.1.25	Sale of Equipment	(Peterson 2010)
3.5.2.1.26	Purchase of Inventory	(Peterson 2010)
3.5.2.1.27	Charging Inventory to a Job	(Peterson 2010)
3.5.2.2	Cost Management	(PMI 2000a), (Sears et al. 2008), (Peterson 2010)
3.5.2.2.1	Cost Estimating	(PMI 2000a), (Schaufelberger and Holm 2002), (Kerzner 2003), (Hendrickson 2000)
3.5.2.2.1.1	Cost Estimating Data	(Sears et al. 2008)
3.5.2.2.1.2	Types of Estimates	(Dykstra 2011), (Schaufelberger and Holm 2002)
3.5.2.2.1.2.1	Conceptual Cost Estimate	(Dykstra 2011), (Schaufelberger and Holm 2002)
3.5.2.2.1.2.2	Preliminary Cost Estimate	(Dykstra 2011), (Schaufelberger and Holm 2002)
3.5.2.2.1.2.3	Detailed Cost Estimate	(Dykstra 2011), (Schaufelberger and Holm 2002)
3.5.2.2.2	Quantity Take-off	(Schaufelberger and Holm 2002)
3.5.2.2.3	Cost Budgeting	(PMI 2000a)
3.5.2.2.4	Cost Control	(PMI 2000a), (Hendrickson 2000)
3.5.2.2.4.1	Performance Management	(Kerzner 2003), (PMI 2000b)
3.5.2.2.4.1.1	Productivity	(Fewings 2012)
3.5.2.2.4.1.1.1	Labor	(Peterson 2010)
3.5.2.2.4.1.1.2	Sub-Contractor	(Peterson 2010)
3.5.2.2.4.1.1.3	Equipment	(Peterson 2010)
3.5.2.2.4.1.1.4	Material	(Peterson 2010)
3.5.2.2.4.2	Monitoring and Accounting	(Fewings 2012), (PMI 2000b)
3.5.2.2.4.2.1	Cost Loaded Schedule	(Peterson 2010)
3.5.2.2.4.2.2	Cost Performance Index	(Peterson 2010)
3.5.2.2.4.2.3	Cost Codes	(Schaufelberger and Holm 2002)
3.5.2.2.5	Cost Reports	(Sears et al. 2008)
3.5.2.2.5.1	Labor-Time Reports	(Sears et al. 2008)
3.5.2.2.5.2	Equipment-Time Reports	(Sears et al. 2008)
3.5.2.2.6	Cost Categories	(Dykstra 2011)
3.5.2.2.6.1	Contractor's Direct Costs	(Bilgin 2011)
3.5.2.2.6.1.1	Field Costs	(Bilgin 2011)
3.5.2.2.6.1.1.1	Labor Costs	(Peterson 2010)
3.5.2.2.6.1.1.1.1	Additional Labor Costs	(Bilgin 2011)
3.5.2.2.6.1.1.2	Material Costs	Perterson
3.5.2.2.6.1.1.2.1	Additional Material Costs	(Bilgin 2011)
3.5.2.2.6.1.1.3	Equipment Costs	(Peterson 2010)
3.5.2.2.6.1.1.3.1	Additional Equipment Costs	(Bilgin 2011)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.5.2.2.6.1.1.4	Site Overhead Costs	(Peterson 2010)
3.5.2.2.6.1.1.4.1	Extended Site Overhead Costs	(Bilgin 2011)
3.5.2.2.6.1.2	Home Office Overhead Costs	(Bilgin 2011)
3.5.2.2.6.1.2.1	Extended Home Office Overhead Costs	(Bilgin 2011)
3.5.2.2.6.1.2.2	Unabsorbed Home Office Overhead Costs	(Bilgin 2011)
3.5.2.2.6.1.3	Lost Productivity Costs	(Bilgin 2011)
3.5.2.2.6.1.4	Acceleration Costs	(Bilgin 2011)
3.5.2.2.6.1.5	Costs of Noncritical Delays	(Bilgin 2011)
3.5.2.2.6.1.6	Disruption Costs	(Bilgin 2011)
3.5.2.2.6.1.7	Consulting and Legal Costs	(Bilgin 2011)
3.5.2.2.6.1.8	Extended Temporary Utility and Facility Costs	(Bilgin 2011)
3.5.2.2.6.1.9	Extended Maintenance and Protection Costs	(Bilgin 2011)
3.5.2.2.6.1.10	Extended Warranty Costs	(Bilgin 2011)
3.5.2.2.6.1.11	Increased Bond Costs	(Bilgin 2011)
3.5.2.2.6.1.12	Increased Financing Costs	(Bilgin 2011)
3.5.2.2.6.1.13	Demolition Costs	(Bilgin 2011)
3.5.2.2.6.1.14	Waste Costs on Abandoned Work	(Bilgin 2011)
3.5.2.2.6.2	Contractor's Indirect Costs	(Bilgin 2011)
3.5.2.2.7	Change Order	(Dykstra 2011)
3.5.2.2.8	Resource Planning	(PMI 2000a)
3.5.3	Quality Management	(PMI 2000a), (Kerzner 2003), (Fewings 2012), (Hendrickson 2000)
3.5.3.1	Quality Policy	(Kerzner 2003)
3.5.3.2	Quality Objectives	(Kerzner 2003)
3.5.3.3	Quality Planning	(PMI 2000a), (Fewings 2012)
3.5.3.4	Quality Assurance	(PMI 2000a)
3.5.3.5	Quality Control	(PMI 2000a)
3.5.3.6	Quality Program Plan	(Kerzner 2003)
3.5.4	Human Resource Management	(PMI 2000a), (Sears et al. 2008), (PMI 2000b)
3.5.4.1	Organizational Planning	(PMI 2000a)
3.5.4.2	Staff Acquisition	(PMI 2000a)
3.5.4.3	Team Development	(PMI 2000a)
3.5.4.4	Project Completion	(PMI 2000a)
3.5.4.5	Training and Education	(Kerzner 2003), (Fewings 2012)
3.5.5	Risk Management	(PMI 2000a), (Kerzner 2003), (Fewings 2012)
3.5.5.1	Risk Management Planning	(PMI 2000a)
3.5.5.2	Risk Identification	(PMI 2000a)
3.5.5.2.1	Analogy	(Nicholas 2004)
3.5.5.2.2	Risk Checklist	(Nicholas 2004)
3.5.5.2.3	WBS Analysis	(Nicholas 2004)
3.5.5.2.4	Flow Charts	(Nicholas 2004)
3.5.5.2.5	Brainstorming	(Nicholas 2004)
3.5.5.3	Qualitative Risk Analysis	(PMI 2000a)
3.5.5.4	Quantitave Risk Analysis	(PMI 2000a)
3.5.5.5	Risk Response Planning	(PMI 2000a)
3.5.5.5.1	Transfer the Risk	(PMI 2000a)
3.5.5.5.2	Avoid Risk	(PMI 2000a)
3.5.5.6	Risk Monitoring and Control	(PMI 2000a)
3.5.5.7	Risk Sources	(Yıldız 2012)
3.5.5.7.1	Internal Risk	(Nicholas 2004)
3.5.5.7.2	External Risk	(Nicholas 2004)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.5.5.7.3	Adverse Country Related Conditions	(Yıldız 2012)
3.5.5.7.3.1	Instability of Economic Condition	(Yıldız 2012)
3.5.5.7.3.2	Instability of Government	(Yıldız 2012)
3.5.5.7.3.3	Instability of International Relations	(Yıldız 2012)
3.5.5.7.3.4	Social Unrest	(Yıldız 2012)
3.5.5.7.3.5	High Level of Bureaucracy	(Yıldız 2012)
3.5.5.7.3.6	Immaturity of Legal System	(Yıldız 2012)
3.5.5.7.3.7	Restrictions for Foreign Companies	(Yıldız 2012)
3.5.5.7.3.8	Unavailability of Local Material	(Yıldız 2012)
3.5.5.7.3.9	Unavailability of Equipment	(Yıldız 2012)
3.5.5.7.3.10	Unavailability of Local Labor	(Yıldız 2012)
3.5.5.7.3.11	Unavailability of Local Subcontractor	(Yıldız 2012)
3.5.5.7.3.12	Unavailability of Infrastructure	(Yıldız 2012)
3.5.5.7.4	Design Problems	(Yıldız 2012)
3.5.5.7.4.1	Poor/Incomplete Design	(Yıldız 2012)
3.5.5.7.4.2	Design Errors	(Yıldız 2012)
3.5.5.7.5	Project Complexity	(Yıldız 2012)
3.5.5.7.5.1	Complexity of Design	(Yıldız 2012)
3.5.5.7.5.2	Low Constructability	(Yıldız 2012)
3.5.5.7.5.3	Complexity of Construction Method	(Yıldız 2012)
3.5.5.7.6	Uncertainty of Geological Problems	(Yıldız 2012)
3.5.5.7.6.1	Uncertainty of Geotechnical Investigation	(Yıldız 2012)
3.5.5.7.7	Strict Requirements	(Yıldız 2012)
3.5.5.7.7.1	Strict Quality Requirements	(Yıldız 2012)
3.5.5.7.7.2	Strict Environmental Requirements	(Yıldız 2012)
3.5.5.7.7.3	Strict Health & Safety Requirements	(Yıldız 2012)
3.5.5.7.7.4	Strict Project Management Requirements	(Yıldız 2012)
3.5.5.7.8	Contract Specific Problems	(Yıldız 2012)
3.5.5.7.8.1	Vagueness of Contract Clauses	(Yıldız 2012)
3.5.5.7.8.2	Contract Errors	(Yıldız 2012)
3.5.5.7.9	Engineer's Incompetency	(Yıldız 2012)
3.5.5.7.9.1	Technical Incompetency of Engineer	(Yıldız 2012)
3.5.5.7.9.2	Managerial Incompetency of Engineer	(Yıldız 2012)
3.5.5.7.9.3	Engineer's Lack of Financial Resources	(Yıldız 2012)
3.5.5.7.10	Client's Incompetency	(Yıldız 2012)
3.5.5.7.10.1	Client’s Unclarity of Objectives	(Yıldız 2012)
3.5.5.7.10.2	Client’s High Level of Bureaucracy	(Yıldız 2012)
3.5.5.7.10.3	Client’s Negative Attitude	(Yıldız 2012)
3.5.5.7.10.4	Client’s Poor Staff Profile	(Yıldız 2012)
3.5.5.7.10.5	Client’s Lack of Financial Resources	(Yıldız 2012)
3.5.5.7.10.6	Client’s Technical Incompetency	(Yıldız 2012)
3.5.5.7.10.7	Client’s Poor Managerial/ Organizational Abilities	(Yıldız 2012)
3.5.5.7.11	Adverse Site Conditions	(Yıldız 2012)
3.5.5.7.11.1	Poor Site Supervision	(Yıldız 2012)
3.5.5.7.11.2	Lack of Site Facilities	(Yıldız 2012)
3.5.5.7.12	Contractor's Lack of Experience	(Yıldız 2012)
3.5.5.7.12.1	Contractor’s Lack of Experience in Similar Projects	(Yıldız 2012)
3.5.5.7.12.2	Contractor’s Lack of Experience in Country	(Yıldız 2012)
3.5.5.7.12.3	Contractor’s Lack of Experience in Project delivery System	(Yıldız 2012)
3.5.5.7.12.4	Contractor’s Lack of Experience with Client	(Yıldız 2012)
3.5.5.7.13	Contractor's Lack of Resources	(Yıldız 2012)
3.5.5.7.13.1	Contractor’s Lack of Financial Resources	(Yıldız 2012)
3.5.5.7.13.2	Contractor’s Lack of Technical Resources	(Yıldız 2012)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	**Tag**	**Resource**
3.5.5.7.13.3	Contractor’s Lack of Staff	(Yıldız 2012)
3.5.5.7.14	Contractor's Lack of Managerial Skills	(Yıldız 2012)
3.5.5.7.14.1	Poor Project Scope Management	(Yıldız 2012)
3.5.5.7.14.2	Poor Project Time Management	(Yıldız 2012)
3.5.5.7.14.3	Poor Project Cost Management	(Yıldız 2012)
3.5.5.7.14.4	Poor Project Quality Management	(Yıldız 2012)
3.5.5.7.14.5	Poor Human Resource Management	(Yıldız 2012)
3.5.5.7.14.6	Poor Communication Management	(Yıldız 2012)
3.5.5.7.14.7	Poor Risk Management	(Yıldız 2012)
3.5.5.7.14.8	Poor Procurement Management	(Yıldız 2012)
3.5.5.7.15	A.C. in Country Economic Conditions	(Yıldız 2012)
3.5.5.7.15.1	Changes in Currency Rate	(Yıldız 2012)
3.5.5.7.15.2	Changes in Economic Indicators	(Yıldız 2012)
3.5.5.7.16	A.C. in Laws& Regulations	(Yıldız 2012)
3.5.5.7.16.1	Change in Taxation Policies	(Yıldız 2012)
3.5.5.7.16.2	Change in Laws & Regulations	(Yıldız 2012)
3.5.5.7.17	Conflicts with Project Stakeholders	(Yıldız 2012)
3.5.5.7.17.1	Conflict with Government	(Yıldız 2012)
3.5.5.7.17.2	Conflict with Engineer	(Yıldız 2012)
3.5.5.7.17.3	Conflict with Client	(Yıldız 2012)
3.5.5.7.17.4	Poor Public Relations	(Yıldız 2012)
3.5.5.7.18	A.C. in Performance of Client	(Yıldız 2012)
3.5.5.7.18.1	Change in Performance of Client Representative	(Yıldız 2012)
3.5.5.7.18.2	Changes in Client’s Staff/ Organization	(Yıldız 2012)
3.5.5.7.18.3	Change in Financial Situation of Client	(Yıldız 2012)
3.5.5.7.19	Changes in Project Specifications	(Yıldız 2012)
3.5.5.7.19.1	Scope Changes	(Yıldız 2012)
3.5.5.7.19.2	Design Changes	(Yıldız 2012)
3.5.5.7.20	A.C. in Performance of Contractor	(Yıldız 2012)
3.5.5.7.20.1	Change in Site/Project Organization	(Yıldız 2012)
3.5.5.7.20.2	Change in Functional Performance of Contractor	(Yıldız 2012)
3.5.5.7.21	A.C. in Availability of Local Resources	(Yıldız 2012)
3.5.5.7.21.1	Change in Availability of Labor	(Yıldız 2012)
3.5.5.7.21.2	Change in Availability of Material	(Yıldız 2012)
3.5.5.7.21.3	Change in Availability of Equipment	(Yıldız 2012)
3.5.5.7.21.4	Change in Availability of Subcontractor	(Yıldız 2012)
3.5.5.7.22	A.C. in Site Conditions	(Yıldız 2012)
3.5.5.7.22.1	Change in Geological Conditions	(Yıldız 2012)
3.5.5.7.22.2	Change in Site Condition	(Yıldız 2012)
3.5.5.7.23	Unexpected Events	(Yıldız 2012)
3.5.5.7.23.1	War/ Hostilities	(Yıldız 2012)
3.5.5.7.23.2	Rebellion/ Terrorism	(Yıldız 2012)
3.5.5.7.23.3	Natural Catastrophes	(Yıldız 2012)
3.5.5.7.24	Delays/ Interruptions	(Yıldız 2012)
3.5.5.7.25	Decrease in Productivity	(Yıldız 2012)
3.5.5.7.26	Increase in Amount of Work	(Yıldız 2012)
3.5.5.7.27	Decrease in Quality of Work	(Yıldız 2012)
3.5.5.7.28	Increase in Unit Cost of Work	(Yıldız 2012)
3.5.5.7.29	Lags in Cash Flow	(Yıldız 2012)
3.5.5.7.30	Cost Overrun	(Yıldız 2012)
3.5.6	Claim Management	(PMI 2000a), (PMI 2000b)
3.5.6.1	Claim	(Dykstra 2011)
3.5.6.1.1	Kinds of Claim	(Bilgin 2011)
3.5.6.1.1.1	Variation Claims	(Bilgin 2011)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.5.6.1.1.1.1	Extra work claims	(Bilgin 2011)
3.5.6.1.1.1.2	Different site conditions claims/Latent condition claims	(Bilgin 2011)
3.5.6.1.1.1.3	Acceleration claims	(Bilgin 2011)
3.5.6.1.1.1.4	Interest claim	(Bilgin 2011)
3.5.6.1.1.2	Time Related Claims	(Bilgin 2011)
3.5.6.1.1.2.1	Extension of time claim	(Bilgin 2011)
3.5.6.1.1.2.2	Liquidated damages claim	(Bilgin 2011)
3.5.6.1.1.2.3	Prolongation claim	(Bilgin 2011)
3.5.6.1.1.2.4	Global/Composite/Rolled-up/Ambit claim	(Bilgin 2011)
3.5.6.1.1.2.5	Disruption/Loss of productivity claim	(Bilgin 2011)
3.5.6.1.1.3	Quantum Meurit Claims	(Bilgin 2011)
3.5.6.1.1.3.1	Total cost claim	(Bilgin 2011)
3.5.6.1.1.3.2	Contractual quantum meurit (Quantum meurit under contract)	(Bilgin 2011)
3.5.6.1.1.3.3	Restitutionary quantum meurit (Quantum meurit on unjust enrichment)	(Bilgin 2011)
3.5.6.1.1.4	Claims after Termination by Frustration	(Bilgin 2011)
3.5.6.1.1.5	Defective Work Claims	(Bilgin 2011)
3.5.6.1.1.6	Licensing and Building Claims	(Bilgin 2011)
3.5.6.1.1.7	Counter-claims	(Bilgin 2011)
3.5.6.1.2	Result of a claim	(Bilgin 2011)
3.5.6.1.2.1	Settlement	(Bilgin 2011)
3.5.6.1.2.2	Dispute	(Bilgin 2011)
3.5.6.2	Dispute and Resolution	(Kerzner 2003), (Dykstra 2011)
