IMPROVING KNOWLEDGE CAPTURE DURING CONCEPTUAL DESIGN PHASE OF BUILDING PROJECTS

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Dedicated to

My dearest parents

whose endless love and care supported me all through the way

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Incomplete knowledge flow between architects and mechanical/electrical engineers engenders large expense and untimely delivery of building projects. It is essential to consider mechanical/electrical requirements from the early stages of design; and many experienced architects acknowledge this knowledge entities and the necessity for considering them at the right time. Therefore, inefficient knowledge flow among professionals during architectural conceptual design is emphasized as a problem for this study. For overcoming this problem, the study intends to improve knowledge capture during conceptual design phase of building projects by formalizing the fundamental requirements of necessary mechanical/electrical knowledge during this phase. To achieve this goal, this research develop three objectives: 1) Specify an appropriate knowledge capture technique for tacit dominated conceptual design phase; 2) Identify fundamental mechanical/electrical requirements to consider by architects during conceptual design phase; and 3) Develop a framework for formalizing tacit mechanical/electrical knowledge during conceptual design phase. Firstly, the study selects an appropriate technique to capture expert's tacit knowledge based on a literature survey by matching existing knowledge capture techniques with conceptual design characteristics. Secondly, mechanical/electrical knowledge is obtained through a case study during conceptual design of a green building project. The mechanical/electrical knowledge and activities are matched in the McMillan Framework (2001) for the conceptual design phase. Later, mechanical/electrical knowledge is matched and assigned to the architectural concept design activities. At the conclusion of the exercise, the study developed a mechanical/electrical knowledge-based framework for the conceptual design phase. Validation of the results was obtained by using computational organizational theory simulation. This study contributes in extending McMillan's Framework to include explicit fundamental required mechanical/electrical knowledge during the conceptual design phase; developing a tacit knowledge capture technique by combining tacit observation and explicit repertory grid documentation; and improving Nissen's (2006) multidimensional model (MDM) by integrating knowledge into Macmillan's framework for conceptual design activities. These results support the need to mitigate potential knowledge losses in tacit-dominant area between experts during conceptual design phase of building projects.

Abstrak ini dibentangkan kepada Senat Universiti Putra Malaysia bagi memenuhi salah satu syarat untuk bergraduat Ijazah Kedoktoran

PENINGKATAN PEMEROLEHAN PENGETAHUAN DALAM FASA KONSEP PROJEK REKA BENTUK BANGUNAN

Oleh

ZOHREH POURZOLFAGHAR

NOVEMBER 2010

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FAKULTI : Kejuruteraan

Aliran ilmu yang tidak efisyen di antara arkitek-arkitek dan jurutera mekanikal/elektrikal diketahui mengakibatkan kos yang tinggi dan kelewatan penyerahan projek binaan tersebut. Adalah penting untuk mempertimbangkan keperluan mekanikal/elektrikal dari fasa awal reka bentuk; dan ramai arkitek yang berpengalaman mengiktirafkan entiti ilmu ini dan kepentingannya untuk dipertimbangan pada masa yang tepat. Justru, kajian ini memfokus kepada permasalahan aliran ilmu yang kurang efisyen di kalangan professional semasa reka bentuk konsep seni bina. Bagi mengatasi permasalahan tersebut, kajian ini bertujuan untuk menambahbaik pemerolehan ilmu semasa fasa reka bentuk konsep projek binaan melalui proses formalisasi keperluan asas mekanikal/elektrikal yang diperlukan semasa fasa ini. Bagi mencapai sasaran ini, kajian membangunkan tiga objektif: 1) merumuskan spesifikasi teknik pemerolehan ilmu untuk fasa reka bentuk yang *tacit-dominant;* mengenal pasti asas keperluan

mekanikal/elektrikal untuk dipertimbangkan oleh arkitek semasa fasa reka bentuk konsep; dan 3) membangunkan sebuah kerangka bagi mengformalisasikan ilmu mekanikal/elektrikal yang *tacit* semasa fasa reka bentuk konsep. Pertamanya, memilih teknik yang bersesuaian bagi memperoleh ilmu melalui kajian perbandingan teknik pemerolehan ilmu sedia ada yang berpadanan dengan ciri-ciri reka bentuk konsep. Keduanya, mendapatkan ilmu mekanikal/elektrikal melalui kajian kes sebuah projek bangunan hijau semasa reka bentuk konsepnya. Ilmu dan aktiviti-aktiviti mekanikal/elektrikal dan aktiviti akan dipadankan dengan Kerangka McMillan (2001) untuk fasa reka bentuk konsep. Setelah itu ilmu mekanikal/elektrikal dipadankan dan ditugaskan kepada aktiviti reka bentuk konsep seni bina. Di akhir langkah ini, kajian membangunkan sebuah kerangka berasaskan ilmu mekanikal/elektrikal untuk fasa reka bentuk konsep. Kesahan hasil kajian didapati dengan mengunakan simulasi *computational organizational theory*. Kajian ini menyumbang di dalam memanjangkan Kerangka McMillan untuk melibatkan keperluan asas ilmu mekanikal/elektrikal yang eksplisit semasa fasa reka bentuk konsep; membangunkan sebuah teknik pemerolehan ilmu yang menggabungkan pemerhatian *tacit* dan explicit *repertory grid documentation*; dan menambah baik multidimensional model (MDM) oleh Nissen (2006) dengan mengintegrasikan ilmu ke dalam aktiviti-aktiviti reka bentuk konsep Kerangka MacMillan. Dapatan dari kajian ini menyokong keperluan untuk mengurangkan potensi kehilangan ilmu di dalam bidang yang *tacit-dominant* di kalangan pakar semasa fasa reka bentuk konsep projek binaan.

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I certify that an Examination Committee has met on 17 March 2011 to conduct the final examination of Zohreh Pourzolfaghar on his Doctor of Philosophy thesis entitled "Improving Knowledge Capture during Conceptual Design Phase of Building Projects" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and is not concurrently submitted for any other degree at Universiti Putra Malaysia or at any other institution.

Zohreh Pourzolfaghar

Date:

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Many researchers have found out that there are some problems in construction industry, which are related to knowledge flow during a building project's life cycle. They also explained that this problem could arise from tacit dominated area of building projects. Some of these notions are discussed below:

Paulson (1976) and Jin & Levitt (1996) stated that incomplete knowledge transfer cause unnecessary rework delay and lost revenue in the construction industry. Ibrahim (2005) explained that knowledge always tends to lie on the critical path of workflow, and as a result affects duration as well as its cost. Hence, we know that in 2005 construction industry was still facing this problem. In addition, Ibrahim and Nissen (2007) believed that knowledge, which was moving through the building project's workflows, could affect its performance. Furthermore, Ibrahim & Paulson (2008) in their qualitative research revealed how incomplete knowledge flows can influence competitive advantage in the construction industry. Nissen (2006) expressed that the flow of knowledge was critical to an organization success. Furthermore, he supports that the flow of knowledge always tends to lie on the critical path of workflows and, as a result, affects organizational performance.

Therefore, Nissen (2006) and Ibrahim and Paulson (2008) expressed importance of knowledge flow to complete a building project successfully. Ibrahim (2008) found that one characteristic which contributes to the knowledge loss phenomenon is the different dominating knowledge types for each lifecycle phase. She argued that knowledge problems could relate to knowledge type. Therefore, the study supports the need to consider different knowledge types in construction industry situations.

Wheeler (Sanvido and Norton, 1994) divided the life of an architectural construction project into nine major phases from planning to occupancy of the facility. Wheeler's fourth, fifth, and sixth phases cover the design stage of a building project to determine sub activities and outputs (Sanvido & Norton, 1994). Martinez(1998) stated that knowledge leaks resulting from the lack of a heightened degree of knowledge sharing, cause repeated mistakes, dependence on a few key individuals, duplicated work, lack of sharing of good ideas, and slow introduction of new products or market solutions. Therefore, in support of Nissen (2006) who stated that knowledge sharing is one stage in knowledge flow life cycle, Martinez had similarly expressed that these problems are due to knowledge flow that cause time and cost overruns. Additionally, Ahmed (2005) stated that engineering firms are facing pressures to increase the quality of their product and to have even shorter lead-time and cost reduction. Many researchers such as Macmillan (2001), Martinez (1998), and Ibrahim (2008) have argued to refocus on the design stage in a building project life cycle since this is the source of long-term time and cost overruns, which arise from inefficient knowledge flow. Indeed, Ibrahim and Paulson (2008) pinpointed that the critical stage where knowledge loss starts to be initiated, is when the building project's team is still struggling to integrate the structural and service requirements of a building while the project sponsor has locked-in the cost and time factors as the source of many design mis-coordination. Accordingly, it is the purpose of this study to improve the knowledge flows at this problematic source.

O'dell et al. (2000) & Mertins et al. (2001) explained that many practitioners get benefit from knowledge management including revenue growth, shorter design time etc. Shelborn (2006) also stated effective KM could reduce project time and cost, improve quality, and provide a major source of competitive advantage for the construction organizations. For this purpose, O'dell (2000) and Shelborn (2006) have introduced KM as a solution for time and cost overrun. This study gains further support as many researchers such as Paulson (1976), Jin & Levitt (1996), Ibrahim & Paulson (2008) emphasize that there are recurring problems related to time and cost in the construction industry. Furthermore, they argued that a large amount of these problems could be explained from the knowledge flow perspective. Studies by Ibrahim and Nissen (2007) and Shumate, Ibrahim and Levitt (in press) provided empirical support on how the overall performance of a building project's team is related to their tacit comprehension specifically to the early design phase. Additionally, researchers such as O'dell et al. (2000), Mertins et al. (2001), Shelborn (2006) and Ibrahim (2008) have stated that effective knowledge management can reduce building project's time and cost and improve quality. Therefore, the researcher posits that focusing more on implementing knowledge management process during design stage can facilitate knowledge flow for improving quality while maintaining time and cost.

Despite the abovementioned arguments, Pektaş (2006) highlighted the lack of research in better understanding and manipulating knowledge flows in project organizations. Even though these organizations have the desire and need to learn from experience, Scott and Harris's (1998) study noted reasons of lacking of time and money and increasing pressure of upcoming work for not capturing and sharing knowledge effectively. For knowledge to be sustainable for competitive advantage and the improvement of organizational performance, project organization must gather and store all its reusable knowledge and make it accessible to others (Javernick et al., 2007). Hence, this thesis supports Levitt (2007) who had suggested that future work about discovering how new processes and mechanisms can facilitate knowledge sharing to deliver a built environment which is more economically, environmentally and socially sustainable through a global supply chain (Levitt, 2007). It is in this direction that this study wants to focus on.

1.2 Definition of Terms

In this section, we explain the frequently used terms.

Knowledge: Knowledge is a set of commitments and beliefs of its holder that enables him/her to undertake certain actions (Nonaka 1994).

Tacit knowledge: Tacit knowledge is highly personal, context specific, and hard to formalize and communicate (Polanyi, 1967).

Explicit knowledge: Explicit knowledge can readily be codified in words and numbers, easily shared in manuals, and is easy to distribute. It can be stored as written documents or procedures and made available to others (Payne and Sheehan, 2004).

Knowledge Management: knowledge Management deals with creating, securing, capturing, coordinating, and combining, retrieving and distributing knowledge (Tserng & Lin, 2005).

Knowledge Conversion: Interaction between the two types of knowledge is called knowledge conversion. Through the conversion process, tacit and explicit knowledge expands in both quality and quantity (Nonaka, 2000).

Knowledge Flows: The process of moving knowledge by way of communicating to retrieve or allocate working information of any knowledge type (either tacit or explicit) that would enable an individual or enterprise to complete a workflow process (Ibrahim, 2005).

Design process: Design is the process by which the needs, wishes, and desires of the owner are defined, quantified, qualified, and communicated to the builder (Sanvido, 1994).

Conceptual Design: The conceptual design phase of any project is a stage of building project life cycle in which major decisions are taken regarding the building type, occupancy, form, dimensions, and type of structural system (Fenevis, 2000).

1.3 Statement of the Problem

Incomplete knowledge flow between building project's team members during conceptual design stage leads to cost and time overrun in building projects. Since, Ibrahim and Paulson (2008) have identified the design development phase as critical phase where knowledge losses are initiated, this study is guided to focus on knowledge moves between two critical professionals: the architect and the mechanical/electrical engineers. Many mechanical and electrical requirements are essential to consider from the early steps of design stage. Many experienced architects are familiar with the mechanical and electrical knowledge requirements and the necessity of considering them at the right time. Due to their familiarity, these experts are more successful in preventing rework resulting from not considering essential requirements. However, the existence of a plethora of requirements may make it difficult in keeping them all in mind. On the other hand, novice architects may not have sufficient knowledge about what they should consider from the mechanical/electrical engineering standpoint. In addition, their low-level experience may lead them to ignoring those requirements at the right time. Hence, potential reworks in design integration may occur later, if not sooner. As a conclusion, this study attempt to expose the required mechanical/electrical knowledge during conceptual design stage to reduce rework and its related over-cost that arises from incomplete knowledge flow perspective. This study wants to propose a knowledge-based framework for concept design in which the right mechanical and electrical knowledge can be specified at the right time.

1.4 Research Questions

The main research question for this study is stated below:

> *Main RQ:* How can tacit knowledge of design requirements be formalized for improving knowledge-flows among professionals during conceptual design phase of building projects?

To answer the main research question there are three sub-research questions:

> *Sub-RQ1:* What are techniques to formalize mechanical/electrical knowledge of design requirements during conceptual design phase of building projects?
>
> *Sub-RQ2:* What are the required mechanical/electrical knowledge during the conceptual design phase of building projects?
>
> *Sub-RQ3:* How do architects and mechanical/electrical engineers know when to transfer the required knowledge for improving conceptual design phase of building projects?

1.5 Research Objectives

There are three objectives for this research, which are explained hereunder:

1- To specify an appropriate knowledge capture technique for tacit dominated conceptual design phase.
2- To identify fundamental mechanical/electrical requirements to consider by architects during conceptual design phase.
3- To develop a framework for formalizing tacit mechanical/electrical knowledge during conceptual design phase.

1.6 Research Methodology

Whereas knowledge of experts is a kind of thinking phenomena, Denzin and Lincoln (2000) recommended use qualitative method. Moreover, to discover this knowledge the process of conceptual design of a building project has to be analyzed. According to Creswell (2003), qualitative research can take place in site or office as it involves actual experience of participants. Based on the abovementioned reasons, qualitative method is appropriately used to solve the stated problem for this research. With the main "how" research question, Yin (2003) recommended case study research methodology to be considered.