3.5.6.2.1	Resolution of Dispute	(Bilgin 2011)
3.5.6.2.1.1	Resolution By Negotiation	(Bilgin 2011)
3.5.6.2.1.2	Resolution By Third Party	(Bilgin 2011)
3.5.6.2.1.2.1	Alternative Dispute Resolution	(Bilgin 2011)
3.5.6.2.1.2.1.1	Third party expert opinion	(Bilgin 2011)
3.5.6.2.1.2.1.2	Conciliation	(Bilgin 2011)
3.5.6.2.1.2.1.3	Mediation	(Bilgin 2011)
3.5.6.2.1.2.1.4	Arbitration	(Bilgin 2011)
3.5.6.2.1.2.2	Litigation	(Bilgin 2011)
3.5.7	Safety and Environmental Management	(PMI 2000a), (Fewings 2012), (PMI 2000b), (Hendrickson 2000)
3.5.7.1	Sustainability	(Fewings 2012)
3.5.7.2	Waste Management	(Fewings 2012)
3.5.8	Procurement Management	(PMI 2000a), (Kerzner 2003), (Fewings 2012), (PMI 2000b)
3.5.8.1	Procurement Planning	(PMI 2000b)
3.5.8.2	Supply Chain Management	(Fewings 2012)
3.5.9	Communications Management	(PMI 2000a), (Fewings 2012)
3.5.9.1	Communications Planning	(PMI 2000a)
3.5.9.2	Information Distribution	(PMI 2000a)
3.5.9.3	Performance Reporting	(PMI 2000a)
3.5.9.4	Administrative Closure	(PMI 2000a)
3.5.9.5	Information Systems	(Kerzner 2003)
3.5.9.6	Document Management/Reporting	(PMI 2000b)
3.5.10	Contract Management	(Kerzner 2003), (PMI 2000b), (Hendrickson 2000)
3.5.10.1	Contract Document	(Dykstra 2011)
3.5.10.2	Contract Types	(Dykstra 2011)
3.5.10.2.1	Lump-Sum Contract	(Dykstra 2011)
3.5.10.2.2	Cost Plus a Fee Contract	(Dykstra 2011)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
3.5.10.2.3	Cost Plus with a Guaranteed Maximum Price Contract	(Dykstra 2011)
3.5.10.2.4	Unit Price Contract	(Dykstra 2011)
4	Resource	(El-Diraby et al. 2005)
4.1	Sub-contractor	(Hughes and Murdoch 2001), (El-Diraby et al. 2005)
4.1.1	Domestic Sub-Contractor	(Hughes and Murdoch 2001)
4.1.2	Nominated sub-contractor	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
4.1.3	Labour-only Sub-contractor	(Hughes and Murdoch 2001)
4.1.4	Specialist Sub-Contractor	(Hughes and Murdoch 2001)
4.1.4.1	Process Contractor	(Hughes and Murdoch 2001)
4.1.4.2	Engineering Contractor	(Hughes and Murdoch 2001)
4.1.4.3	Specialist Trade Contractor	(Hughes and Murdoch 2001)
4.2	Construction Machinery and Equipment	(International Organization for Standardization 2010)
4.2.1	Earth-moving machinery and equipment	(International Organization for Standardization 2010)
4.2.1.1	Tractor-dozers	(International Organization for Standardization 2010)
4.2.1.1.1	Wheeled dozers	(International Organization for Standardization 2010)
4.2.1.1.2	Crawler dozers	(International Organization for Standardization 2010)
4.2.1.2	Loaders	(International Organization for Standardization 2010)
4.2.1.2.1	Wheeled loaders	(International Organization for Standardization 2010)
4.2.1.2.2	Crawler loaders	(International Organization for Standardization 2010)
4.2.1.2.3	Digging arm loaders	(International Organization for Standardization 2010)
4.2.1.3	Backhoe loaders	(International Organization for Standardization 2010)
4.2.1.3.1	Wheeled backhoe loaders	(International Organization for Standardization 2010)
4.2.1.3.2	Crawler backhoe loaders	(International Organization for Standardization 2010)
4.2.1.4	Excavators	(International Organization for Standardization 2010)
4.2.1.4.1	Hydraulic excavators	(International Organization for Standardization 2010)
4.2.1.4.2	Cable excavators	(International Organization for Standardization 2010)
4.2.1.4.3	Wheel excavators	(International Organization for Standardization 2010)
4.2.1.4.4	Bucket chain excavators	(International Organization for Standardization 2010)
4.2.1.4.5	Others	(International Organization for Standardization 2010)
4.2.1.5	Dumpers	(International Organization for Standardization 2010)
4.2.1.5.1	Articulated steer dumpers	(International Organization for Standardization 2010)
4.2.1.5.2	Rigid frame dumpers	(International Organization for Standardization 2010)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
4.2.1.5.3	Site (dumpers) carriers	(International Organization for Standardization 2010)
4.2.1.5.4	Crawler dumpers	(International Organization for Standardization 2010)
4.2.1.6	Tractors-scrapers	(International Organization for Standardization 2010)
4.2.1.6.1	Articulated steer	(International Organization for Standardization 2010)
4.2.1.6.2	Wheel steer	(International Organization for Standardization 2010)
4.2.1.7	Graders	(International Organization for Standardization 2010)
4.2.1.7.1	Articulated steer	(International Organization for Standardization 2010)
4.2.1.7.2	Wheel steer	(International Organization for Standardization 2010)
4.2.1.8	Landfill compactors	(International Organization for Standardization 2010)
4.2.1.9	Trenchers	(International Organization for Standardization 2010)
4.2.1.10	Pipelayers	(International Organization for Standardization 2010)
4.2.1.11	Rotating pipelayers	(International Organization for Standardization 2010)
4.2.1.12	Rollers	(International Organization for Standardization 2010)
4.2.1.12.1	Smooth drum rollers	(International Organization for Standardization 2010)
4.2.1.12.2	Pneumatic tyred rollers	(International Organization for Standardization 2010)
4.2.1.12.3	Combination rollers	(International Organization for Standardization 2010)
4.2.1.13	Compact machines (excavators and loaders)	(International Organization for Standardization 2010)
4.2.1.14	Compact dumpers	(International Organization for Standardization 2010)
4.2.1.15	Compact tool carriers	(International Organization for Standardization 2010)
4.2.1.16	Equipment for trenchless	(International Organization for Standardization 2010)
4.2.1.17	Equipment for trenchless technology: pipe-jacking (pushing), impact ramming (moling), and microtunnelling equipment	(International Organization for Standardization 2010)
4.2.1.18	Remote control systems for earth- moving machinery	(International Organization for Standardization 2010)
4.2.1.19	Hydro-excavation and air- excavation equipment	(International Organization for Standardization 2010)
4.2.1.20	Others	(International Organization for Standardization 2010)
4.2.2	Foundation and drilling equipment	(International Organization for Standardization 2010)
4.2.2.1	Pile driving and extracting equipment	(International Organization for Standardization 2010)
4.2.2.1.1	Pile Hammers	(Peurifoy et al. 2006)
4.2.2.1.1.1	Drop Hammers	(Peurifoy et al. 2006)
4.2.2.1.1.2	Single-Acting Hammers	(Peurifoy et al. 2006)
4.2.2.1.1.3	Double-Acting Hammers	(Peurifoy et al. 2006)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
4.2.2.1.1.4	Differential-Acting Hammers	(Peurifoy et al. 2006)
4.2.2.1.1.5	Diesel Hammers	(Peurifoy et al. 2006)
4.2.2.1.1.6	Hydraulic Impact Hammers	(Peurifoy et al. 2006)
4.2.2.1.1.7	Hydraulic Drivers	(Peurifoy et al. 2006)
4.2.2.1.1.8	Vibratory Pile Drivers	(Peurifoy et al. 2006)
4.2.2.2	Pile forming rigs (pile drilling rigs)	(International Organization for Standardization 2010)
4.2.2.3	Equipment for soil strengthening (grouting processes)	(International Organization for Standardization 2010)
4.2.2.4	Drill rigs for water wells, soil and, geothermal energy exploration, mining and quarrying, and other applications	(International Organization for Standardization 2010)
4.2.2.5	Diaphragm walling equipment	(International Organization for Standardization 2010)
4.2.2.6	Others	(International Organization for Standardization 2010)
4.2.3	Equipment for preparing, conveying and compaction of concrete, mortar and processing reinforceent	(International Organization for Standardization 2010)
4.2.3.1	Equipment for storage of materials	(International Organization for Standardization 2010)
4.2.3.2	Machines and equipment for concrete mix production	(International Organization for Standardization 2010)
4.2.3.2.1	Concrete mixing plants	(International Organization for Standardization 2010)
4.2.3.2.2	Concrete mix batching plants	(International Organization for Standardization 2010)
4.2.3.2.3	Concrete mixers	(International Organization for Standardization 2010)
4.2.3.3	Machinery and equipment for concrete mix transport from the producer to jobsite	(International Organization for Standardization 2010)
4.2.3.3.1	Truck mixers	(International Organization for Standardization 2010)
4.2.3.3.2	Truck mixers with concrete pumps or belt conveyors	(International Organization for Standardization 2010)
4.2.3.3.3	Concrete transport skips	(International Organization for Standardization 2010)
4.2.3.4	Machinery and equipment for conveying concrete mix to final location on the job site	(International Organization for Standardization 2010)
4.2.3.4.1	Concrete pumps	(International Organization for Standardization 2010)
4.2.3.4.2	Tower-mounted concrete mix distributing booms	(International Organization for Standardization 2010)
4.2.3.4.3	Self-loading mobile mixers	(International Organization for Standardization 2010)
4.2.3.4.4	Concrete dumpers	(International Organization for Standardization 2010)
4.2.3.4.5	Truck-mounted belt conveyors for concrete	(International Organization for Standardization 2010)
4.2.3.4.6	Feeders of fresh concrete and mortar	(International Organization for Standardization 2010)
4.2.3.4.7	Concrete buckets and concrete mix transfer tanks	(International Organization for Standardization 2010)
4.2.3.4.8	Concrete spraying machines	(International Organization for Standardization 2010)
4.2.3.5	Machines and equipment for placing concrete mix at its final location	(International Organization for Standardization 2010)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
4.2.3.5.1	Horizontal concrete mix distributors	(International Organization for Standardization 2010)
4.2.3.5.2	Concrete compactors: internal, external and surface vibrators	(International Organization for Standardization 2010)
4.2.3.5.3	Floor screeding and compaction equipment	(International Organization for Standardization 2010)
4.2.3.5.4	Floating machines	(International Organization for Standardization 2010)
4.2.3.5.5	Concrete vacuum treatment units	(International Organization for Standardization 2010)
4.2.3.6	Machines for plastering	(International Organization for Standardization 2010)
4.2.3.6.1	Plastering units for cement-lime mortars	(International Organization for Standardization 2010)
4.2.3.6.2	Spraying unit for plaster like coats	(International Organization for Standardization 2010)
4.2.3.6.3	Plastering units for gypsum mortars	(International Organization for Standardization 2010)
4.2.3.6.4	Equipment for storing and transporting dry mortar	(International Organization for Standardization 2010)
4.2.3.6.5	Mortar mixers and pumps	(International Organization for Standardization 2010)
4.2.3.6.6	Mortar rending units	(International Organization for Standardization 2010)
4.2.3.6.7	Float finish device	(International Organization for Standardization 2010)
4.2.3.7	Formworks and moulds	(International Organization for Standardization 2010)
4.2.3.8	Adjustable telescopic steel props	(International Organization for Standardization 2010)
4.2.3.9	Machinery and equipment for reinforcement work	(International Organization for Standardization 2010)
4.2.3.9.1	Steel bar bending/cutting machines	(International Organization for Standardization 2010)
4.2.3.9.2	Steel mesh bending/cutting machines	(International Organization for Standardization 2010)
4.2.3.9.3	Equipment for welding and fixation bars	(International Organization for Standardization 2010)
4.2.3.10	Equipment used for production of prestressed and postensioned concrete elements	(International Organization for Standardization 2010)
4.2.3.11	Others	(International Organization for Standardization 2010)
4.2.4	Lifting machinery and equipment	(International Organization for Standardization 2010)
4.2.4.1	Tower cranes	(International Organization for Standardization 2010)
4.2.4.1.1	Stationary	(International Organization for Standardization 2010)
4.2.4.1.2	Rail-mounted	(International Organization for Standardization 2010)
4.2.4.1.3	Track (moving on track)	(International Organization for Standardization 2010)