1.6.1 Research Framework

Yin (2003) stated that there five components for this case study methodology: (1) research question; (2) theoretical proposition; (3) unit of analysis; (4) linking data to proposition; and (5) criteria for interpreting data. The framework of this research is shown in Figure 1.1.

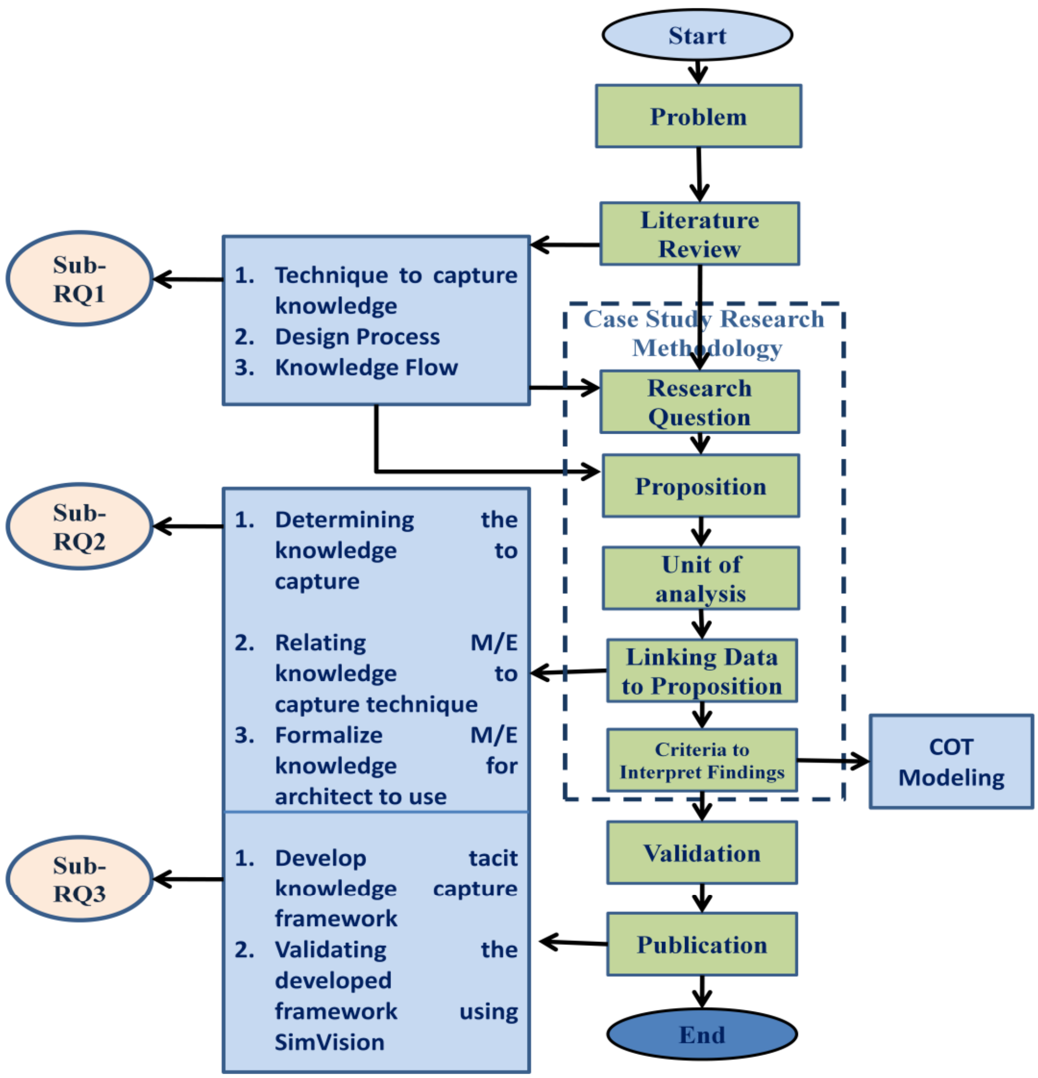

Figure 1.1. Research Framework

Five main components of case study according to Yin (2003) are explained in the following sections:

1.6.2 Research Questions

Main research question of this research is, “how can tacit knowledge of mechanical/electrical requirements be formalized for improving knowledge flows among design professionals during conceptual design phase of a building project?”

1.6.3 Theoretical Proposition

With reference to Yin (2003) there are two general analytic strategies consisting of: (1) relying on theoretical proposition and, (2) developing a case description. Since we have a theoretical proposition, we will rely on a theoretical proposition.

Based on literature -about knowledge flow in construction industry, conceptual design process, difficulty of organizing and formalizing tacit knowledge- the study proposes, “By understanding tacit knowledge early at the conceptual design stage of a building project, a project team can improve its organizational performance by facilitating knowledge flow” as the project progresses.

1.6.4 Unit of Analysis

The unit of analysis for this study is a team of six 4th year architectural students in a public university who won a competition to design a building project. The Faculty of Design and Architecture undertakes the concept design stage of the project. This project investigates various building technologies that could reduce the impact of building on the environment. This building project was selected due to importance of considering all mechanical and electrical requirements for Green building project.

1.6.5 Linking Data to Proposition

To provide a linkage between collected data and proposition there is a need to go through the following steps:

1- Capturing mechanical/electrical tacit knowledge of experts through the conceptual design stage of ITMA building project, by observing team members' activities to specify the required knowledge during this stage;

2- Explicating mechanical/electrical tacit knowledge during conceptual design phase of ITMA building project, by proposing a tacit knowledge capture technique to expedite knowledge movement;

3- Making the mechanical /electrical knowledge applicable through the concept design stage by proposing a knowledge-based framework to enable work flow; and

4- Validating the proposed knowledge-based framework, during concept design phase by simulating the results using SimVision.

To validate the proposed knowledge-base framework for the conceptual design phase of the building project using Simvision, we develop three hypothesizes which arise from tacitness and explicitness of knowledge. The results from simulation corroborate improvement of project performance arising from utilizing knowledge-base framework for conceptual design phase. More details about linking the collected data to the proposition are explained in Chapter 3.

1.6.6 Criteria for Interpreting the Findings

We have two criteria for interpreting data:

1- Checking collected data against mechanical/electrical requirements (Berberry, 1992), and green building standards for Malaysia (such as MS 1525). We expect that the proposed concept to satisfy more than 95% of mechanical/electrical and green building standards.

2- Simulating the proposed framework by this study, using computational organizational tool (COT) by SimVision software. To validate the proposed framework, results of simulating existing framework is compares with the result of simulating the proposed framework which entails the required knowledge. This study will use SimVision (Computational Organizational Tool) to simulate the base framework and also the proposed framework.

Then, the PRI (Project Risk Index) and FRI (Functional Risk Index) for both models are compared. These two factors have to be under 0.5. Simvision defines Project Risk Index (PRI) represents the likelihood that the components produced by this project will not be integrated at the end of the project, or that the integration will have defects based on rework and exception handling. On the other hand, Functional Risk Index (FRI) represents the likelihood that components produced by this facility development have defects based on rework and exception handling. FRI and PRI for the proposed framework have to be less than the base line model. Hence, there are two main criteria to interpret the finding:

As a result, the study hypothesizes that:

H1: A building project team member who has sufficient knowledge which is required for other team members' tasks can improve performance of the receiver's task. The study expects the FRI and PRI to be less than 0.5.

H2: A building project team member who does not have sufficient knowledge which has to be considered by other team members to do their task, by transferring incomplete knowledge can increase the risk involved in the receiver's task. The study expects the FRI and PRI to be less than 0.5.

H3: By specifying the entity of the required knowledge during conceptual design phase, performance of building project improves due to explicitness of entity of knowledge. The study expects the FRI and PRI to be less than 0.5.

The study expects all three hypothesizes be affirmed for supporting the proposed framework.

1.7 Importance of Study

Many researchers support that stakeholders in construction industry such as consulting firms and property developers would benefit from completing their project on time if they maintain their tacit knowledge asset, which give them competitive advantage. Construction industry can make more profit when property developers have higher success rates in completing their project from conception to construction within the specified time and cost (Ibrahim & Paulson, 2008). In construction industry, tacit knowledge has been recognized as a critical resource in the development of sustainable competitive advantage and firm growth (Woo et al., 2004).

Sternberg et al. (2000) pointed out the contribution of tacit knowledge to successful performance and to the establishment of a relationship between the possession of tacit knowledge and job performance. Particularly, they insisted that tacit knowledge could be a source of highly effective performance in workplace. In addition, they expressed that the efficacy of tacit knowledge depends on effective acquisition and utilization (Strenberg et al., 2000).

Construction industry is an information and knowledge-rich industry. However, because of its fragmented, project-based nature and the wide variety of trades involved in it, information and knowledge are scattered over different processes, trades, and the people in different construction projects in an organization. Knowledge stored within an employee who develops it, is difficult for others to access, and the loss rate is high when the employee moves from one company to another.

Managing knowledge effectively is critical to the survival and advance of a company, especially in project-based industries such as construction. However, capturing knowledge in construction projects is a tedious task, as knowledge is usually experience based, tacit, and hard to pass on to others (Kirvak, et al. 2008). In today's knowledge-based economy, effective knowledge management can reduce project time and cost, improve quality, and provide a major source of competitive advantage for the construction organizations (Shelbourn, et al. 2006). Being a project-based industry where experience-based knowledge is generated at every stage of a project, the construction industry has the potential to benefit from systematic management of knowledge; however, effective mechanisms should be developed, especially for capturing and reusing tacit knowledge (Kirvak, et al. 2008).

An organization's competitive advantage lies in the knowledge residing in the heads of its employees and the capability to harness the knowledge for meeting its business objectives. The efforts to share and reuse knowledge generated on construction projects are undermined mainly by the loss of important insights and knowledge due to the time lapse in capturing the knowledge, staff turnover, and people's reluctance to share knowledge. To address this, it is crucial for knowledge to be captured "live" in a collaborative environment while the project is being executed and presented in a format that will facilitate its reuse during and after the project (Tan, et al. 2007). Construction projects usually involve many disciplines and require integration of knowledge from civil, mechanical, electrical, and other engineering domains. Therefore, the technical knowledge required for delivering construction projects effectively is quite diverse. The accumulation and preservation of such knowledge plays a vital part in the company's success (Mohamed & AbouRizk, 2005).

Arain et al. (2004) argues that integration of construction knowledge and experience at the early design phase could improve overall project performance in the construction industry. Arain (2005) advocates providing a structured and systematic way to aid the transfer and utilization of construction knowledge and experience; also, organizing this knowledge is essential during the early design process. Arain and Low (2005a) identified the design phase as the most likely area on which to focus, to reduce the variations in future institutional projects. Arain (2005b) believed that focusing on what the project team can do to eliminate these problems at the design phase can be a way to reduce these problems. Ellis et al. (2002) stated that building designers are being increasingly pressurized to design buildings with high standards of energy efficiency, performance and comfort in the shortest possible time.

According to many researchers such as Lizardos (1993), Kereider et al. (1994), Kato (1995), and Coad (1997), modern buildings and their heating, ventilation and air-conditioning (HVAC) systems are required to be more energy efficient while adhering to an ever-increasing demand for better indoor air quality and performance. Economical considerations and environmental issues also need to be taken into account. Chow et al. (2005) contends that developed countries emphasize the protection of the environment, using less energy through natural ventilation provisions and daylight utilization, developing better waste management and reckoning with water conservation. In this way, they reason that architectural and building design, electrical and mechanical systems, and building management have to be upgraded.

Kuo et al. (2011) state that modern buildings are equipped with a diverse range of service systems, such as mechanical, electric, and plumbing (MEP) works, which include air-conditioning (AC) conduits, water and gas pipes, irrigation and sanitary lines, telecommunication and security networks, HVAC and LVAC, fire fighting and fire control, and so forth. Investigators are continuing to add more sensitive regulatory systems in modern buildings to make the living spaces more convenient, comfortable, decorative and safer, as well as energy-saving. However, De Saram (2001), Riley (2005) and Khanzode (2008) conclude that multi-system facilities of a building significantly increase the complexity of the planning, design, and construction management processes. Many researchers have also pointed out that coordination is one of the most critical challenges in a project involving multiple systems.

Fischer et al. (2002) and Liston et al. (2000) contend that a typical modern project involves many experts and contractors as multiple sources of information which have complex informational interdependencies. This could influence many aspects of project such as work schedule. Project teams very often spend a great amount of time trying to describe, explain, and understand the interdependencies of project information and could fail to leverage off the interdependencies between various construction project information, and thus struggle with decision-making.

In conclusion, it is apparent that the construction industry can benefit when the projects have higher success within time and cost rates. Moreover, tacit knowledge has been recognized as a critical resource, which contributes to successful building project's performance. Efficacy of tacit knowledge depends on effective acquisition and utilization. Additionally, the construction industry has the potential to benefit from systematic management of knowledge especially for capturing and reusing tacit knowledge. Construction projects usually involve many disciplines and require integration of knowledge from civil, mechanical, electrical, and other engineering domains. According to the studied literature, many problems reported by different researchers associated with knowledge movement during design phase. Furthermore, considering increasing advancement of mechanical and electrical technologies, realized that considering mechanical and electrical knowledge during design phase is essential.

As a result, it has been realized that live capture of mechanical and electrical knowledge in collaborative project environment is crucial to knowledge loss phenomena. Considering the abovementioned story, this study attempted to facilitate knowledge capture during conceptual design stage by providing a linkage between concept design process and the required mechanical/electrical knowledge.

1.8 Organization of Thesis

This study is organized in five chapters whose details are explained below:

Chapter 1: Firstly, there is a journey through the background of the study. Then the problem, research question and research objectives are expressed. Finally, methodology to solve the stated problem and also other criteria and requirement for validating data and results are explained.

Chapter 2: This chapter explains the structure of studied literature toward gathering sufficient information, existing knowledge associated with the subject of this research and performed researches in relation with knowledge flow and design process.

Chapter 3: In this chapter selected research methodology and its relevant components are explained in detail. The approach adopted in this research to solve the stated problem is based on Yin (2003) case study methodology.

Chapter 4: In this chapter, the procedure of data collection through observation in a case study is explained. As a result, at the end of this chapter the first objective of this study and therefore the first sub research question is answered. Furthermore, the process of validating the obtained results by using simulation (using SimVision) is explained.