4.2.4.1.4	Climbing cranes (moving up with erected building structure)	(International Organization for Standardization 2010)
4.2.4.1.5	Quick-assembling (self-erecting)	(International Organization for Standardization 2010)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
4.2.4.2	Mobile cranes	(International Organization for Standardization 2010)
4.2.4.2.1	Truck mounted	(International Organization for Standardization 2010)
4.2.4.2.2	Terrain wheeled	(International Organization for Standardization 2010)
4.2.4.2.3	Crawler	(International Organization for Standardization 2010)
4.2.4.3	Derrick cranes	(International Organization for Standardization 2010)
4.2.4.4	Off-shore cranes	(International Organization for Standardization 2010)
4.2.4.5	Cable type cranes	(International Organization for Standardization 2010)
4.2.4.6	Gantry cranes	(International Organization for Standardization 2010)
4.2.4.7	Small capacity portable cranes, gantries and winches (up to 2500N lifting capacity)	(International Organization for Standardization 2010)
4.2.4.8	Variable-reach trucks	(International Organization for Standardization 2010)
4.2.4.8.1	Industrial trucks	(International Organization for Standardization 2010)
4.2.4.8.2	Variable reach rough-terrain forklift trucks (tele-handlers)	(International Organization for Standardization 2010)
4.2.4.9	Building hoists	(International Organization for Standardization 2010)
4.2.4.9.1	Builder's hoist for goods	(International Organization for Standardization 2010)
4.2.4.9.2	Builder's hoist for persons and materials	(International Organization for Standardization 2010)
4.2.4.10	Winches, pulley blocks, etc.	(International Organization for Standardization 2010)
4.2.4.11	Lifting accessories	(International Organization for Standardization 2010)
4.2.4.11.1	Lifting straps and slings	(International Organization for Standardization 2010)
4.2.4.11.2	Chains	(International Organization for Standardization 2010)
4.2.4.11.3	Steel wire ropes	(International Organization for Standardization 2010)
4.2.4.11.4	Hooks	(International Organization for Standardization 2010)
4.2.5	Access machinery and equipment	(International Organization for Standardization 2010)
4.2.5.1	Static scaffolds (stationary and portable)	(International Organization for Standardization 2010)
4.2.5.1.1	Tube coupler type	(International Organization for Standardization 2010)
4.2.5.1.2	Ladder type	(International Organization for Standardization 2010)
4.2.5.1.3	Prefabricated elements (system scaffolds)	(International Organization for Standardization 2010)
4.2.5.2	Hanging scaffolds and cradles	(International Organization for Standardization 2010)
4.2.5.2.1	Stationary	(International Organization for Standardization 2010)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
4.2.5.2.2	Mobile	(International Organization for Standardization 2010)
4.2.5.3	Elevating work platforms	(International Organization for Standardization 2010)
4.2.5.3.1	Mast climbing	(International Organization for Standardization 2010)
4.2.5.3.2	Mobile	(International Organization for Standardization 2010)
4.2.5.4	Trench lining equipment	(International Organization for Standardization 2010)
4.2.5.5	Others	(International Organization for Standardization 2010)
4.2.6	Equipment for installation, finishing work and maintenance	(International Organization for Standardization 2010)
4.2.6.1	Wallpaper preparation devices	(International Organization for Standardization 2010)
4.2.6.2	Facing works (ceramic tiles, stoneware setting)	(International Organization for Standardization 2010)
4.2.6.3	Painting and polishing equipment	(International Organization for Standardization 2010)
4.2.6.4	Machines for floor works	(International Organization for Standardization 2010)
4.2.6.5	Equipment for roof work (damp- proofing machines)	(International Organization for Standardization 2010)
4.2.6.6	Clean-up equipment	(International Organization for Standardization 2010)
4.2.6.7	Equipment for sanitary, electrical, gas and air-conditioning installations	(International Organization for Standardization 2010)
4.2.6.8	Equipment for fixing and connecting	(International Organization for Standardization 2010)
4.2.6.9	Others	(International Organization for Standardization 2010)
4.2.7	Road construction and maintenance machinery and equipment	(International Organization for Standardization 2010)
4.2.7.1	Machinery and equipment for pavement construction and restoration including among others powder binder spreaders and soil stabilizers	(International Organization for Standardization 2010)
4.2.7.2	Machines and equipment for bituminous binders including among others spreaders/sprayers	(International Organization for Standardization 2010)
4.2.7.3	Machines and equipment for asphalt mix production including asphalt mixing plants	(International Organization for Standardization 2010)
4.2.7.4	Machines and equipment for concrete asphalt pavement construction including among others chipping spreaders and asphalt pavers	(International Organization for Standardization 2010)
4.2.7.5	Machines and equipment for concrete pavement construction including among others slipform pavers	(International Organization for Standardization 2010)
4.2.7.6	Machines and equipment for finishing road works	(International Organization for Standardization 2010)
4.2.7.7	Road-cleaning machines	(International Organization for Standardization 2010)
4.2.7.8	Machines and equipment for removal of undesired vegetation	(International Organization for Standardization 2010)
4.2.7.9	Machines and equipment for road winter maintenance	(International Organization for Standardization 2010)
4.2.7.10	Machines and equipment for road repairs including road milling machinery	(International Organization for Standardization 2010)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
4.2.8	Machines and equipment for specialized works and processes in construction	(International Organization for Standardization 2010)
4.2.8.1	Machines and equipment for tunnel-building and underground engineering	(International Organization for Standardization 2010)
4.2.8.1.1	Shield tunnels	(International Organization for Standardization 2010)
4.2.8.1.2	Mountain tunnels	(International Organization for Standardization 2010)
4.2.8.2	Machines and equipment for underwater works — dredgers, pneumatic caisson, and others	(International Organization for Standardization 2010)
4.2.8.3	Machines and equipment for railway works — track-laying and restoration	(International Organization for Standardization 2010)
4.2.8.4	Bridge building equipment	(International Organization for Standardization 2010)
4.2.8.5	Machines for power and telecommunication lines construction	(International Organization for Standardization 2010)
4.2.8.6	Machines for aggregate processing — crushing, screening and washing equipment	(International Organization for Standardization 2010)
4.2.8.7	Demolition equipment	(International Organization for Standardization 2010)
4.2.8.7.1	Demolition units equipped with hydraulic brakers, hammers, shearers and pulverizers	(International Organization for Standardization 2010)
4.2.8.7.2	Water-jet concrete chipping units	(International Organization for Standardization 2010)
4.2.8.7.3	Hydraulic bursters	(International Organization for Standardization 2010)
4.2.8.8	Machines for recycling building materials	(International Organization for Standardization 2010)
4.2.8.9	Equipment for abrasives blasting	(International Organization for Standardization 2010)
4.2.8.10	Fireproof covering material spraying equipment	(International Organization for Standardization 2010)
4.2.8.11	Material handling equipment for interior finishes	(International Organization for Standardization 2010)
4.2.8.12	Machines and equipment for execution of buildings in automated building construction systems (ABCS)	(International Organization for Standardization 2010)
4.2.8.13	Wall saws and wire saws for job site	(International Organization for Standardization 2010)
4.2.8.14	Core drilling machines on stands	(International Organization for Standardization 2010)
4.2.8.15	Masonry and cutting-off machines for job site	(International Organization for Standardization 2010)
4.2.8.16	Floor cutting machines	(International Organization for Standardization 2010)
4.2.8.17	Pedestrien controlled-vibratory plates and rammers	(International Organization for Standardization 2010)
4.2.8.18	Equipment for protection of workers from accidents	(International Organization for Standardization 2010)
4.2.8.18.1	Barriers and nets	(International Organization for Standardization 2010)
4.2.8.18.2	Heavy machinery accident prevention systems	(International Organization for Standardization 2010)
4.2.8.19	Special equipment for topographic survey in construction works	(International Organization for Standardization 2010)
4.2.8.20	Equipment for maintenance buildings	(International Organization for Standardization 2010)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
4.2.8.21	Equipment for trenchless technology - pipeline internal inspection and rehabilitation systems	(International Organization for Standardization 2010)
4.2.8.22	Cleaning equipment for construction machinery, e.g. scaffold elements and undercarriages of building machines	(International Organization for Standardization 2010)
4.2.8.23	Equipment for inspection and monitoring: rooms' environment, piping, exterior wall tiles, underwater structures and so on	(International Organization for Standardization 2010)
4.2.8.24	Others	(International Organization for Standardization 2010)
4.2.9	General-use machinery and equipment used in construction	(International Organization for Standardization 2010)
4.2.9.1	On road trucks, tipping trucks, trailers and semi-trailers	(International Organization for Standardization 2010)
4.2.9.2	Industrial trucks	(International Organization for Standardization 2010)
4.2.9.3	Belt conveyors	(International Organization for Standardization 2010)
4.2.9.4	Screw and hydraulic lift jacks	(International Organization for Standardization 2010)
4.2.9.5	Capstans	(International Organization for Standardization 2010)
4.2.9.6	Machinery and equipment for generation, conversion and transmission of energy	(International Organization for Standardization 2010)
4.2.9.6.1	Electric power machines	(International Organization for Standardization 2010)
4.2.9.6.2	Thermal energy machines	(International Organization for Standardization 2010)
4.2.9.6.3	Compressed air machines	(International Organization for Standardization 2010)
4.2.9.6.3.1	Stationary Compressors	(Peurifoy et al. 2006)
4.2.9.6.3.2	Portable Compressors	(Peurifoy et al. 2006)
4.2.9.6.3.3	Rotary Compressors	(Peurifoy et al. 2006)
4.2.9.7	Hand-held motor-operated electric tools	(International Organization for Standardization 2010)
4.2.9.8	Electric, pneumatic, hydraulic and petrol-driven portable hand-guided hammers	(International Organization for Standardization 2010)
4.2.9.9	Equipment for welding and other jointing processes	(International Organization for Standardization 2010)
4.2.9.10	Pumps	(International Organization for Standardization 2010)
4.2.9.11	Ladders	(International Organization for Standardization 2010)
4.2.9.12	Measuring and inspection equipment	(International Organization for Standardization 2010)
4.2.9.13	Personal protection clothing and equipment: protection against falls, dust, gases, chemicals, mechanical and thermal injuries, noise and vibration	(International Organization for Standardization 2010)
4.2.9.14	Others	(International Organization for Standardization 2010)
4.3	Software	(El-Diraby et al. 2005)
4.4	Manpower	(El-Diraby et al. 2005), (Hendrickson 2000)
4.4.1	Foreman	(International Organization for Standardization 2014b)
4.4.2	Labour	(International Organization for Standardization 2014b)

Table A.1: Complete Taxonomy for Developed Tag Tree (continued)

Outline Code	Tag	Resource
4.5	Personnel	(El-Diraby et al. 2005)
4.5.1	Feasibility Consultan	(Hughes and Murdoch 2001)
4.5.2	Construction Manager	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
4.5.2.1	Section Manager	(International Organization for Standardization 2014b)
4.5.2.2	Site Manager	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
4.5.2.3	Construction Planner	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
4.5.2.4	Contract Manager	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
4.5.2.5	Project Manager	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
4.5.3	Design	(Hughes and Murdoch 2001)
4.5.3.1	Leed Designer	(Hughes and Murdoch 2001)
4.5.3.2	Acoustic Consultant	(Hughes and Murdoch 2001)
4.5.3.3	Architect	(Hughes and Murdoch 2001), (International Organization for Standardization 2014b)
4.5.3.4	Electrical Engineer	(Hughes and Murdoch 2001)
4.5.3.5	Mechanical Engineer	(Hughes and Murdoch 2001)
4.5.3.6	Enviromental Engineer	(Hughes and Murdoch 2001)
4.5.3.7	Structural Engineer	(Hughes and Murdoch 2001)
4.5.3.8	Fire Engineer	(Hughes and Murdoch 2001)
4.5.3.9	Geotechnical Engineer	(Hughes and Murdoch 2001)
4.5.3.10	Landscape Consultant	(Hughes and Murdoch 2001)
4.5.3.11	Materials Engineer	(Hughes and Murdoch 2001)
4.5.3.12	Traffic Consultant	(Hughes and Murdoch 2001)
4.5.4	Financial	(Hughes and Murdoch 2001)
4.5.4.1	Cost Consultant	(Hughes and Murdoch 2001)
4.5.4.2	Quantity Surveyor	(Hughes and Murdoch 2001)
4.5.4.3	Quantity Surveying Technician	(International Organization for Standardization 2014b)
4.5.5	Administration	(Hughes and Murdoch 2001)
4.5.5.1	Contract Administrator	(Hughes and Murdoch 2001)
4.5.5.2	Planning Supervisor	(Hughes and Murdoch 2001)
4.6	Material	(El-Diraby et al. 2005), (Hendrickson 2000)