Chapter 5: This chapter is for validating the extended model for conceptual design process of building projects. According to the simulation results we confirm that the proposed knowledge-based framework mitigates cost and time overrun for building projects.

Chapter 6: This chapter concludes all the findings related to the proposed knowledge capture technique and activity-knowledge based framework for conceptual design stage of building project. Moreover, limitation of this study, knowledge contribution and future studies are explained.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Many researchers such as Paulson (1976), Jin & Levitt (1996), Ibrahim (2005), Ibrahim and Paulson (2005), Nissen (2006), Ibrahim (2008) have found problems in the construction industry, which are related to the knowledge flow of a building project life cycle. They also explained that this problem could arise from tacit dominant part of projects. Some of these notions are mentioned below.

Rounce (1998) found out that design-caused wastes from the point of view of time form the largest category. Macmillan et al. (2001) believed that the rapid and dynamic information and knowledge transfer between designers during the conceptual phase of building projects could result in disorganized behavior within the team. Martinez (1998) stated that when an organization lacks a heightened degree of knowledge share, knowledge leaks consequently cause: repeated mistakes, dependence on a few key individuals, duplicated work, lack of sharing of good ideas, and slow introduction of new products or market solutions. Saeema Ahmed (2005) stated that engineering firms are facing pressures to increase the quality of their product to have even shorter lead-time and reduced cost.

Considering the abovementioned literature, in the first place, it is necessary to learn what tacit knowledge, capturing knowledge, knowledge flow and conceptual design process are. Hence, literature review for this study has three main parts: (1) knowledge management; (2) knowledge flow; and (3) design process. Through reviewing knowledge management part, first, different definitions for knowledge are presented. Then, I will focus more intently on knowledge capture as a component of knowledge management process. Then, considering the stated problem for this research, knowledge flow and its related theories are examined. Accordingly, design stage as a process in which flow of knowledge takes place is investigated too. The studied literature can be divided in accordance with the abovementioned constructs. These constructs are laid out in Figure 2.1.

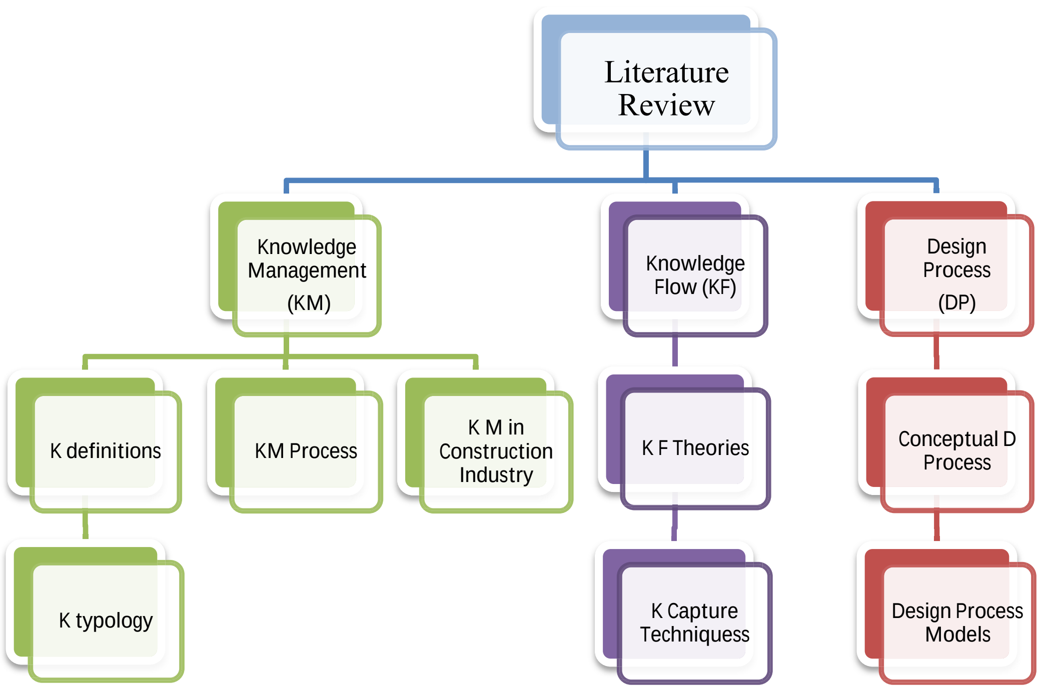

Figure 2.1. Construct Division from Literature

2.2 Knowledge Management

Knowledge management is developing strategies and processes to identify, capture, structure, value, leverage and share an organization's intellectual assets to enhance its performance and competitiveness. Therefore, knowledge management can contribute to organizations' success. Using knowledge management organizations possess the capability to capture the knowledge that is critical to them, improve it and make it available in the most effective manner. Therefore, knowledge is a valuable asset for organizations which should be well managed. As a result, knowledge is an essential concept which has to be inspected more deeply. Through the next sections different definitions for knowledge, its typology and other related concepts are investigated.

2.2.1 Knowledge Definitions

An organization must strive to maintain its most valuable resource and knowledge, in order to be more productive and competitive. There are different definitions for Knowledge. Turban and Frenzel (1992) defined knowledge as information that has been organized and analyzed to make it understandable and applicable to problem solving or decision-making. Wiig (1993) agreed that knowledge is different from information, which consists of facts and data that are organized to describe a particular situation or condition. He believed that knowledge is accumulated and integrated and held over longer periods to be available to be applied to handle specific situations and problems. It is subsequently applied to interpret the available information about a particular situation and to decide how to manage it.

According to Nonaka and Takeuchi (1995), knowledge is a vital organizational resource that gives market advantage. For Davenport and Prusak (1998), knowledge is a fluid mix of framed experience, values, contextual information, and expert insight. Drucker (1998) also stated that knowledge, by definition, is specialized: in fact, truly knowledgeable people, whatever their field, tend toward overspecialization, precisely because there is always so much more for them to know. Giannetto and Wheeler (2000) explained that knowledge involves beliefs and values, creativity, judgment, skills and expertise, theories, rules, relationships, opinions, concepts, and previous experiences. It is more than data or information.

Based on the abovementioned literature we found out that knowledge consists of facts and data that are organized to describe a particular situation or condition. Knowledge can be a fluid mix of framed experience, values, contextual information and expert insight. Furthermore, knowledge is a vital organizational resource that gives market advantage. Ibrahim (2005) also has argued that different forms of knowledge are dominant during different facility development life cycle phases. She defined knowledge as selected information, which enables action by either the source or recipient. She agreed with Nonaka (1994) who defined knowledge as a set of commitments and beliefs of its holder that enables the holder to undertake certain action.

2.2.2 Knowledge Typology

Polanyi (1967) first introduced the distinction of knowledge as explicit and tacit. According to his definition, tacit knowledge is highly personal and context specific; therefore, it is hard to formalize and communicate. It is stored in humans' minds, and is difficult to see, share, copy, and manage. On the other hand, explicit knowledge can readily be codified in words and numbers, easily shared in manuals, and is easy to distribute (Payne and Sheehan, 2004). Furthermore, it can be stored as written documents or procedures and made available to others. Some examples of explicit knowledge are textbooks, specifications and design codes. Many other researchers such as Nonaka & Takeuchi (1999), Von Krong (2000) and Alter (2002) also mentioned that there are two types of Knowledge. Nonaka and Takeuchi (cited in Beckman 1999) differentiate these two typologies of knowledge in terms of experience–rational and practice–theory aspects. Tacit knowledge is knowledge of experience and it is related to practical aspects, while explicit knowledge is knowledge of rationality and it is related to theoretical aspects (Table 2.1).

Table 2.1. Differences between tacit and explicit knowledge

(Source: Nonaka and Takauchi, 1999)

	Theoretical	**Practical**
Rationality	**Explicit Knowledge**	
Experience		**Tacit Knowledge**

Von Krogh et al. (2000) noted that tacit knowledge is tied to the senses, skills in bodily movement, individual perception, physical experiences, rules of thumb, and intuition. Alter (2002) stated that explicit knowledge is defined as knowledge that is precisely and formally articulated and is often codified in databases of corporate procedures and best practices, whereas tacit knowledge is understood and applied unconsciously.

There are different notions about tacit and explicit knowledge, which have been stated below. Some of them have argued that the diffusion of tacit knowledge is more difficult than sharing explicit knowledge (e.g., Nonaka & Konno, 1998; Leonard & Sensiper, 1998). An organization's core competency is more than the explicit knowledge of "know what;" it requires the more tacit "know-how" to put "know what" into practice (Brown & Duguid, 1998). Brockmann and Anthony (1998) noted that the efficiency of making decisions, serving customers, or producing products, and the accuracy of task performance are improved by the use of tacit knowledge. Haldin-Herrgard (2000) has discovered four major reasons that make it difficult to share tacit knowledge: (1) perception and language; (2) available time; (3) value difference; and (4) distance. By this, he emphasized that difficulties involved in sharing tacit knowledge occurs when expressing or documenting the knowledge appears obvious and natural to one. He asserted that the most common way of transferring tacit knowledge to clarify what exactly a person wants is through face-to-face interaction. This kind of interaction allows the people involved to have some conversation at the same time about probable questions.

Hence, it is apparent that tacit knowledge is a valuable asset for organizations. However, articulating and sharing tacit knowledge is difficult due to the fact that it is located in people's mind. On the other hand, explicit knowledge is not facing these kinds of problems. Therefore, converting knowledge from tacit to explicit one can attenuate the mentioned problems.

2.2.3 Knowledge Management Process

Managing knowledge effectively is critical to the survival and advancement of an organization. There are many definitions for Knowledge Management. Some of these definitions are stated as follow. Davenport & Prusak (1998) mentioned that knowledge management is the process of creating value for an organization's intangible assets. Another definition for knowledge management is offered by Laudon and Laudon (1998) as "the process of systematically and actively managing and leveraging the stores of knowledge in an organization". According to Liebowitz and Beckman (1998), the idea of knowledge management is to create a knowledge sharing environment whereby "sharing knowledge is power," as opposed to the old belief that "knowledge is power." Hibbard (1999) described the knowledge management as the process of capturing a company's collective expertise wherever it resides in databases, on paper, or in people's head- and distributing it to wherever it can help produce the biggest payoff.

Tserng et al. (2005) expressed that knowledge management deals with creating, securing, and capturing, coordinating, combining, retrieving and distributing knowledge (Su, 2006). Alavi et al. (2001) considering grounded framework in the sociology of knowledge (by Burger et al., 1971 and Holzner et al., 1979) stated that organizations as knowledge systems consist of four sets of socially enacted knowledge processes: (1) creation, (2) storage/retrieval, (3) transfer, and (4) application. As Abdullah (2008) mentioned in order to insure the standardization process in knowledge management of the learning organization as a strategic vision, this study uses a classification for this process in terms of its creation, storage, distribution and application of knowledge. Considering this taxonomy, different models for knowledge management process have been summarized in Table 2.2.

Table 2.2. Knowledge Management process models

(Source: adopted classification from integrating (Alavi, 2001) and (Abdullah, 2008))

By	Year	Creation	Storage	Transfer	Application
Holzner	1979	Consciousness	Extension	Transformation	Implementation
Pentland	1995	Construction	Organization+ Storage	Distribution	Application
Leonard-Barton	1995	Acquisition	Collaboration	Integration	Experiment
Nonaka	1995	Creation	Access	Dissemination	Application
Demarest	1997	Construction	Embodiment	Dissemination	Use
Wiig	1997	Create & Maintain	Renew & Organize	Transfer	Realize
Beckman	1997	Identify &	Select & Store	Share	Apply & Create &

		Capture			Sale
Alavi	1997	Acquisition & Indexing	Filtering & Linking	Distribution	Application
Delong	1997	Capture	Not allocated	Transfer	Use
Daal	1998	Creation	Draw-up	Dissemination	Apply & Evaluate
Davenport	1998	Creation	Not allocated	Transference	Asset Management
Liebowitz	1998	Identify & Capture	Store	Share	Apply & Sell
Burk	1999	Creation	Organization	Sharing	Utilization/ Reutilization
Armistead	1999	Creation	Not allocated	Transfer	Embedding
Ahmed	1999	Creating	Not allocated	Sharing	Measuring & Learning/Improvin g
Chen, Tsai & Wu	2001	Capture	Collaborate & Correct	Circulation	Create
Nissen	2002	Creating	Organize & Formalize	Dissemination	Application & Evolution
Tiwana	2002	Acquisition	Not allocated	Dissemination	Utilization
Darroch	2003	Acquisition	Not allocated	Dissemination	Utilization
Bose	2004	Create & Capture	Refine & Store	Disseminate	Manage
Chen & Chen	2005	Creation & Conversion	Not allocated	Circulation	Completion
Lee,Lee & Kang	2005	Creation	Accumulation	Sharing	Utilization & Internalization
Oliveira & Goldoni	2006	Creation	Storage	Dissemination	Utilization & Results
Nissen	2006	Creating	Organize & Formalize	Sharing	Applying & Refining

Holzner et al. (1979) is the first researcher who has established theory for knowledge management process. Hence, we start the history of this theory by introducing the theory of this researcher. He divided knowledge management process into four stages, namely consciousness, extension, transformation and implementation (Holzner & Marx, 1979).

Pentland (1995) identified a set of five “knowledge processes”: (1) construction which is the process through which new material is added or replaced within the collective stock of knowledge; (2) organization which is the process by which bodies of knowledge are related to each other, classified, or integrated; (3) storage i.e once a new observation or experience has passed the test and been socially ratified as knowledge, it must be stored somehow. Without storage, there is no possibility for “memory” or application; (4) distribution, a critical issue in any organization which is distributing knowledge to places where it is needed and can be applied; (5) Application. Unless knowledge is applied in practice, there is no possibility of obtaining the kind of performance improvement that is characteristic of our intuitive understanding of learning (Petland, 1995). Leonard-Barton (1995), on the other hand, distinguished between acquisition, collaboration, integration, and experiment (Leonard-Barton, 1995).

Nonaka et al. (1995) also divided the process of knowledge management into four steps: (1) creation, (2) access, (3) dissemination, and (4) application. At the same time, they focused on knowledge creation step by suggesting a comprehensive model which was termed the SECI model. They have identified four modes for converting explicit to tacit knowledge or vice versa: (1) socialization, (2) externalization, (3) combination, and (4) Internalization (Nonaka, 2000).

Demarest (1997) proposes five phases for the knowledge management process: construction, embodiment, dissemination, use, and management. First phase involves the creation of new knowledge; the embodiment of knowledge consists in transforming knowledge created in processes, practice, material and culture within the organization. Dissemination aims to distribute transformed knowledge to all the members of the organization. Use is the application of created knowledge, transformed and distributed through the anterior phases. Management consists in monitoring, measuring and interfering in the knowledge management process phases (Damarest, 1997). Wiig (1997) stated that from a managerial perspective systematic knowledge management comprises four areas of emphasis. They focus on: (1) Top-down monitoring and facilitation of knowledge-related activities; (2) Creation and maintenance of knowledge infrastructure; (3) Renewing, organizing, and transferring knowledge assets; and (4) Leveraging (using) knowledge assets to realize their value (Wiig, 1997).

Beckman (1997) proposed eight stages of the knowledge management process: (1) identifying, determining core competencies, sourcing strategy, and knowledge domain; (2) capturing, formalizing existing knowledge; (3) selecting, assessing knowledge relevance, value, and accuracy; (4) storing, representing corporate memory in knowledge repository with various knowledge schema; (5) sharing, distributing knowledge automatically to users based on interest and work; (6) applying, retrieving and using knowledge in making decisions, solving problems, automating or supporting work, job aids, and training; (7) creating, discovering new knowledge through research, experimenting, and creative thinking; and (8) Selling, developing, and marketing new knowledge-based products and services (Beckman, 1997). Alavi (1997) stated six steps for knowledge management process consist of: (1) Acquisition; (2) Indexing; (3) Filtering; (4) Linking; (5) Distribution; (6) Application (Alavi, 1997). DeLong (1997) classified the processes into capturing, transfer and use of knowledge (Delong, 1997).

Davenport (1998) stated three main stages for knowledge management process: (1) Creation; (2) Transference; (3) Asset management (Davenport, Long, & Beers, 1998). Liebowitz and Beckman (1998) propose an eight-stage process for knowledge management: (1) Identify: Determine core competencies, sourcing strategy, and knowledge domains; (2) Capture: Formalize existing knowledge; (3) Select: Assess knowledge relevance, value, accuracy, and resolve conflicting knowledge; (4) Store: Represent corporate memory in knowledge repositories with various knowledge schema; (5) Share: Distribute knowledge automatically to users based on interest and work. Collaborate on knowledge work through virtual teams; (6) Apply: Retrieve and use knowledge in making decisions, solving problems, automating or supporting work, job aids, and training; (7) Create: Discover new knowledge through research, experimenting, and creative thinking; and (8) Sell: Develop and market new knowledge based products and services (Liebowitz, 1999).

Burk (1999) presented the cycle of knowledge through four stages: creation, organization, sharing, and utilization/reutilization. In the first stage, knowledge is created or found by different means such as publications, conference, meetings, experiences, and research. In the sequence, the sharing stage means to make knowledge available through the organization's communication channels. Utilization and reutilization is the application of new knowledge on real problems (Burk, 1999). Armistead (1999) expressed that knowledge management processes is the creation of knowledge, transfer and sharing of knowledge and the embedding and use of knowledge. Process of creation requires innovative individuals, more often than not working in teams. These are networks of experts with access to knowledge technologies including those for knowledge capture, storage and transfer. Knowledge transfer process has some of the aspects of creation in the sense of input being sources of existing knowledge. However, emphasis is given to the role of individuals who facilitate the access and transfer of knowledge. The knowledge embedding process is concerned with organizational effectiveness through the incorporation of knowledge into the fabric of the organizational process and into its products and services (Armistead, 1999).

Ahmed, Lim and Zairi (1999) brought forth a sight in knowledge management process related to the PDCA cycle (plan, do, check and act). The first stage is knowledge creation ("plan"), during this phase, the organization counts with external sources, structured internal sources, or non-structural internal sources of knowledge. In the next stage, the organization may use communication tools to share knowledge. The following stage associated with "check" is the measurement of the effects. Learning and improvement correspond to "act" in the PDCA cycle (Ahmed, Lime, & Zairi, 1999). Chen (2001) proposed five stages for knowledge management process: (1) Capture; (2) Collaborate; (3) Correct; (4) Circulation; (5) Create (Chen et al., 2001). Nissen (2002) extended Nonaka (1995) dynamic of knowledge flow theory by integrating the life cycle process of knowledge flow through the enterprise: (1) creation, (2) organization, (3) formalization, (4) distribution, (5) application, and (6) evolution.

Tiwana (2002) and Darroch (2003) divided the knowledge management process in three parts: acquisition, dissemination, and utilization of knowledge. The knowledge acquisition includes the development process and the making of insights and relations. Dissemination consists on sharing acquired knowledge. Utilization is regarded as the capacity of the organization in applying knowledge generated in new situations (Oliveira & Goldoni, 2006). Bose (2004) presented the stages of a cyclic process in knowledge management. The process proposed by him is composed of creation, capturing, refining, storing, managing and disseminating knowledge (Oliveira & Goldoni, 2006).

Chen (2005) reached a general conclusion from a collection of related knowledge management research and defined the '4C' process of knowledge management activities: creation, conversion, circulation and completion. Knowledge creation relates to knowledge addition and the correction of existing knowledge. Knowledge conversion relates to individual and organizational memory. While organizational memory reflects the shared interpretation of social interactions, individual memory depends on the individual's experiences and observations. Knowledge circulation is the didactic exchange of knowledge between source and receiver. Transfer occurs at various levels: transfer of knowledge between individuals, from individuals to explicit sources, from individuals to groups, between groups, across groups, and from the groups to the organization. An important aspect of the knowledge completion is that the source of competitive advantage resides in the knowledge itself. Here, a major challenge is how to integrate internal knowledge and the knowledge gained from the outside (Chen & Chen, 2005).

Lee et al. (2005) proposed a process of knowledge circulation. They attributed five stages to this process: creation, accumulation, sharing, utilization, and internalization of knowledge. Creation is defined as a stage where individuals are interrelated in a new way to bring new knowledge. In the accumulation stage, storage of already created knowledge occurs while the sharing stage promotes the diffusion of knowledge within the organization. Knowledge is applied in the utilization stage. Internalization occurs after utilization when the individuals adopt the new knowledge in their daily life (Lee et al., 2005). Oliveira and Goldoni (2006) proposed the stages of creation – addition of new knowledge and settling of existent knowledge; storage – codification of knowledge for its storage in knowledge databases; dissemination – communication or distribution of knowledge within the organization; utilization – application of knowledge; measurement – evaluation of the phases of knowledge management process and results. The latter stage occurs in parallel with others (Oliveira & Goldoni, 2006).

Nissen (2006) in his review of the state of the art and practice of knowledge management identified six activities associated with the life cycle of a knowledge flow within an organization, including creating, organizing, formalizing, and sharing, applying, and refining knowledge. Nissen's work provides discrete qualitative categories for potential operationalization of knowledge flow in an enterprise. His four knowledge flow dimensions were: (1) type of knowledge (tacit or explicit), (2) level of socialization associated with the knowledge (individual, group, organization, and inter-organization), (3) activities of knowledge work (create, organize, formalize, etc.), and flow time (Nissen, 2006).

Considering the different models reviewed above, it becomes clear that all the researchers had similar definitions for knowledge management. They just used different words for nominating different steps of this process. According to the studied definitions about the steps proposed for knowledge management, all used create/acquire/capture for the first step in which knowledge is born to start its life cycle. As such, all other steps were defined with similar and synonymous words and similar function. Nonaka (1995) suggested a SECI model of knowledge creation, which emphasized on the movement of knowledge between the individual and an organization considering its typology. Then, Nissen (2002) extended Nonaka SECI model by integrating it through an enterprise. Nissen (2006) in review of his previous work proposed a multidimensional model for knowledge management, which is associated with the life cycle of knowledge flow within an organization. Since the main concern of this study is associated with knowledge flow during conceptual design stage of building projects, Nissen (2006) multidimensional model is used as the background theory for this research. Knowledge flow theories are explained with more details in the following section.

2.2.4 Point of Departure for Knowledge Management Literature

As a conclusion for knowledge, and knowledge management part of literature review, we found out that there are two types of knowledge, explicit and tacit. In the construction industry, explicit knowledge refers to documented information such as project information, design drawings and specifications, cost reports, risk analysis results, and other information collected, stored, and archived in paper or electronic format. As Zhang et al. (2009) expressed tacit knowledge is the experience and expertise kept in the construction professional's mind, company culture, lessons learned, know-how, and other elusive yet valuable information.

Knowledge management is particularly important in the construction industry. First reason is the fact that the construction industry is extremely competitive due to tight construction schedule, low profit margins, and the complexity, diversity and non-standard production of construction projects. Effective knowledge management will facilitate the generation of new technologies and processes, which will improve the industry's productivity, profitability and competitiveness. Second reason is related to the characteristics of project organizations. As Ibrahim and Paulson (2008) stated there are two important characteristics for project organizations: (1) complex multiple concurrent and sequential workflows, and (2) tacit knowledge regressive life cycle. It means that a project contains both concurrent and sequential phases. Moreover, knowledge movement in project organizations is performing through a tacit regressive life cycle. Whereas tacit knowledge resides in experts' mind, as Lin et al. (2005) stated without a knowledge management system it is difficult to reuse a professional's knowledge if he/she leaves the company or if he/she is not a team member of a new project even if he/she is still in the company.

In conclusion, it is apparent that knowledge management can improve construction industry productivity and can help to preserve expert knowledge in organization. Moreover, it is realized that there are four modes of knowledge conversion (i.e. socialization, externalization etc.) between tacit and explicit through knowledge management process to move between individuals and an organization. In this condition, there is a need to examine knowledge flow, knowledge conversion and its related theories more thoroughly, which is performed in the next section.

2.3 Dynamic Knowledge Flow

Knowledge flows are dynamic. According to Ibrahim (2005) knowledge flow is the process of moving knowledge by way of communicating to retrieve or allocate working information of any knowledge type (either tacit or explicit) that would enable an individual or enterprise to complete a workflow process. There are different theories for knowledge flow process which are inspected in the following sections.

2.3.1 Dynamic Knowledge Flow Theory (Nonaka, 1995)

Some researchers attempted to model dynamics of knowledge flows to help understand such flows. One of the best known models for knowledge flows has been established by Nonaka et al. in 1995. They identified four modes for converting explicit to tacit knowledge or vice versa: (1) socialization, (2) externalization, (3) combination, and (4) Internalization. These are sometimes termed the "SECI" model. Socialization is the process of converting new tacit knowledge through shared experiences. Since tacit knowledge is difficult to formalize and often time- and space-specific, it can be acquired only through shared experience, such as spending time together or living in the same environment.

Externalization is the process of articulating tacit knowledge into explicit knowledge. When tacit knowledge is made explicit, knowledge is crystallized, thus allowing it to be shared by others, and it becomes the basis of new knowledge. The successful conversion of tacit knowledge into explicit knowledge depends on the sequential use of metaphor, analogy and model. Combination is the process of converting explicit knowledge into more complex and systematic sets of explicit knowledge. Explicit knowledge is collected from inside or outside the organization of new knowledge. The new explicit knowledge is then disseminated among the members of the organization.

Internalization is the process of embodying explicit knowledge into tacit knowledge. Through internalization, explicit knowledge is created and shared throughout an organization and converted into tacit knowledge by individuals. Internalization is closely related to `learning by doing'. Explicit knowledge, such as the product concepts or the manufacturing procedures, has to be actualized through action and practice. Some factors that constitute the knowledge-conversion process are explained in the following section.

Socialization: from tacit to tacit

- Tacit knowledge accumulation: managers gather information from sales and production sites, share experiences with suppliers and customers and engage in dialogue with competitors.
- Extra-firm social information collection (wandering outside): managers engage in bodily experience through management by wandering about, and getting ideas for corporate strategy from daily social life, interaction with external experts and informal meetings with competitors outside the firm.

- Intra-firm social information collection (wandering inside): managers find new strategies and market opportunities by wandering inside the firm.
- Transfer of tacit knowledge: managers create a work environment that allows peers to understand craftsmanship and expertise through practice and demonstrations by a master.

Externalization: from tacit to explicit

- Managers facilitate creative and essential dialogue, the use of metaphors in dialogue for concept creation and the involvement of the industrial designers in project teams.

Combination: from explicit to explicit

- Acquisition and integration: managers are engaged in planning strategies and operations, assembling internal and external data by using published literature, computer simulation and forecasting.
- Synthesis and processing: managers build and create manuals, documents and databases on products and services and build up material by gathering management figures or technical information from all over the company.
- Dissemination: managers engage in planning and implementation of presentations to transmit newly created concepts.

Internalization: from explicit to tacit

- Personal experience: real world knowledge acquisition: managers engage in "enactive liaising" activities with functional departments through cross-functional development teams and overlapping product development. They search for and share new values and thoughts, and share and try to understand management visions and values through communications with fellow members of the organization.
- Simulation and experimentation; virtual world knowledge acquisition: managers engage in facilitating prototyping, and benchmarking and facilitating a challenging spirit within the organization. Managers form teams as a model, conduct experiments, and share results with the entire department.

As stated above, knowledge creation is a continuous process of dynamic interactions between tacit and explicit knowledge. Such interactions are shaped by shifts between different modes of knowledge conversion, not just through one mode of interaction. Knowledge created through each of the four modes of knowledge conversion interacts in the spiral of knowledge creation. Figure 2.2 shows the four modes of knowledge conversion and the evolving spiral movement of knowledge through the SECI (Socialization, Externalization, Combination, and Internalization) process.

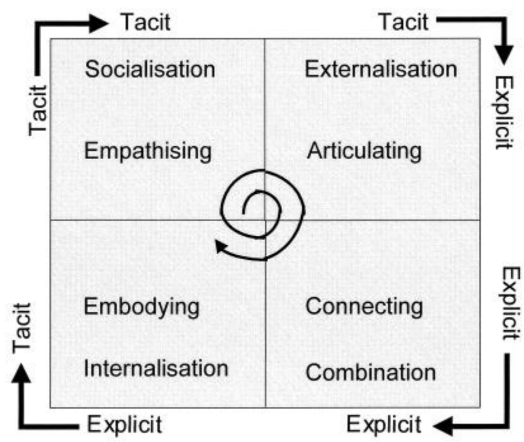

Figure 2.2. The SECI Process

(Source: Nonaka & Takeuchi, 1995)

2.3.2 Dynamic Knowledge Flow Theory (Nissen, 2002)

Nissen (2002) extended Nonaka's dynamic of knowledge flow theory by integrating the life cycle process of knowledge flow through the enterprise: (1) creation, (2) organization, (3) formalization, (4) distribution, (5) application, and (6) evolution. Then, in 2006 he reviewed the extended theory by identifying six activities associated with the life cycle of a knowledge flow within an organization. Indeed, he developed a multidimensional model for knowledge flow life cycle through an enterprise. This model dimensions were (1) type of knowledge, (2) level of socialization associated with the knowledge (individual, group, organization, and inter-organization), (3) activities of knowledge work (create, organize, formalize, etc.), and flow time.