APPENDIX B

B: AUTHORIZATION DETAILS

Table B.1: Relations between Roles and Operations

	Roles						
Operations	**Admin**	**Lesson Approval**	**Lesson Editing**	**Lesson Entry**	**Lesson View**	**Project Creation**	**User Management**
User Preferences - Admin Panel - Edit Library – Save	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Edit Library - Subjects – Remove	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Edit Library - Edit – Save	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Edit Library - Change Order of Subjects	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Edit Library - File Upload	✓	×	×	×	×	×	×
Actors - Add Actor – Save	✓	✓	✓	✓	×	✓	×
Actors - Display Actors – Remove	✓	✓	×	×	×	✓	×
Actors - Display Actors - Edit – Save	✓	✓	×	×	×	✓	×
User Preferences - Admin Panel - Roles and Authorization - Roles - Add New Role – Save	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Roles - Edit – Save	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Roles - Get All	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Roles - Get by Id	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Authorization – Search	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Authorization - Get Rules by Action Id	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Authorization - Authorize - Select Role	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Authorization – Remove	✓	×	×	×	×	×	×
User Preferences - Admin Panel - User Management - Users - Assign a Role To User – Add	✓	×	×	×	×	×	✓
User Preferences - Admin Panel - User Management - Users - Assign a Role To Use – Remove	✓	×	×	×	×	×	✓

Table B.1: Relations Between Roles and Operations (continued)

Operations	Roles: Admin	Lesson Approval	Lesson Editing	Lesson Entry	Lesson View	Project Creation	User Management
User Preferences - Admin Panel - Roles and Authorization - Roles – Remove	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Menu Role Relations - Select Menu - Get Associated Roles	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Menu Role Relations - Associate Role With Menu Item	✓	×	×	×	×	×	×
User Preferences - Admin Panel - Roles and Authorization - Menu Role Relations - Cancel Role Association	✓	×	×	×	×	×	×
User Preferences - Admin Panel - User Management - Users - Assign a Role To User - Get User Roles	✓	×	×	×	×	×	✓
Projects - Project Inputs - Project Types – Add	✓	×	×	×	×	✓	×
Projects - Project Inputs - Project Types – Remove	✓	×	×	×	×	✓	×
Projects - Project Inputs - Project Types – Edit	✓	×	×	×	×	✓	×
Projects - Project Inputs - Contract Types – Add	✓	×	×	×	×	✓	×
Projects - Project Inputs - Contract Types – Remove	✓	×	×	×	×	✓	×
Projects - Project Inputs - Contract Types – Edit	✓	×	×	×	×	✓	×
Projects - Project Inputs - Partnership Types Add	✓	×	×	×	×	✓	×
Projects - Project Inputs - Partnership Types – Remove	✓	×	×	×	×	✓	×
Projects - Project Inputs - Partnership Types – Edit	✓	×	×	×	×	✓	×
User Preferences - Tag Tree - Right Click – Add	✓	✓	×	×	×	×	×
User Preferences - Tag Tree - Right Click – Delete	✓	✓	×	×	×	×	×
User Preferences - Tag Tree - Left Click – Save	✓	✓	×	×	×	×	×
User Preferences - Tag Tree - Reset Tag Tree	✓	✓	×	×	×	×	×
User Preferences - Tag Tree - Change Location of Tag	✓	✓	×	×	×	×	×
Projects - Project Inputs - Technologies – Add	✓	×	×	×	×	✓	×
Projects - Project Inputs - Technologies – Remove	✓	×	×	×	×	✓	×
Projects - Project Inputs - Technologies – Edit	✓	×	×	×	×	✓	×
User Preferences - Project Similarity Coefficients - Save / Update	✓	×	×	×	×	✓	×
Projects - Add Project – Save	✓	×	×	×	×	✓	×
Projects - Display Project - Operations - Edit – Save	✓	×	×	×	×	✓	×
Projects - Display Project - Operations – Remove	✓	×	×	×	×	✓	×
Lesson Learned Entry – Save	✓	✓	✓	✓	×	×	×
Projects - Display Project - Lessons Learned Entry – Remove	✓	✓	×	×	×	×	×
Projects - Display Project - Lessons Learned Entry - Detail/Edit – Save	✓	✓	✓	✓	×	×	×
Projects - Display Project - Lessons Learned Entry - Approve/Disapprove	✓	✓	×	×	×	×	×
Display Lessons Learned - Filtering – Search	✓	✓	✓	✓	✓	×	×
Display Lessons Learned - Similarity – Search	✓	✓	✓	✓	✓	×	×
Display Lessons Learned - Tags – Search	✓	✓	✓	✓	✓	×	×
User Preferences - Admin Panel - User Management – Users	✓	×	×	×	×	×	✓
User Preferences - Admin Panel - User Management - Users – Search	✓	×	×	×	×	×	✓
User Preferences - Admin Panel - User Management - Users – Remove	✓	×	×	×	×	×	✓
User Preferences - Admin Panel - User Management - Users - Reset Password	✓	×	×	×	×	×	✓

Table B.2: Relations between Roles and Menu Links

Order No	Menu Link	Roles: Admin	Lesson Approval	Lesson Editing	Lesson Entry	Lesson View	Project Creation	User Management
1	Display Lesson Learned	✓	✓	✓	✓	✓	✗	✗
2	Lesson Learned Entry	✓	✓	✓	✓	✗	✗	✗
3	Projects	✓	✓	✓	✓	✓	✓	✗
3.1	Add Project	✓	✗	✗	✗	✗	✓	✗
3.2	Display Project	✓	✓	✓	✓	✓	✓	✗
3.3	Project Inputs	✓	✗	✗	✗	✗	✓	✗
3.3.1	Project Types	✓	✗	✗	✗	✗	✓	✗
3.3.2	Contract Types	✓	✗	✗	✗	✗	✓	✗
3.3.3	Partnership Types	✓	✗	✗	✗	✗	✓	✗
3.3.4	Technologies	✓	✗	✗	✗	✗	✓	✗
4	Actors	✓	✓	✓	✓	✓	✓	✗
4.1	Add Actor	✓	✗	✗	✗	✗	✓	✗
4.2	Display Actors	✓	✓	✓	✓	✓	✓	✗
5	User Preferences	✓	✓	✗	✗	✗	✓	✓
5.1	Tag Tree	✓	✓	✗	✗	✗	✗	✗
5.2	Project Similarity Coefficients	✓	✗	✗	✗	✗	✓	✗
5.3	Admin Panel	✓	✗	✗	✗	✗	✗	✓
5.3.1	User Management	✓	✗	✗	✗	✗	✗	✓
5.3.1.1	Add User	✓	✗	✗	✗	✗	✗	✓
5.3.1.2	Users	✓	✗	✗	✗	✗	✗	✓
5.3.2	Roles and Authorization	✓	✗	✗	✗	✗	✗	✗
5.3.2.1	Roles	✓	✗	✗	✗	✗	✗	✗
5.3.2.2	Authorization	✓	✗	✗	✗	✗	✗	✗
5.3.2.3	Menu Role Relations	✓	✗	✗	✗	✗	✗	✗
5.3.3	Edit Library	✓	✗	✗	✗	✗	✗	✗
6	Library	✓	✓	✓	✓	✓	✓	✓

APPENDIX C

C: TESTING DATA

Table C.1: List of Projects and Lessons Learned

<table>
<tr><td colspan="2">Project Name:
Project 1</td><td colspan="4">Project Scope:
Construction of 30-storey office building and 50.000 m2 shopping mall</td></tr>
<tr><td colspan="2">Project Type:
Trade Center</td><td>Client:
Client 2</td><td>Country:
Russian Federation</td><td>Partnership Type:
Consortium</td><td>Partner Company:
Partner 1</td></tr>
<tr><td colspan="2">Contract Type:
FIDIC</td><td>Start Date:
01/01/2001</td><td>End Date:
01/06/2004</td><td>Planned Duration:
1024 Workdays</td><td>Technologies:
Post-Tension Concrete
Tunnel Formwork</td></tr>
<tr><td colspan="6">Lesson List for Project 1</td></tr>
<tr><td>No</td><td colspan="4">Lessons Learned Title</td><td>Best practice or not</td></tr>
<tr><td rowspan="2">1</td><td colspan="4">Material procurement for permanent anchor</td><td></td></tr>
<tr><td colspan="5">Tags: Process, Contract Formation, Identify the Price, Management, Risk Management, Risk Sources, Contractor's Lack of Managerial Skills, Poor Procurement Management, Resource, Personnel, Financial, Cost Consultant, Material</td></tr>
<tr><td rowspan="2">2</td><td colspan="4">Site accessibility problems</td><td></td></tr>
<tr><td colspan="5">Tags: Actor, Regulators, Local Authority, Development Control Authority, Staff, Construction Manager, Site Manager, Project Manager, Process, Construction, Construction Works, Earthwork, Concrete Works, Management, Time Management, Planning / Schedules, Activity Duration Estimating, Delay, Causes of Delay, External Causes, Rules and Regulations Related Causes, Types of Delay, Compensability of Delay, Excusable compensable delays, Impacts of Delay, Cost Overrun</td></tr>
<tr><td rowspan="2">3</td><td colspan="4">Cold weather and productivity</td><td></td></tr>
<tr><td colspan="5">Tags: Actor, Staff, Worker, Foreman, Labour, Process, Management, Time Management, Delay, Causes of Delay, External Causes, Inclement Weather Causes, Financial Management, Cost Management, Cost Budgetin,g Cost Categories, Contractor's Direct Costs, Lost Productivity Costs, Human Resource Management, Staff Acquisition, Risk Management, Risk Identification</td></tr>
<tr><td rowspan="2">4</td><td colspan="4">High productivity on tunnel formwork/communication</td><td>Best Practice</td></tr>
<tr><td colspan="5">Tags: Actor, Staff, Design, Electrical Engineer, Mechanical Engineer, Structural Engineer, Process, Design, Design Branch, Mechanical Design, Construction, Construction Works, Concrete Works, Concrete Forming and Accessories, Concrete Forming, Mechanical Systems, Management, Communications Management, Communications Planning, Resource, Construction, Machinery and Equipment, Equipment for preparing, conveying and compaction of concrete, mortar and processing reinforcement, Formworks and moulds</td></tr>
<tr><td rowspan="2">5</td><td colspan="4">Delays in progress payments</td><td></td></tr>
<tr><td colspan="5">Tags: Actor, Client, Project Sponsor, Funder, Constructors, Partial Responsibility, Sub-contractor, Staff, Construction Manager, Contract Manager, Process, Management, Financial Management, Accounting Transactions, Paying an Employee's Wages, Receiving Payment from a Client, Cost Management, Cost Control, Performance Management, Productivity, Sub-Contractor, Risk Management, Risk Identification, Risk Response Planning, Transfer the Risk, Risk Sources, Lags in Cash Flow, Contract Management, Contract Document</td></tr>
<tr><td rowspan="2">6</td><td colspan="4">Visa limitations</td><td></td></tr>
<tr><td colspan="5">Tags: Process, Management, Risk Management, Risk Sources, Contractor's Lack of Experience, Contractor’s Lack of Experience in Country, Resource, Manpower, Labour</td></tr>
</table>

Table C.1: List of Projects and Lessons Learned (continued)

Project Name: Project 2	**Project Scope:** 1000 mw natural gas combined cycle power plant			
Project Type: Power Plant	**Client:** Client 1	**Country:** Turkmenistan	**Partnership Type:** Joint Venture	**Partner Company:** Partner 1
Contract Type: -	**Start Date:** 01/01/2003	**End Date:** 01/06/2008	**Planned Duration:** 1625 Workdays	**Technologies:** Building Information Modeling Pre-stressed Concrete Remove