One research (Javernick et al., 2007) aimed to build upon Nissen's (2006) model of the multi-dimensional aspects of knowledge flow. This research attempted to examine the flow of knowledge based on knowledge type, the phase within the knowledge lifecycle, and the "reach" of the knowledge as it spreads from individual to group, project team, organization and beyond.

Recalling the stated problem for this study, incomplete knowledge flow has been recognized as a problem during conceptual design stage as a tacit-dominated area of building project's life cycle. Moreover, many researchers have emphasized on performing more studies on this area. Nissen (2006) multidimensional (See Figure 2.3) theory for product life cycle focuses on knowledge flow regarding its typology. Because some researchers have expressed the importance of knowledge typology on project performance, Nissen (2006) theory is used as the background theory for this study. Given this, to improve flow of knowledge we need to know more about knowledge creation, conversion and its related techniques.

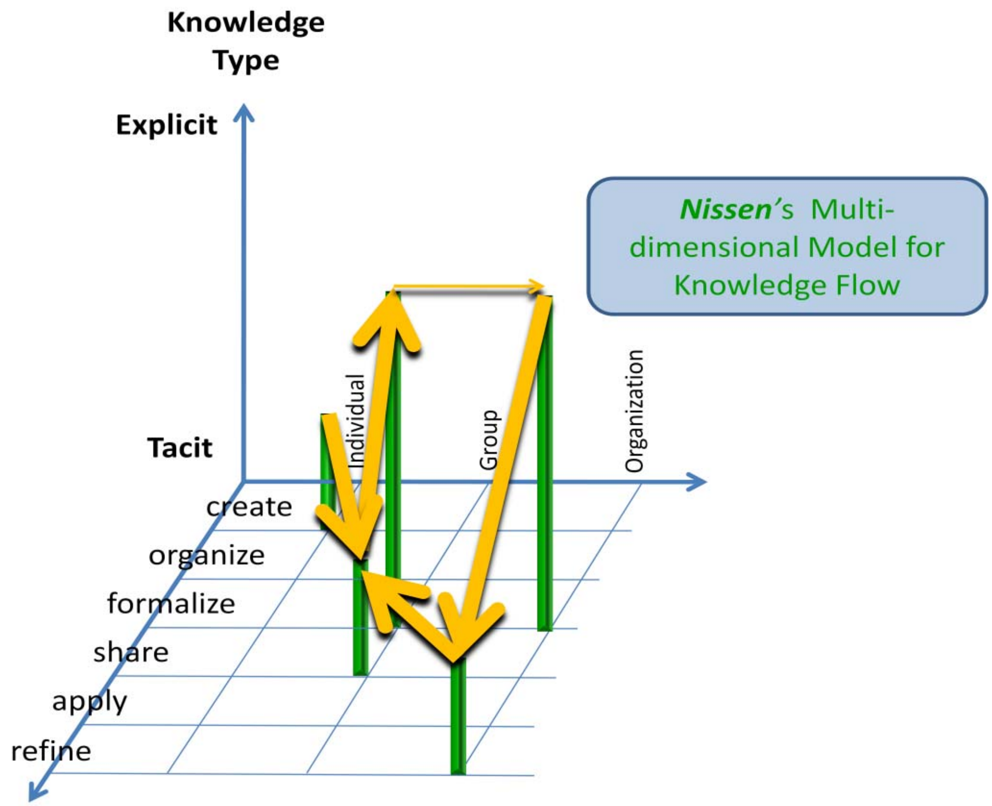

Figure 2.3. Multidimensional Knowledge Flow Visualization

(Source: Nissen, 2005)

2.3.3 Knowledge Conversion Process

An organization creates knowledge through the interactions between explicit knowledge and tacit knowledge. Interaction between the two types of knowledge is called knowledge conversion. Through the conversion process, tacit and explicit knowledge expands in both quality and quantity. Nonaka and Takeuchi (2004) stressed that organizational knowledge is created through the continuous social interaction of tacit and explicit knowledge. Knowledge management initiatives in Japanese firms have shown that the creation and sharing of knowledge can only happen when individuals cooperate willingly. According to Nonaka, employees need to have the opportunity to create and not to be controlled nor monitored (Salim et al., 2005).

Knowledge-based organizations are dependent on the efficient management of human resources as this resource is the prime source of the organization's knowledge, capabilities, and systems (Abernethy, 2003). Since human resources are mobile and governed by self-interest, organizations seek to convert individuals' tacit or unobserved knowledge to explicit or organizational knowledge in order to build organizational capabilities (e.g., Nonaka, 1994; Nonaka and Takeuchi, 1995). Converting tacit knowledge to explicit knowledge is a tough task because tacit knowledge is difficult to articulate. Tacit knowledge is the know-how which is deeply embedded in the individual's mind and is typically acquired through sharing experience (Forrester, 1994).

According to Ambrosini and Bowman (2001), tacitness of knowledge is a matter of degree. At one extreme, knowledge is deeply ingrained and very unavailable. At the other extreme, knowledge can be easily communicated and shared. In the middle lies knowledge that has the potential to be articulated. This knowledge can be made available to the organization by asking the right questions. Articulating tacit knowledge through inquiry allows management to learn and thus improve their understanding of how their organizations achieve success (Ambrosini and Bowman, 2001). According to Abernethy (2005), tacit knowledge of experts is essential to understand the inputs and processes, which contribute to the success of knowledge-based organizations. From literature review, it can be inferred that tacit knowledge is difficult to communicate and to transfer to other people. Therefore, this study proposes that tacit knowledge be converted to explicit type to facilitate the movements. In response to this need, in the next section techniques for converting tacit knowledge to explicit are reviewed.

2.3.4 Knowledge Conversion Techniques

In line with recommendations from scholars (Polanyi 1967; Payne and Sheehan, 2004), in order to convert the knowledge, which resides in the experts' mind, to the explicit one, we need to bring the latter under our control.. In order to perform this task, the thesis now reviews existing techniques related to this conversion. A list of recognized conversion techniques by this study is shown in Table 2.3. There are some existing techniques to capture/convert tacit knowledge to explicit type, which are explained as follow:

On-Site Observation (Action Protocol) (Liou, 1992)

On-site observation is a process, which involves observing, recording, and interpreting the expert's problem-solving process while it takes place. Through this process a developer of knowledge does more listening than talking and does not give advice or make judgments even it if something seems incorrect. , Nor does he/she argue with the expert while the expert is performing the task. As an advantage, this process brings the knowledge developer closer to the actual steps, techniques, and procedures used by the expert (In comparison with Interview). In addition, there are some disadvantages in this technique, which are explained here: (1) sometimes some experts do not like the idea of being observed; (2) the reaction of other people (in the observation setting) can also be a problem causing distraction, and (3) the accuracy/completeness of the captured knowledge. Accuracy or completeness of captured knowledge weakened by time gap between observation and recording.

Brainstorming (Liou, 1992)

Brainstorm is an unstructured and consensus-based approach towards generating ideas about creative solution of a problem, which involves multiple experts in a session. In this process questions can be raised for clarification, but no evaluations are done at the spot. Similarities that emerge through opinions are usually grouped together logically and evaluated by asking some questions like:

- What benefits are to be gained if a particular idea is followed?

- What specific problems that idea can possibly solve?
- What new problems can arise through this issue?

The general procedure for conducting a brainstorming session: (1) Introducing the session, (2) Presenting the problem to the experts, (3) Prompting the experts to generate ideas, and (4) Looking for signs of possible convergence. If the experts are unable to agree on a specific solution, the knowledge developer may call for a vote/consensus.

Electronic Brainstorming (Liou, 1992) is a computer-aided approach for dealing with multiple experts. This Process usually begins with a pre-session plan, which identifies objectives and structures the agenda, which is then presented to the experts for approval. During the session, each expert sits at a PC and gets himself engaged in a predefined approach towards resolving an issue, and generating ideas. This allows experts to present their opinions through their PC without having to wait for their turn. Usually the comments/suggestions are displayed electronically on a large screen without identifying the source. This approach protects the introvert experts and prevents tagging comments to individuals.

1. The benefit includes improved communication, effective discussion regarding sensitive issues, and closes the meeting with concise recommendations for necessary action.
2. This eventually leads to the convergence of ideas and helps to set final specifications.

3. The result is usually the joint ownership of the solution.

Protocol Analysis (Think-Aloud Method) (Bolloju et al., 2002)

In this Method, protocols (scenarios) are collected by asking experts to solve the specific problem and verbalize their decision process by stating directly what they think. Knowledge developers do not interrupt in the interim. The elicited information is structured later when the knowledge developer analyzes the protocol. Here, the term *scenario* refers to a detailed and somehow complex sequence of events or more precisely, an episode. A scenario can involve individuals and objects. A scenario provides a concrete vision of how some specific human activity can be supported by information technology.

Consensus Decision Making (Giordano, Passarella, Uricchio, & Vurro, 2007)

Consensus decision making usually follows brainstorming. This method is effective if and only if each expert has been provided with equal and adequate opportunity to present his or her views. In order to arrive at a consensus, the knowledge developer conducting the exercise tries to rally the experts towards one or two alternatives. The knowledge developer follows a procedure designed to ensure fairness and standardization. This method is democratic in nature. However, this method can be sometimes tedious and can take hours.

Repertory Grid (Bradshaw, Ford, Adams-Webber, & Boose, 1993)

Repertory Grid is a tool that is used for knowledge capture. The domain expert classifies and categorizes a problem domain using his/her own model. The grid is used for capturing and evaluating the expert's model. Two experts (in the same problem domain) may produce distinct sets of personal and subjective results. The grid is a scale (or a bipolar construct) on which elements can be placed within gradations. The knowledge developer usually elicits the constructs and then asks the domain expert to provide a set of examples called *elements*. Each element is rated according to the constructs which have been provided.

Nominal Group Technique (NGT) (Liou, 1992)

NGT provides an interface between consensus and brainstorming. The panel of experts becomes a *Nominal Group* whose meetings are structured in order to effectively pool individual judgment. *Idea writing* is a structured group approach used for developing ideas as well as exploring their meaning and the net result is usually a written report. NGT Steps are stated hereunder:

1. Given a problem and the alternate solutions, each expert is asked to list their pros and cons,
2. A list of these pros and cons are compiled,
3. Given the list, each expert is asked to rank them on basis of their priorities,

4. Knowledge developer leads a discussion on the relative ranks in hope of achieving convergence,
5. Choose the "best" solution from the alternatives.

Some advantages for NGT are: (1) effective in minimizing differences in status among multiple experts, (2) each expert has an equal chance to express ideas in parallel with other experts in the group, (3) with discussion proceeding in sequential order; it can be more efficient and productive than brainstorming.

Delphi Method (Chu & Hwang, 2008)

Delphi is a survey of experts where a series of questionnaires are used to pool the experts' responses for solving a specific problem. Each expert's contributions are shared with the rest of the experts by using the results from each questionnaire to construct the next questionnaire.

Concept Mapping (Awad & Ghaziri, 2007)

Concept Mapping is a network of concepts consisting of nodes and links. A node represents a concept, and a link represents the relationship between concepts. Concept mapping is designed to transform new concepts/propositions into the existing cognitive structures related to knowledge capture. It is a structured conceptualization and also an effective way for a group to function without losing their individuality. Concept mapping can be done for several reasons: (1) to design complex structures, (2) to generate ideas, (3) to communicate ideas, and (4) to diagnose misunderstanding. There is a six-step procedure for using a concept map as a tool (Figure 2.4): (1) Preparation, (2) Idea generation, (3) Statement structuring, (4) Representation, (5) Interpretation, and (6) Utilization (Awad & Ghaziri, 2007).

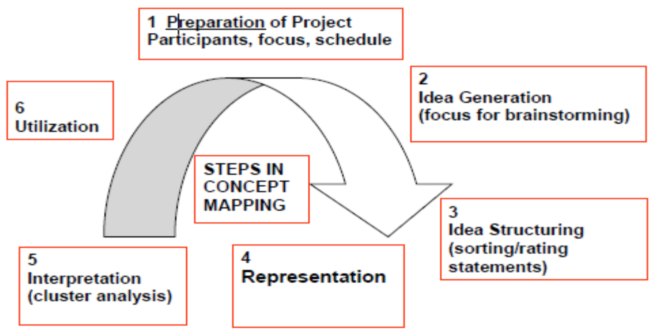

Figure 2.4. Six Steps in Concept Mapping

(Source: Awad, 2007)

Blackboarding (Yang & Ho, 2007)

In this method, experts work together to solve a specific problem using the blackboard as their workspace. Each expert gets equal opportunity to contribute to the solution via the blackboard. It is assumed that all participants are experts, but they might have acquired their individual expertise in situations different from those of the other experts in the group. The process of blackboarding continues till the solution has been reached. Characteristics of blackboard system consist of: (1) Diverse approaches to problem-solving., (2) Common language for interaction, (3) Efficient storage of information, (4) Flexible representation of information, (5) Iterative approach to problem-solving, (6) Organized participation. Components of blackboard system are composed of:

1. The knowledge sources which are the experts who try to contribute to a higher-level partial solution.
2. The blackboard, which is a global memory structure, a database, or a repository, can store all partial solutions and other necessary data.
3. A Control Mechanism which coordinates the pattern and flow of the problem solution.

The inference engine and the knowledge base are part of the blackboard system. This approach is useful with respect to situations involving multiple expertise, diverse knowledge representations, or situations involving uncertain knowledge representation.

Kinematic Analysis (Nemati et al. 2002)

A potential application of artificial intelligence to tacit knowledge sharing is the use of kinematic analysis of the physical process. Kinematics includes the use of reflective dots and/or sensors attached to the various appendages and joints of the demonstrator to enhance the determination of quick or subtle movements or actions during the demonstrated process; also to detect twisting or turning of the fingers while a master chef kneads bread dough. Once the process is recorded, kinematic analysis software is used to further analyze the relative motion of the appendages and joints; thus, kinematics provides a natural conversion of tacit knowledge to explicit knowledge (Nemati et al., 2002).