Lesson List for Project 2

No	Lessons Learned Title	Best practice or not
1	**Inexperienced staff on BIM**	
	Tags: Process, Design, Stage, Information for Construction, Management, Human Resource Management, Team Development, Communications Management, Information Distribution, Document Management/Reporting, Resource, Sub-contractor, Specialist Sub-Contractor, Engineering Contractor, Software	
2	**Precast Element Delivery**	
	Tags: Actor, Constructors, Partial Responsibility, Supplier, Process, Contract Formation, Agree Contractual Terms, Construction, Construction Works, Concrete Works, Precast Concrete, Precast Structural Concrete, Management, Time Management, Planning / Schedules, Activity Sequencing, Delay, Causes of Delay, Contractor Causes, Subcontractor Causes, Types of Delay, Criticality of Delay, Non-critical delays: Delay to progress, Risk Management, Risk Sources, Contractor's Lack of Managerial Skills, Poor Procurement Management, Procurement Management, Procurement Planning, Communications Management, Document Management/Reporting, Contract Management, Contract Document	
3	**Low strength concrete**	
	Tags: Actor, Client, Client's Representative, Constructors, Partial Responsibility, Supplier, Staff, Construction Manager, Section Manager, Process, Construction, Construction Works, Concrete Works, Cast-in-Place Concrete, Structural Concrete, Management, Quality Management, Quality Control, Communications Management, Document Management/Reporting, Resource, Material	
4	**Scope change and design problems**	
	Tags: Process, Construction, Site Works, Site Set Up, Road construction, Management, Time Management, Delay, Causes of Delay, Owner Causes, Owner Generated Causes, Types of Delay, Criticality of Delay, Critical delays: Delay to completion, Impacts of Delay, Time Overrun, Cost Overrun, Mitigation of Delay, Changing the Work Sequence, Changing the Contract, Relaxing the contract restrictions, Delay Analysis, Financial Management, Cost Management, Cost Categories, Contractor's Direct Costs, Extended Temporary Utility and Facility Costs, Risk Management, Risk Sources, Changes in Project Specifications, Scope Changes, Claim Management, Claim, Result of a claim, Dispute	
5	**Unbalanced cash flow due to poor planning**	
	Tags: Project, Civil engineering works, Complex constructions on industrial sites, Complex constructions on industrial sites, Power plant constructions, Process, Contract Formation, Agree Contractual Terms, Construction, Plant Equipment, Management, Financial Management, Accounting Transactions, Receiving Payment from a Client, Lease Payments on a Capital Lease, Cost Management, Cost Control, Monitoring and Accounting, Procurement Management, Procurement Planning, Resource, Personnel, Financial, Cost Consultant	

Table C.1: List of Projects and Lessons Learned (continued)

Project Name: Project 3	**Project Scope:** 15-storey 10 block housing project			
Project Type: Housing Project	**Client:** Client 2	**Country:** Russian Federation	**Partnership Type:** -	**Partner Company:** -
Contract Type: FIDIC	**Start Date:** 01/01/2004	**End Date:** 01/05/2006	**Planned Duration:** 700 Workdays	**Technologies:** Tunnel Formwork

	Lesson List for Project 3	
No	**Lessons Learned Title**	**Best practice or not**
1	**Occupational accident due to scaffolding**	
	Tags: Process, Management, Time Management, Delay, Causes of Delay, Contractor Causes, Health and Safety Related Causes, Risk Management, Risk Sources, Strict Requirements, Strict Health & Safety Requirements, Safety and Environmental Management, Resource, Construction Machinery and Equipment, Access machinery and equipment, Static scaffolds (stationary and portable) , Prefabricated elements (system scaffolds) , Personnel, Construction Manager, Site Manager	
2	**Green building materials**	Best Practice
	Tags: Process, Contract Formation, Agree Contractual Terms, Management, Procurement Management, Procurement Planning	
3	**Inclinometer pipe placement problem**	
	Tags: Process, Construction, Site Works, Subsurface Investigation, Geotechnical Investigations, Construction Works, Earthwork, Special Foundations and Load-Bearing Elements, Driven Piles, Specialities and Equipment	
4	**Extracting and reusing inclinometer devices**	Best Practice
	Tags: Process, Construction, Construction Works, Earthwork, Excavation Support and Protection, Special Foundations and Load-Bearing Elements, Bored Piles, Resource, Construction Machinery and Equipment, Foundation and drilling equipment, Pile driving and extracting equipment	
5	**False productivity estimation for subcontractor**	
	Tags: Actor, Constructors, Partial responsibility, Sub-contractor, Specialist Sub-Contractor, Process, Management, Time Management, Planning / Schedules, Schedule Control, Acceleration (Fast tracking) , Financial Management, Cost Management, Cost Control, Performance Management, Productivity, Cost Categories, Contractor's Direct Costs, Lost Productivity Costs	

Project Name: Project 4	**Project Scope:** Three 13-storey apartment houses, 4 triplex villas and recreational facilities			
Project Type: Housing Project	**Client:** Client 2	**Country:** Turkmenistan	**Partnership Type:** -	**Partner Company:** -
Contract Type: -	**Start Date:** 01/01/2008	**End Date:** 01/07/2009	**Planned Duration:** 450 Workdays	**Technologies:** Tunnel Formwork

	Lesson List for Project 4	
No	**Lessons Learned Title**	**Best practice or not**
1	**Low productivity rate for local labor**	
	Tags: Process, Management, Financial Management, Cost Management, Cost Control, Performance Management, Productivity, Labor, Cost Categories, Contractor's Direct Costs, Field Costs, Labor Costs, Additional Labor Costs, Risk Management, Risk Sources, Adverse Country Related Conditions, Unavailability of Local Labor, Decrease in Productivity, Resource, Manpower, Labour	
2	**Import problem in customs for electronic devices**	
	Tags: Process, Construction, Electrical, Communication and Automation Systems, Integrated Automation, Management, Risk Management, Risk Sources, A.C. in Laws& Regulations, Procurement Management, Procurement Planning	
3	**Unexpected geotechnical conditions**	
	Tags: Process, Construction, Site Works, Subsurface Investigation, Geotechnical Investigations, Subsurface Drilling and Sampling, Geotechnical Monitoring Before Construction, Resource, Construction Machinery and Equipment, Earth-moving machinery and equipment, Foundation and drilling equipment	

Table C.1: List of Projects and Lessons Learned (continued)

Project Name: Project 5	**Project Scope:** 30-storey office and hotel building			
Project Type: Trade Center	**Client:** Client 2	**Country:** Kazakhstan	**Partnership Type:** -	**Partner Company:** -
Contract Type: FIDIC	**Start Date:** 01/01/2009	**End Date:** 01/10/2011	**Planned Duration:** 825 Workdays	**Technologies:** Post-Tension Concrete

Lesson List for Project 5		
No	**Lessons Learned Title**	**Best practice or not**
1	**Nominated sub-contractor**	
	Tags: Actor, Client, Client's Representative, Constructors, Partial Responsibilirty, Sub-contractor, Nominated sub-contractor, Process, Management, Time Management, Schedule Control, Progress Monitoring, Communications Management, Document Management/Reporting	
2	**Benefits of labour only sub-contractor**	Best Practice
	Tags: Actor, Staff, Worker, Labour, Process, Management, Financial Management, Accounting Transactions, Human Resource Management, Staff Acquisition, Contract Management, Contract Document, Resource, Sub-contractor, Labour-only Sub-contractor	
3	**Elevator sub-contractor**	
	Tags: Actor, Constructors, Partial Responsibility, Sub-contractor, Specialist Sub-Contractor, Supplier, Specialist Supplier, Regulators, Local Authority, Building Control Officer, Process, Design, Stage, Information for Construction, Specification, Construction, Conveying Equipment, Elevators	

Project Name: Project 6	**Project Scope:** 5 Million Tons Processing Capacity			
Project Type: Oil Refinery	**Client:** Client 3	**Country:** Libyan Arab Jamahir	**Partnership Type:** -	**Partner Company:** -
Contract Type: NEC3	**Start Date:** 01/01/2008	**End Date:** 01/01/2013	**Planned Duration:** 1500 Workdays	**Technologies:** Cold Formed Steel

Lesson List for Project 6		
No	**Lessons Learned Title**	**Best practice or not**
1	**Quality control problems**	
	Tags: Actor, Client, Client's Representative, Staff, Site Inspector, Resident Engineer, Process, Construction, Construction Works, Metal Works, Mechanical Systems, Process Interconnections, Gas and Vapor Process Piping and Ductwork, Welding and Cutting Gases Piping, Management, Time Management, Delay, Causes of Delay, Contractor Causes, Equipment Related Causes, Impacts of Delay, Time Overrun, Cost Overrun, Quality Management, Quality Control, Risk Management, Risk Sources, Strict Requirements, Strict Quality Requirements, Contractor's Lack of Managerial Skills, Poor Project Quality Management	
2	**Delay in delivery of process equipment**	
	Tags: Actor, Constructors, Partial Responsibility, Supplier, Specialist Supplier, Process, Construction, Plant Equipment, Industry-Specific Manufacturing Equipment, Petroleum and Coal Products Manufacturing Equipment, Management, Risk Management, Risk Identification, Risk Sources, Delays/ Interruptions	
3	**Local labour availability**	
	Tags: Actor, Constructors, Partial Responsibility, Sub-contractor, Labour-only Sub-contractor, Staff, Worker, Labour, Process, Management, Human Resource Management, Staff Acquisition, Risk Management, Risk Identification, Risk Response Planning, Transfer the Risk, Risk Sources, A.C. in Availability of Local Resources, Change in Availability of Labour	