Cognitive Map (CM) (Noh et al. 2000)

Cognitive map introduced by Tolman (1948) has originally been used for representing knowledge in political and social sciences, representing the cause± effect relationships which are perceived to exist among the elements of a given environment. Tacit knowledge is often elicited by means of figurative language and symbolism to express the inexpressible (Numata et al., 1997). Cognitive map is well known as a highly promising technique for capturing tacit knowledge (Lenz & Engledow, 1986). Also Lee and Courtney (Lee & Courtney, 1989) has suggested a cognitive map as a means for constructing organizational memory, and claimed that cognitive map is more superior to common knowledge representation scheme such as rule and frame. Therefore, cognitive map can be used effectively for making tacit knowledge explicable.

The concern of cognitive map is to see whether the state of one element is perceived to have an influence on the state of the other. Phase 1 is named as formalization phase. After the completion of phase 1, tacit knowledge is stored in the case base and prepared to be retrieved according to the characteristics of problems. Reuse of tacit knowledge is triggered by the presence of problems which decision-makers want to solve. Formalization phase tries to formalize tacit knowledge with the aid of cognitive map. Daily activities in an organization involve many individuals who try to solve given decision-making problems on hand. Regardless of the success or failure, his/her problem-solving experience is stored in their memory as tacit knowledge. Cognitive map can be used to extract this tacit knowledge as a more explicit form. However, if multiple cognitive maps are retrieved for decision-makers to be considered, then those multiple cognitive maps should be integrated into one single cognitive map which represents consensus cognitive map for a given problem. The unified cognitive map is represented in a frame-typed case and stored in the case base.

Formal Interview (Neve, 2003)

Formal interviews are a useful method of making tacit knowledge explicit. Outside observers can assist in the knowledge conversion process by asking employees a series of structured questions. How do you manage your knowledge? How do you interact with your environment? From where do you draw your knowledge? What knowledge gives you a major advantage? Do you know things that others in the organization do not know (Baumard, 1999)? These questions should be asked in an iterative fashion, in at least two different interviews, so that the observer can be sure (through feedback from the "expert") that his or her observations are accurate. But the observer must be careful not to impose him/herself as the sole "articulator of tacit knowledge," (Baumard, 1999, p. 175) for this could result in less ambiguity (which could be good or bad) or even greater rigidity (which is usually bad). The interviewer should remember that "individuals with different cognitive styles have very different tolerances towards ambiguity" (Baumard, 1999, p. 175).

Interaction with others, as opposed to isolation, is important if knowledge conversion is to take place. Knowledge creation in an organization does not occur in a vacuum. It is shared, clarified, and recreated through interacting with others (Nonaka et al., 2001). Teams must work together in a complimentary manner and create knowledge (both tacit and explicit) through collaborative relationships, informal conversations, and formal information transfer (Choo, 1998). Technology must never be allowed to replace or supersede human relationships (Desouza, 2003; Hislop, 2002). All abovementioned tools and techniques for converting tacit knowledge to explicit type have been summarized in the Table 2.3.

Table 2.3. Techniques for capturing/converting tacit knowledge

No.	Technique	Researchers	Description	Technique to Capture	Technique to Convert	Form of Explicit Output
1	**Observation**	(Liou, 1992) ,(Maiden et al., 1996), (Woo et al., 2004), (Hadikusumo et al., 2004), (Awad et al., 2007), (Teerajetgul et al., 2008)	Process which involves observing, recording, and interpreting the expert's problem-solving	1. Observing, 2. Recording, 3. Interpreting	Interpreting Records	Records
2	**Brainstorming**	(Liou, 1992), (Maiden et al., 1996), (Neve, 2003), (Hari et al., 2005), (Awad et al., 2007)	An unstructured, consensus-based approach to generating ideas about a problem which is suitable for multiple experts. All possible solutions considered equally and emphasis is on the frequency of responses during the session. Concluding will be by idea evaluation	1. Presenting the problem, 2. Generating ideas by experts, 3. Evaluating ideas	Choosing convergence ideas	ideas, likes and dislikes as text streams
3	**Protocol Analysis**	(Wright et al., 1987), (Liou, 1992), (Maiden et al. 1996), (Bollojuet al., 2002), (Awad et al., 2007)	Think-aloud approach	1. Verbalizing problem solution 2. Collecting and analyzing Protocols, 3. Structuring of elicited information	Structuring elicited information from knowledge developers	Protocol to solve a problem

Table 2.3. Techniques for capturing/converting tacit knowledge-Continue

No.	Technique	Researchers	Description	Technique to Capture	Technique to Convert	Form of Explicit Output
4	**Consensus Decision Making**	(Liou, 1992), (Herrera et al., 1996), (Balasubramanian et al., 1999), (Giordanoet al., 2007), (Awad et al., 2007).	Experts are asked to vote on the alternate solutions they generated. Procedure should ensure fairness and standardization in the way experts arrive at a consensus	1. Present the problem, 2. Generating ideas, 3. Voting on the alternate solutions	Voting on alternate solutions	Consensus about solutions
5	**Repertory Grid**	(Stewart et al., 1981), (Boose, 1989), (Shema et al., 1990), (Liou, 1992), (Bradshaw et al., 1993), (Moynihan, 2002), (Neve, 2003), (Awad et al., 2007).	Because of complexity and manageability, the tool is normally used in the early stages of knowledge capture.	1. Conceptualizing problem using a model, 2. Using a grid to facilitate capture and evaluation of models, 3. Representing experts' reasoning about problem	Using a reasoning grid	A grid of entities and attributes filled by values
6	**Nominal Group Technique**	(Liou, 1992), (Anderson et al., 1997), (Potter et al., 2004), (Hari et al., 2005), (Awad et al., 2007).	An idea writing technique to provide a link between brainstorming and consensus decision making, also a structured approach to clarify ideas and their meanings.	1. Given a problem and the alternate solutions, 2. A list of pros and cons are compiled, 3. Ranking Pros and Cons, 4. Choose the best solution from the alternatives.	Consensus about a solution	The end result is a written report

Table 2.3. Techniques for capturing/converting tacit knowledge-Continue

No.	Technique	Researchers	Description	Technique to Capture	Technique to Convert	Form of Explicit Output
7	**Delphi**	(Liou, 1992), (Nelms et al., 1985), (Awad et al., 2007), (Nevo et al., 2007), (Chu et al., 2008).	survey of experts- each expert contributions are shared with the rest by using the results from each questionnaire to construct the next one	1. Sending questionnaire for experts, 2. Providing next questionnaire with regard to repeated responses.	questionnaire	Solving a specific problem
8	**Concept Map**	(Leake et al., 2003), (Fourie et al., 2004), (Marshall, et al., 2006), (Becerra-Fernandez et al., 2004), (Awad et al., 2007).	A network of concepts, consisting of nodes and links.	1. Idea generation, 2. Statement structuring, 3. Representation, 4. Interpretation, 5. Utilization.	Interpret	-Designed complex structures, - Generated ideas, -Communicate ideas, -Diagnosed misunderstanding.
9	**Blackboarding**	(Chen, 1992), (Roy, 1994), (Park, 2003), (Yang et al., 2007), (Awad et al., 2007).	This approach is useful in case of situations involving multiple expertise, diverse knowledge representations, or situations involving uncertain knowledge.	1. Present the problem on the blackboard, 2. Contribute to solve the problem, 3. Continue until solution.	Expressed solution	Solution for a specific problem

Table 2.3. Techniques for capturing/converting tacit knowledge-Continue

No.	Technique	Researchers	Description	Technique to Capture	Technique to Convert	Form of Explicit Output
10	**Kinematic Analysis**	(Carson et al., 2001), (Nemati et al., 2002), (Herschel et al., 2005),				

selected techniques for their work. Description of the techniques will be followed later in this section.

Table 2.4. Advantages and disadvantages of capturing techniques against tacitness and multidisciplinary area

#	Technique	Advantages				Disadvantages
		Appropriate for Multiple Experts		Recommended for tacit knowledge capture		
		Y/N	Supported By	Y/N	Supported By	
1	Observation	Y	(Liou, 1992)	Y	(Maiden et al., 1996)	Experts do not like to observe
2	Protocol Analysis	Y	(Liou, 1992)	Y	(Maiden et al., 1996)	Appropriate to analyze protocols to solve a problem
3	Concept Map	Y	(Huff, 1990)	Y	(Lenz et al., 1986), (Noh et al., 2000)	Appropriate to explore activities and relations between them.
4	Cognitive Map	Y	(Giordano et al., 2007)	Y	(Eden, 1992)	Appropriate for inspecting influence of one element on the other one.
5	Brainstorm	Y	(Awad et al., 2007),(Liou, 1992)	N	(Maiden et al., 1996)	Inappropriate for Tacit dominant area
6	Repertory Grid	Y	(Boose, 1989),(Liou, 1992)	N	(Maiden et al., 1996)	Inappropriate for tacit dominant area
7	Formal Interview	Y	(Liou, 1992)	N	(Maiden et al., 1996)	Inappropriate for Tacit dominant area
8	Consensus Decision	Y	(Liou, 1992)	-	---------------	Appropriate to vote about alternative

	Making					solutions
9	Nominal Group Technique	Y	(Liou, 1992)	-	---------------	Based on brainstorming and consensus decision-making, it is not appropriate for tacit dominant and useful to vote about alternative solutions.
10	Delphi	Y	(Liou, 1992)	-	---------------	Appropriate for obtaining consensus using repeated response of questionnaires.
11	Blackboarding	Y	(Nemati et al., 2002)	-	---------------	Appropriate for obtaining consensus solution for a specific problem
12	Kinematic Analysis	-	---------------	-	---------------	Appropriate for physical motion capture

From Table 2.4, the study concludes that four techniques are appropriate for multiple expert environment and tacit dominated area: (1) Observation, (2) Protocol analysis, (3) Concept map, and (4) Cognitive map. Next three techniques means Brainstorm, Repertory grid and Formal interview have been recognized as appropriate techniques for multiple expert environments. Researchers such as Maiden et al. (1996) stated that these techniques are not appropriate for tacit dominated area. Then, the next four techniques i.e. Consensus decision making, Nominal Group technique, Delphi and Blackboarding have been just recommended for multiple expert environment. Indeed, this study has not found any support for tacit-dominated area for these techniques.

The last technique means Kinematic analysis has not been used by other researchers for multiple expert environments and also tacit-dominated area at all. However, as Liou (1992) clarified some of these techniques such as repertory grid and observation become more complicated when multiple experts are involved. In relation with usability of technique for tacit-dominated area, Maiden (1996) believed that brainstorm, repertory grid and formal interview are not recommended.

Now, the disadvantages of the recognized knowledge capture techniques against the mentioned characteristics for conceptual design stage are explained. The most important disadvantage for ***observation*** is the fact that experts do not like to observe. Using some devices to reduce disturbance for experts may attenuate the stated disadvantage. P***rotocol analysis*** deals with the protocols, which are used by different experts to solve a specific problem. This technique is applicable to find a proper protocol to solve a specified problem rather than the knowledge that is used to solve it. ***Consensus decision making*** is the process of choosing the best solution for a problem. This technique is for voting about exist solutions. Furthermore, any recommendation for using this technique in a tacit dominant area was not found. ***NGT*** technique is also based on brainstorming and consensus decision making and use to rank exist solutions. Hence, this technique has similar problems which were previously discussed.

In ***Delphi*** technique there is a questionnaire which has been provided based on exist knowledge. Furthermore, researchers using this technique try to obtain consensus by repeated response of questionnaires. However, in this study our concern is about capturing the knowledge which is in expert's mind. ***Concept Mapping*** is proper to explore activities and relations between them. Through this technique, experts explain what they do. Although Lenz et al. (1986) and Noh (2000) have recommended concept map for tacit dominant area, considering its properties, it can be used to provide workflow rather than explore the required knowledge to do it. ***Blackboarding*** is used to solve a specific problem using the blackboard as their workspace and its outcome will be solution for the stated problem.

Kinematic analysis is used in tacit knowledge sharing. Kinematics includes the use of reflective dots and/or sensors attached to the various appendages and joints of the demonstrator to enhance the determination of quick or subtle movements or actions during the demonstrated process. The outcomes of this method are physical actions concerned with decision-making. Therefore, Kinematic analysis is useful for detecting physical motions. ***Cognitive Map*** is relying on cause and effect relations and Eden (1992) has recommended it for tacit dominant area. However, this technique is concerned with the difficulty of studying the influence of one element on the state of the other. The results are stored in the case base and can be used in case of problems. Hence, Cognitive map is useful to provide cases to solve problems. As a conclusion, observation technique can be used as an appropriate technique for capturing tacit knowledge of experts during conceptual design phase of building projects.

2.3.6 Conclusion for Knowledge Flow Literature

As Lin and Wang (2005) stated without a knowledge management system it is difficult to reuse a professional's knowledge if he/she leaves the company or if he/she is not a team member of a new project even if he/she is still in the company. Hence, it is necessary to find a proper way to manage tacit knowledge in the construction industry. Based on knowledge flow theories, Nissen (2002) extended Nonaka's dynamic of knowledge flow theory by integrating the life cycle process of knowledge flow through the enterprise. Ibrahim (2005) extends Nonaka (1995) theory for dynamic knowledge flow in construction industry. This study is about knowledge flow during conceptual phase. Hence, this study supports the utilization of Nissen (2006) multidimensional model for knowledge flow as the fundamental point of departure for this study.

Referring to literature review of knowledge flow and knowledge management process we find that created knowledge tends to reside in experts' mind and becomes tacit knowledge when not explicitly documented among building professionals. In order to elicit this knowledge there is a need to select an appropriate technique to convert tacit knowledge. In response to this need, a further literature review was performed on knowledge capture techniques (See section 2.3.3 for details). As a result of the research's literature, the study revealed that various knowledge capture techniques deal with different inputs and produce different forms of outputs. Since this study is concerned with capturing tacit knowledge, the ability for accepting tacit knowledge as input is an essential characteristic for the selected technique. Moreover, the applicability of the selected technique in capturing multiple experts' knowledge is essential especially during multidisciplinary conceptual design stage.

In order to capture tacit knowledge in a multidisciplinary area, the study posits that any technique to perform this task must support two characteristics: (1) applicable in tacit-dominated area, (2) applicable for multiple experts. When the study evaluated these two characteristics against recognized techniques (See Table 2.4), it recommends observation as an appropriate technique for the task of converting tacit knowledge.

2.4 Design Process

In this section different definitions for design stage are reviewed. Because design stage is an important phase of construction industry, we, therefore, examine research results concerning the effects of this stage on the overall performance of the project. Shumate et al. (2010) utilize social network analysis tool to examine knowledge allocation and retrieve pattern in project teams. They found significant differences in the flow of tacit knowledge vs. explicit type. Indeed, social network analysis, according to Wasserman and Faust (1994), is a useful tool for conducting research on the interaction of human relationship. Social network analysis has emerged as a set of methods for the analysis of social structures, methods which are specifically geared towards an investigation of the relational aspects of these structures. The use of these methods, therefore, depends on the availability of relational rather than attribute data (Scott, 1992).

The unit of analysis in network analysis is not the individual, but an entity consisting of a collection of individuals and the linkages among them. According to Wasserman et al. (1994), network methods focus on two or three actors and their ties, or larger systems (subgroups of individuals, or entire networks). Social Network Analysis (SNA) has four major underlying principles; first, actors or participants in the system are viewed as interdependent upon one another, rather than independent: such an assumption underlines the holistic rather than methodological-individualist nature of SNA research. Second, relations among actors provide access to resources. Third, the relationships that exist among the actors are determined by and in turn determine the structure of the actors' interactions. The final point is that the interactions between actors determine their social, economic and political structures (Wasserman and Faust, 1994; Wetherell, 1998). One final consideration when undertaking Social Network Analysis research, relates to whether the Whole of the Network (WN) or an Egocentric Network (EC) approach should be considered (Wetherell, 1998). The latter approach concentrates on the relationships of the individual rather than the whole of organizational network (Hanneman, 2002; Liebowitz, 2005).

According to the abovementioned history about social network analysis, it is realized that this tool could not be used for knowledge flow problem. This tool is useful for inspecting the relationships between professionals. Therefore, this study was narrowed down to the stage of design process to be more specific on critical steps where the knowledge problem stems from. Design as Sanvido et al. (1994) argue, is a process by which the needs, wishes, and desires of the owner are defined, quantified, qualified, and communicated to the builder. As such, it is the particular phase of the building project where many key decisions are made. The early design effort starts with a minimum number of professionals who make relatively isolated decisions on important parts of the design problem (Howard et al., 1989). Meniru et al. (2003) showed that the success of the final design solution depends not only on the successful interpretation of these decisions by other professionals who become involved at different times in the process, but also on how easily all designers can coordinate/combine knowledge at the earliest possible time. In the same context, Moum (2006) supports that notion when he mentioned that a good design process is a fundamental mainstay of a successful building project.

Marples (1960) believed that design is a sequence of decisions starting from the original statement of functional requirements and ending by the technical specification of the artifact to be produced. According to AIA (1993) the design process starts with the owners' new need for a particular reason and ends when the owner moves into the building and starts to use the building. Some researchers such as Aken (2005) believed that for large and complex design-processes traditional approaches to process design may no longer suffice. Prescriptive knowledge models which have an eye to the required knowledge through design stage may support a more professional approach to design process. However, their impact on the practice of process design is still too limited (Aken, 2005). Aken also expressed that the organization and planning of the design process is an important issue both in architectural design and in engineering design. Despite the importance, experts tend to use traditional approaches to process design (Aken, 2005).

The above literature has shown that design approach is an essential factor in building project success, which could be supported by knowledge approach models. Further literature should guide us to examine fundamental concepts and also existing definitions for design process in order to develop a knowledge base model for conceptual design stage. The recognized models are analyzed regarding their steps and also the amount of their activities' definitions, due to the need for providing linkage between the knowledge and design process steps. Toward this goal, we will have a deeper focus on the design process proposed by different researchers. This section concludes by proposing an appropriate model for conceptual design step.

2.4.1 Design Process Definitions

According to Austin et al. (2001) many scholars in the field of design research have produced maps and procedures for negotiating what has become commonly known as the design process. Markus (1969) and Maver (1970), French (1971), Pahl and Beitz (1986), Pugh and Morley (1988), Cross (1993) and Archer (1995) are just some of them in architectural and engineering design domains, who had attempted to generate standardized design procedures (Austin et al., 2001). Moreover, Austin (2001) expressed that conceptual design phase of any project is a vibrant, creative and dynamic period, which can be disorganized with incomplete exchange of information between design team members. Whereas transfer of information, ideas and opinion is critical to the development of concepts, it needs to be understood and, ultimately, managed (Austin, 2001).

According to Fenevis et al. (2000) building design is an iterative process that follows three stages of refinement: conceptual design, preliminary design, and detailed design. He stated that conceptual design is the first stage where the most important characteristics of the building are defined. Major decisions are made regarding the building architectures and also salient features of the engineering support systems. During the conceptual phase of building design, as Fenves (2000) stated major decisions are taken regarding the building type, occupancy, form, dimensions, and type of structural system, all of which have great impact on the final form, constructability, cost, and overall performance of a building. Fenevis et al. (2000) believed that time and resources allocated to this phase are limited. Consequently, designers perform conceptual design by intuition and experience rather than by exploring the vast space of possibilities in a systematic manner (Fenevis et al., 2000).

Wheeler (unpublished, 1978) divided the life of an architectural construction project into nine major phases containing: (1) project master plan, (2) site analysis, (3) programming, (4) schematics, (5) design development, (6) construction documents, (7) bidding, (8) construction, (9) occupancy (Chung, 1989). His model was presented in matrix form which depicted the project phases, steps, and activities as performed by each of the project participants such as the owner, the project manager, the design manager, the construction manager, and so on. According to Wheeler the fourth, fifth, and sixth phases cover the design stage of a project and assist the determination of many of the sub activities and outputs.

2.4.2 Design Process Models

As mentioned earlier, the concern of this study is exploring the required knowledge during conceptual design stage of a building project. Furthermore, there is a need to have a deeper inspection of design process models to be able to link the discovered knowledge to the activities of the design stage. In response to the abovementioned need, in this section we narrow down to the details of existing design process models. The design literature has produced a great variety of models of design processes, including the following list, wherein the author's name and the principal elements of the model have been mentioned. A major source for this list was the review paper by Evbuonwan et al. (1996). We have summarized all the models in Table 2.10.

Marples (1960) believed that design is a sequence of decisions which start from stating requirements and ending by producing technical specifications of product. The functional specifications of decisions were represented in a tree. The Maple tree is a graphical method of recording a sequence of design decisions in the form of a series of problems and solutions which radiate from a design objective. The Marple tree can be used inductively to record past design rationale or speculatively to explore alternative courses of action (Cross & Sivaloganathan, 2005).

Asimow (1964) divided design process into three stages: (1) feasibility study phase, (2) preliminary design phase, and (3) detailed design phase. As such Watts stated that design process entails cycles of analysis, synthesis and evaluation, moving through design decisions from abstract levels to ever more concrete ones. French (1971) expressed four steps for design process which were: analysis, conceptual design, development of the generated schemes, and detailing. Also, Jones (1980) stated three stages consisting of analysis, synthesis and evaluation for design process. Hubka (1982) believed that design process entails: establishing function structure technical process, applying technical system, establishing boundaries, and so on. Pahl and Beitz (1986) proposed four steps for design process: clarification of tasks, conceptual design, embodiment design-which consists of preliminary layouts and configurations, selecting the most desirable preliminary layouts and refining and evaluating against technical and economic criteria-and detailed design.

According to Architects rules 1986 (Scale of minimum fees) the basic services by architect divide into four major steps: (1) Schematic design phase, (2) Design development phase, (3) Contract Documentation Phase, and (4) Contract Implementation and Management Phase. More details about these two steps are shown in Table 2.5.

Table 2.5. Design process base on Architects Scale of Minimum Fees Rules (1986)

Phase	Sub-activities
Schematic design phase	1. Taking the client's instructions and analyzing the project brief.
	2. Preparing preliminary conceptual sketch proposals to interpret the project brief.
	3. Developing the preliminary conceptual sketch proposals into sketch designs to a stage sufficient to enable an application to be made for planning approval or approval in principle to comply with the relevant by-laws.
	4. Preparing preliminary estimates of the probable construction cost based on current area, volume or other unit costs.
	5. Where applicable, preparing and submitting the drawings and other necessary documents to relevant approving authorities for either town planning approval or approval in principle.
Design development phase	1. Upon the approval of the proposals by either the relevant authority or the client, developing the schematic design drawings to a stage to enable other consultants to commence their detailed design work.
	2. Preparing working drawings and submitting the same together with all necessary particulars to the relevant approving authorities to obtain statutory building approval.
	3. Updating the preliminary estimates of construction costs and submitting the same to the client for his approval.
	4. Updating the project planning and implementation schedule and submitting the same to the client for his approval.
Contract Documentation Phase	1. Upon the approval by the client of the updated estimates of construction cost and the planning and implementation schedule, preparing and finalizing the detailed drawings and other particulars necessary to the stage of completion adequate for bills of quantities to be prepared by an independent quantity surveyor.

	2. Preparing all documents necessary for obtaining competitive tenders for the work;
	3. Inviting, on behalf of the client, tenders for the work or collaborating with the independent quantity surveyor engaged by the client to do so.
	4. Evaluating the results of the tenders and submitting a report and recommendation to the client.
	5. Awarding the contract on behalf of the client.
	6. Preparing the contract documents either alone or in collaboration with other independent consultants appointed by the client for signature by the client and the contractor.
Contract Implementation and Management Phase	1. Performing all the functions and duties of the architect under the terms and conditions of the building contract.
	2. Providing information and issuing instructions to the contractor as required under the terms and conditions of the building contract to enable the contractor to proceed with the works.
	3. Examining the works program submitted by the contractor to be determined that the works can reasonably be completed within the contract period.
	4. Inspecting the works at periodic intervals so as to ensure that the works are being executed in general accordance with the building contract and to enable the Architect to certify the completion of the various stages of the works required in support of an application for a certificate of fitness for occupation from the relevant approving authority.
	5. Where necessary, applying for a certificate of fitness for occupation or its equivalent from the appropriate authority.
	6. Accepting on behalf of the client, the works at various stages of completion.
	7. Providing a set of drawings showing the building as constructed and obtaining for the client the drawings of the building's services as installed together with all warranties and maintenance manuals as provided for in the contracts.

As such, Vanegas (1987) modeled the early phases of the design process into pre-design and preliminary design to aid the field of design-construction integration research. The scope of the model focuses on the early phases of design in private sector building construction. This model focuses on the roles and activities of the "owner team, design team, and construction team" during these early design stages. Its primary purpose is to improve the construct ability input in early design. German association of engineers (1987) produced VDI 2221 model for design process. This model consisted of: clarification and definition of the design task, determination of the required functions, search for solution principles for all sub-functions and combination into principal solutions, division of solution into principal modules, development of key modules into a set of preliminary layouts, development of definitive layouts and final documentation (German Association of Engineers, 1987).

Norton (1989) developed a model of the basic technical activities required to design a facility. This model included typical conceptual design, schematic design, detailed design, and working drawing phases. This model had four functions and fifteen sub-functions which are shown in Table 2.6. Norton model was successfully confirmed with the American Institute of Architects (AIA) standards of practice (Sanvido et al., 1994). The four key phases: understanding the functional requirements, exploring concepts, developing the system schematics, and developing the design and also (Sanvido et al., 1994).

Table 2.6. Architectural design activities

(Source: Norton, 1989)

Key Phases	**Activity**
Understand functional requirements	Assimilate and analyze information
	Establish project objectives
	Establish design parameters
Explore concepts	Perform preliminary studies
	Prepare and develop concepts
	Coordinate concepts
	Evaluate and select concepts
Develop systems schematics	Develop standard systems schemes
	Coordinate to find compatibilities
	Develop integrated schematics
	Evaluate and select schematics
Develop design	Perform systems development and layouts
	Perform studies and reviews
	Develop preliminary specification, drawings, schedules
	Acquire design approval

Cross (1993) stated six stages for design process consisting of: clarifying objectives, establishing functions, setting requirements, generating alternatives, evaluating alternatives, improving details. In 1993 American Institute of Architects (AIA) expressed that the building projects consist of five major phases: Originate, focus, design, build, and occupy (AIA, 1993). According to AIA (1993) design phase starts exactly when the project requirements are determined. During this phase expectations of owner are realized in drawings. The design phase stops with client's approval to the plans that will lead to construction (AIA, 1993). All concept design tasks proposed by AIA are summarized in Table 2.7.

Table 2.7. Design tasks proposed by AIA (1993)

Phase	Sub-Phases	Expected Tasks (partial)
Conceptual Design	pre-design	- design objectives
		- limitations and criteria
		- site requirements
		- space relations
		- initial approximate facility areas and space requirements
		- flexibility and expandability, etc.
	site analysis	- site analysis and selection
		- site development planning
		- on-site utility studies
		- zoning processing, etc.
	schematic design	- space layout or space schematics
		- conceptual site and building plans
		- preliminary sections and elevations
		- preliminary selection of building systems and materials
		- approximate dimensions, areas and volumes, perspective sketches, study models

Archer (1995) proposed six stages for design which consist of: (1) programming, (2) data collection, (3) analysis, (4) synthesis, (5) development, and (6) communication. Roozenburg and Eekels (1994) stated that design process has four basic steps: (1) analysis, (2) synthesis of the solution to the design problem, (3) simulation to predict the properties of the product, and (4) evaluation (Roozenburg and Eekels, 1994). Reymen (2001) organized the overall design process in a sequence of design sessions which start with planning and end with reflection (Reymen, 2001).

Macmillan et al. (2001) developed and verified a structured framework, which had been generated to aid and support the interdisciplinary team in undertaking conceptual design. Table 2.8 shows the combination of sources and empirical data to demonstrate the genesis of the preliminary design framework. In fact Macmillan et al. (2001) established the proposed framework for conceptual design based on precedent studies and attempted to cover their recognized gaps. As it is apparent in Table 2.8 each column presents the proposed models by different researchers such as Hubka (1982), Pahl and Beitz (1988), Cross (1989) and Jones (1992). Empty cell through each columns present the gaps which have been covered by Macmillan framework. Referring to the Table 2.8, Macmillan attempted to revise and combine abovementioned researchers' work. Macmillan framework was verified through a case study process. In this condition, they realized impossibility of implementing this framework in a real project due to lack of definitions for the activities. For this reason they attempted to define detailed definitions for activities which have been shown in Table 2.9. In fact, these definitions can be used to compare with the performed activities by team members to discover the required knowledge.