Table C.1: List of Projects and Lessons Learned (continued)

Project Name: Project 7	**Project Scope:** 500 mw thermal power plant			
Project Type: Power Plant	**Client:** Client 1	**Country:** Libyan Arab Jamahir	**Partnership Type:** Joint Venture	**Partner Company:** Partner 1
Contract Type: FIDIC	**Start Date:** 01/01/2011	**End Date:** 01/04/2013	**Planned Duration:** 450 Workdays	**Technologies:** Building Information Modeling Pre-stressed Concrete

Lesson List for Project 7

No	Lessons Learned Title	Best practice or not
1	**Insufficient WBS and activities**	
	Tags: Actor, Staff, Construction Manager, Construction Planner, Process, Management, Time Management, Schedule Techniques, Critical Path Method (CPM), Planning / Schedules, WBS, Activity Sequencing, Activity Duration Estimating, Schedule Development, Activity Weights Definition, Schedule Control, Progress Monitoring, Resource, Software	
2	**Unrealistic unit price for steel erection**	
	Tags: Process, Construction, Construction Works, Metal Works, Structural Metal Framing, Structural Steel Framing, Management, Time Management, Planning / Schedules, WBS, Financial Management, Cost Management, Cost Estimating, Cost Budgeting, Cost Control, Monitoring and Accounting, Cost Loaded Schedule, Cost Categories, Contractor's Direct Costs, Field Costs, Labour Costs, Material Costs	
3	**Early delivery of generator equipment**	
	Tags: Actor, Staff, Construction Manager, Project Manager, Process, Management, Time Management, Planning / Schedules, Schedule Development, Schedule Control, Progress Monitoring, Risk Management, Risk Sources, Contractor's Lack of Managerial Skills, Poor Procurement Management, Procurement Management, Procurement Planning	

Project Name: Project 8	**Project Scope:** 600 mw thermal power plant			
Project Type: Power Plant	**Client:** Client 2	**Country:** Iraq	**Partnership Type:** -	**Partner Company:** -
Contract Type: NEC3	**Start Date:** 01/01/2012	**End Date:** 01/09/2014	**Planned Duration:** 825 Workdays	**Technologies:** Building Information Modeling Seismic Base Isolator

Lesson List for Project 8

No	Lessons Learned Title	Best practice or not
1	**Site security problem**	
	Tags: Process, Construction, Site Works, Site Set Up, Site security, Management, Risk Management, Risk Identification, Risk Checklist, Risk Response Planning, Risk Sources, Unexpected Events	
2	**3d model and clash detection**	Best Practice
	Tags: Process, Design, Stage, Information for Construction, Design Branch, Structural Design, Electrical Design, Mechanical Design, Management, Communications Management, Information Distribution, Information Systems, Resource, Software	
3	**Fire in temporary buildings**	
	Tags: Project, Buildings, Mobile And Temporary Buildings, Temporary Buildings, Actor, Constructors, Partial Responsibility, Sub-contractor, Specialist Sub-Contractor	

Table C.1: List of Projects and Lessons Learned (continued)

Project Name: Project 9	**Project Scope:** 65 km highway and 3 viaduct			
Project Type: Road / Viaduct	**Client:** Client 4	**Country:** Iraq	**Partnership Type:** Joint Venture	**Partner Company:** Partner 2
Contract Type: FIDIC	**Start Date:** 01/01/2013	**End Date:** 01/07/2017	**Planned Duration:** 1350 Workdays	**Technologies:** Precast Concrete

Lesson List for Project 9		
No	**Lessons Learned Title**	**Best practice or not**
1	**Delay due to Landslide**	
	Tags: Process, Design, Design Branch, Geotechnical Design, Construction, Site Works, Subsurface Investigation, Geotechnical Investigations, Subsurface Drilling and Sampling, Material Testing, Geotechnical Monitoring Before Construction, Construction Works, Earthwork, Earth Moving, Excavation and Fill, Excavation Support and Protection	
2	**Low contingency premium**	
	Tags: Actor, Client, Project Sponsor, Funder, Dispute Resolvers, Process, Management, Time Management, Schedule Control, Progress Monitoring, Delay, Causes of Delay, Owner Causes, Owner's Financial Causes, Types of Delay, Criticality of Delay, Critical delays: Delay to completion, Impacts of Delay, Cost Overrun, Dispute	
3	**Change in client economic conditions**	
	Tags: Actor, Client, Project Sponsor, Funder, Dispute Resolvers, Process, Management, Time Management, Schedule Control, Progress Monitoring, Delay, Causes of Delay, Owner Causes, Owner's Financial Causes, Types of Delay, Criticality of Delay, Critical delays: Delay to completion, Impacts of Delay, Cost Overrun, Dispute	

Table C.1: List of Projects and Lessons Learned (continued)

<table>
<tr><td colspan="2">Project Name:
Project 10</td><td colspan="4">Project Scope:
46 km. long, 15 m. wide highway and related structures</td></tr>
<tr><td colspan="2">Project Type:
Road / Viaduct</td><td>Client:
Client 5</td><td>Country:
Russian Federation</td><td>Partnership Type:
Joint Venture</td><td>Partner Company:
Partner 1</td></tr>
<tr><td colspan="2">Contract Type:
NEC3</td><td>Start Date:
01/01/2013</td><td>End Date:
01/11/2016</td><td>Planned Duration:
1150 Workdays</td><td>Technologies:
Seismic Base Isolator
Pre-stressed Concrete</td></tr>
<tr><td colspan="6">Lesson List for Project 10</td></tr>
<tr><td>No</td><td colspan="4">Lessons Learned Title</td><td>Best practice or not</td></tr>
<tr><td rowspan="2">1</td><td colspan="4">Late expropriation and delay</td><td></td></tr>
<tr><td colspan="5">Tags: Process, Management, Time Management, Planning / Schedules, Schedule Development, Delay, Causes of Delay, Owner Causes, Types of Delay, Criticality of Delay, Critical delays: Delay to completion, Impacts of Delay, Cost Overrun, Financial Management, Cost Management, Cost Categories, Contractor's Direct Costs, Acceleration Costs, Claim Management, Claim, Kinds of Claim, Variation Claims, Different site conditions claims/Latent condition claims, Quantum Meurit Claims, Total cost claim, Result of a claim, Dispute</td></tr>
<tr><td rowspan="2">2</td><td colspan="4">Weather condition and low asphalt cast rate</td><td></td></tr>
<tr><td colspan="5">Tags: Process, Management, Time Management, Planning / Schedules, Schedule Development, Delay, Causes of Delay, External Causes, Inclement Weather Causes, Impacts of Delay, Lost Productivity, Financial Management, Cost Management, Cost Control, Performance Management, Productivity, Risk Management, Risk Sources, Decrease in Productivity</td></tr>
<tr><td rowspan="2">3</td><td colspan="4">Precast beam delivery problem for viaducts</td><td></td></tr>
<tr><td colspan="5">Tags: Actor, Constructors, Partial Responsibility, Supplier, Specialist Supplier, Process, Construction, Construction Works, Concrete Works, Precast Concrete, Precast Structural Concrete, Management, Time Management, Planning / Schedules, Risk Management, Risk Sources, Contractor's Lack of Managerial Skills, Poor Procurement Management, Procurement Management, Procurement Planning</td></tr>
<tr><td rowspan="2">4</td><td colspan="4">Quantity increase and project cost change</td><td>Best Practice</td></tr>
<tr><td colspan="5">Tags: Actor, Staff, Financial, Quantity Surveyor, Process, Management, Financial Management, Cost Management, Cost Estimating, Cost Estimating Data, Quantity Take-off, Cost Budgeting, Risk Management, Risk Sources, Changes in Project Specifications</td></tr>
<tr><td rowspan="2">5</td><td colspan="4">Quality problem on ballast material</td><td></td></tr>
<tr><td colspan="5">Tags: Actor, Staff, Site Inspector, Clerk of Works, Process, Management, Quality Management, Quality Objectives, Quality Assurance, Risk Management, Risk Sources, Adverse Country Related Conditions, Unavailability of Local Material, Strict Requirements, Strict Quality Requirements, A.C. in Availability of Local Resources, Change in Availability of Material, Cost Overrun</td></tr>
</table>

<table>
<tr><td>Project Name:
Project 11</td><td colspan="4">Project Scope:
1000 mw thermal power plant</td></tr>
<tr><td>Project Type:
Power Plant</td><td>Client:
Client 2</td><td>Country:
Russian Federation</td><td>Partnership Type:
-</td><td>Partner Company:
-</td></tr>
<tr><td>Contract Type:
FIDIC</td><td>Start Date:
01/06/2017</td><td>End Date:
01/09/2020</td><td>Planned Duration:
850 Workdays</td><td>Technologies:
Building Information Modeling
Pre-stressed Concrete</td></tr>
</table>