Table 2.8. Concept design models which used by Macmillan (2001) to establish conceptual design framework

Hubka (1982)	Pahl & Beitz (1988)	Cross (1989)	Jones (1992)	Macmillan (2001)
				Specify the need
		Clarifying objectives		Assess the requirements
	Identify essential problems			Identify essential problems
Establish function structure	Establish function structures	Establishing functions	Design situation explored	Develop the requirements
Establish technical process				
Apply technical systems and establish boundaries		Setting requirements	Problem structure perceived And transformed	Set key requirements
Establish groupings of functions		Determining characteristics		Determine project characteristics
Establish functional structure and represent			Boundaries located sub-solutions described and conflicts identified	
Establish inputs and modes of action	Search for solution principles	Generating alternatives		Search for solutions
Establish classes of function				
Combine function carriers and examine relationships	Combine solution principles			Transform and combine solutions
	Select suitable combinations		Sub-solutions combined into alternative designs	Select suitable combinations
Establish basic arrangement	Firm into concept variants			Firm into concept variants
			Alternative designs evaluated and final design selected	
	Evaluate against technical and economic criteria	Evaluating alternatives		Evaluation and choice of alternatives
		Improving details		Improve details and cost options

Macmillan et al. (2001) also provided detailed definitions for all defined activities which are shown in Table 2.9. To confirm applicability of the framework to building design, it applied to real-time design activity.

Table 2.9. Definitions of activities of Macmillan (2001) framework

No.	Activities	Definition
1	Specifying the business need	- Recognizing business needs(interdisciplinary design team must fully understand this need before any attempt) - Gathering available information and generating mission statement to define what is required
2	Assessing Stakeholder Requirements	Taking the specified business need and attempting to elicit information from client aspiration in terms of requirements for functionality.
3	Identifying problems with existing solutions	- Specify constraints of the problem - Guide the design by setting some design drivers and constraints
4	Developing Requirements	- Extend acceptable solution boundary by identifying real users of facility and questioning them as a means of understanding their value requirements - Combining experience and expertise into the design environment - Contest both convention and client wishes to develop function structure by design team members
5	Setting Requirements	Producing a list of all requirements by client and design team
6	Determining Project Characteristics	- Defining boundaries of the research by using pre-set requirements - Rank the requirements in order of their perceived value - Define the project characteristics using value hierarchy (value datum to assess conceptual design proposal)
7	Generating initial concepts	- Generate initial solutions based on exist solutions or abstract ideas - Use creative thinking in conjunction with experience and prior knowledge

8	Transformation/ combination of concepts	- Have a number of holistically solutions as a result of uninhibited thought (maybe unusable in present form) - Developing, transforming and combining individual proposals to mould them into usable proposals
9	Selecting suitable combinations	- Elimination of totally unsuitable proposals - Giving preference to better remained solutions
10	Firming up into concept proposals	- Reveal gaps in information about important elements of the design - Necessity of knowing working principles such as performance, space requirements, pinch-points in structure, services, co-ordination etc. approximately
11	Evaluating and choosing proposal	- Evaluating solution proposal by interdisciplinary team - Gauging concept variants against one another, an imaginary ideal and/or pre-set value hierarchy of design characteristics and requirements
12	Improving detail and costing proposal	- Detailing cost of proposals - Developing the chosen proposal to a level that allows the critical unknowns to be improved to the point where they pose little or no risk to the subsequent development and success of the project - Document must satisfy and ensure client needs

By comparing Macmillan (2001) framework and precedent models which used to establish this framework, it was realized that most of its activities have been used in precedent models. Moreover, the activities' definition for Macmillan model can be used to be compared with the performed activities by team members to discover the required knowledge. Lawson (2005) concluded that design involves a tremendously wide range of human endeavour and requires problem finding, and problem solving, deduction and the drawing of inferences, induction and the creating of new ideas, analysis and synthesis.

Eilouti's (2009) model included encoded forms, functions, processes, concepts, scenarios, principles and components of previous design products. Eilouti used typological classification and organization to form abstract pieces of knowledge within clear structures. The hierarchy of Eilouti model is illustrated in Figure 2.5. This Figure shows a sequence of five levels for extracting and implementing precedent-base knowledge. The first level is selecting precedents. The second level is deciding about the method of applying selected precedents which can be retrospective for pre-design reasoning, or prospective for design and post-design phases. The third level is detailing all the phases. The phases of this model are divided into: (1) Pre-design, (2) Design, and (3) Post-design. The pre-design phase entails reasoning or organization activities. The design phase of this model includes various design activities such as mapping, adaptation and so on. Post-design part includes evaluation tasks. All sets of tasks are detailed in the subsequent levels. In the fourth level, the pre-design reasoning activity branches into precedent case retrieval, and the study of its multiple layers. The organization activity branches into the tasks of classification of its analyzed layers, the representation of the extracted information into more accessible forms, and the prototyping of its representations to function as templates for future design solutions. The design activities include mapping of a precedent to a design problem, modification of the solutions it represents, the adaptation of the revealed sub-solutions, their synthesis and development, and the documentation of the selected solutions. The post-design phase includes the comparison of a generated solution to other precedents that can be considered successful solutions, and the performance simulation of some proposed scenarios of the generated design. In the fifth level, the task of retrieval is further detailed into the search for potential precedents and the selection of the proper ones. Similarly, the study task is further detailed into the interpretation of the selected precedents and the morphological and structural analysis of their compositions. In this level, the precedent-based sub-solutions are either modified or combined, and the synthesis of the sub solutions takes either the form of puzzle-making where sub-solutions are assembled, or the mutation and subsequent refinement of a potential solution.

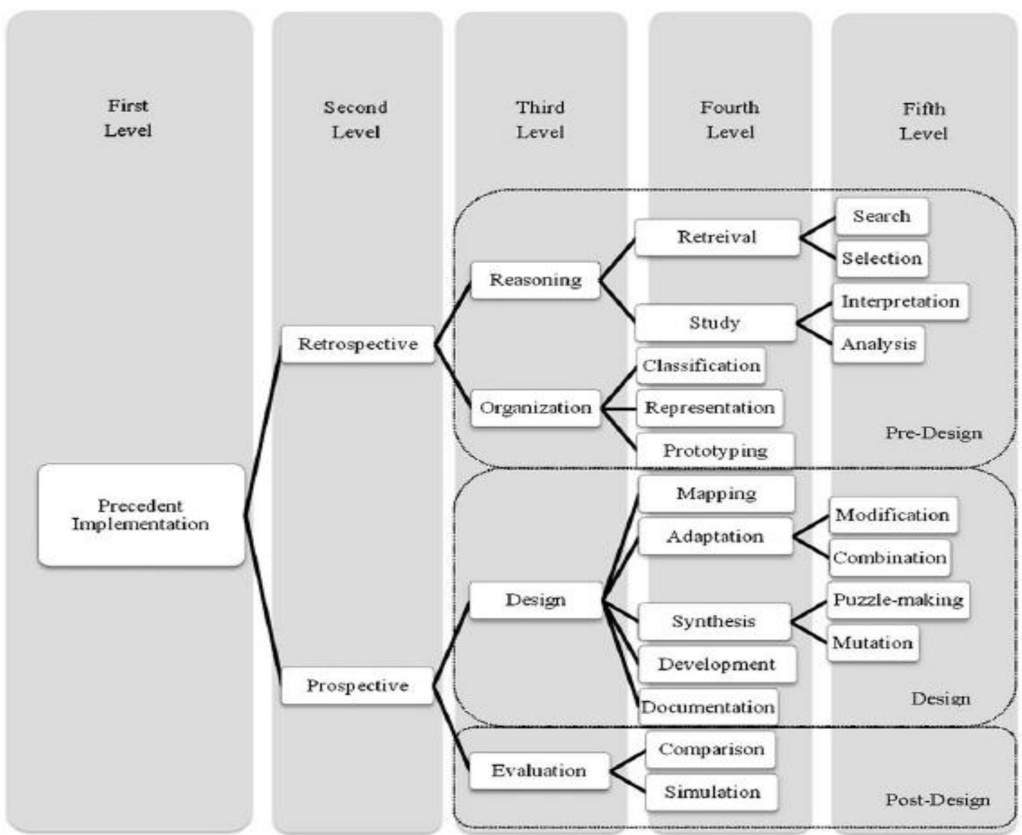

Figure 2.5. Hierarchy of precedent-based design processing activities

(Source: Eilouti, 2009)

The whole cycle of retrospective investigation and prospective implementation of precedent-based knowledge in design is graphically illustrated below. Firstly, relevant precedents to the current design problem are investigated and selected. Through interpretation stage new explanations are added to the raw data embedded in precedents to restructure the data to more comprehensive forms. Then, all aspects of the selected examples are analyzed according to the pre-defined criteria and objectives. After analyzing the precedents, they are categorized according to organizational criteria or goals. In representation stage precedent-based information are represented in more accessible forms. Finally, in prototyping stage the representations are organized in easy forms to reuse templates. The developed templates are refined and developed into labeled models. There are some activities from abstract prototypes to synthesized proposals. This stage starts with the mapping of a given design problem to one or more of the sub-solutions offered by the developed models in the retrospective stages. Each precedent-based model by passing through the modification or combination stage can be a potential solution for design problem. Next step is synthesizing models to propose alternatives for new design solutions. Then, the alternative solutions are compared and evaluated according to preset goals. Upon this stage a new elected solution may be developed into a final design. The result of the development of the synthesized solutions is refined and communicated as a new concrete precedent case.

According to Aken (2005) some design models are based on a synthesis of case-studies, like the model of Marples, others are based on the experience of prominent designers, like the VDI 2221 model (Pahl & Beitz, 1996). Empirical basis for several models is unclear and seems to be based on experience or thinking of authors which may derive from the literature. This is a respectable basis, especially in a design environment because many good designs are made in this way (Aken, 2005). Recalling researchers' work to model the design process, the researcher recognized that models can be distinguished in two different meanings: (1) models which explain design process, (2) model which entails design phases. Tables 2.10 and 2.11 respectively show existing models for design process and design phases.

Table 2.10. List of models for design process

Author	Year	Description
Marples	1960	Design is a sequence of decisions starting from the original statement of functional requirements and ending by the technical specification of the artifact to be produced
Watts	1996	Cycles of analysis, synthesis and evaluation, moving through design decisions from abstract levels to ever more concrete one
Jones	1980	Three stages: analysis, Synthesis, Evaluation
Hubka	1982	Establish function structure technical process, apply technical system, establish boundaries, etc.
Venegas	1987	Pre-design and preliminary design
German Association of engineers-VDI 2221	1987	Definition of the design task, determination of required functions, search for solution principles, division of solution into principal modules, development of key modules into a set of preliminary layouts, development of definitive layouts, final documentation.
Reymen	2001	Organize the overall design process in a sequence of design sessions, each starting with planning and ending with reflection
Lawson	2005	Problem finding, problem solving, deduction and the drawing of inferences, induction and the creating of new ideas, analysis and synthesis.

Table 2.11. List of models for design phases

Author	Year	Description
Asimow	1964	Analysis, conceptual design, development of generated schemes
French	1971	Four steps for design process: analysis, conceptual design, development of the generated schemes, and detailing
Pahl and Beitz	1986	Clarification of tasks, conceptual design, embodiment design, detailed design
Architects Scale of Minimum Fees	1986	Schematic design, design development, contract documentation, contract implementation.
Venegas	1987	Pre-design and preliminary design
Norton	1989	Conceptual design, schematic design, detailed design, working drawing.
Cross	1993	Six stages, three decomposing the overall problem into sub-problems, and three stages synthesizing the overall solution
AIA	1993	Pre-design, site analysis, schematic design
Archer	1995	Six stages with iterations between stages where necessary
Roozenburg	1995	Four basic steps with possible iterations between the steps
Macmillan	2001	Preliminary conceptual design framework
Eilouti	2009	Pre-design, design, post design.

After examining the existing design models we found that the proposed model by Macmillan (2001) can be a good choice for our study. The justifications to choose this model are explained as follow. Firstly, this model has been founded on many other researches carried out by Hubka (1982), Pahl and Beitz (1988) and so on. Furthermore, as it is evident in Table 2.8 this model attempted to cover the precedent works' gaps (Macmillan, 2001). In addition, the comparison among existing models revealed that most of the activities in this model are used in other models, too. Eventually, defining definitions for this model's activities made it implementable in real projects (Macmillan, 2001). Hence, these detailed definitions for activities are a reasonable justification for choosing this model due to the methodology of this study which links knowledge to the framework activities. Indeed, activities' definitions are descriptive of design-related events and different participants of design team members through each activity. Finally, the most important advantage of Macmillan model focused on conceptual design stage which is the target phase for this study.

2.4.3 Information Flow in Design

The Architecture/Engineering/Construction (AEC) industry is one of the multidisciplinary domains in which collaboration among related parties is of utmost importance. Despite the intense flow of information between professionals involved in design process, as Pektaş (2006) stated there is a lack of research to better understand and manipulate these flows. Ibrahim and Nissen (2005) emphasized on the importance of knowledge movement between professionals. As an example, they stated that a costly mistake caused a problem in designing a facility which stemmed from improper movement of knowledge from architecture to a mechanical engineer. Furthermore, Ibrahim and Fay (2006) explained that design organizations are working in dominantly tacit knowledge areas during planning and conceptual design phase, which increasingly progress towards explicit dominant knowledge areas culminating in the property management phase.

Ibrahim (2005) expressed that information is the selective collection of facts which can be used to perform a task while knowledge is information in action. According to Macmillan (2001) the rapid and dynamic information and knowledge flow between designers during the conceptual phase of building projects can result in disorganized behavior within the team. According to Ibrahim (2005) team members can become frustrated by the lack of a common understanding of what the other team members know. Evidence suggests that design teams are better equipped to undertake design activity when in possession of a general program of events or activities through which they are likely to pass than when no such structuring concept is held (Macmillan, 2001). Macmillan proposed a framework for conceptual design stage of a building project. Although many researchers such as Macmillan have recognized immense influence of knowledge flow on project performance, their works would not entail knowledge flow between experts. Therefore, there is a need to synthesize knowledge flow with the proposed workflow by previous works.

2.4.4 Point of Departure for Design Literature Review

After examining the selected design models it became clear that Macmillan (2001) framework can be a good choice for our study. Justifications to choose this framework have been explained below. As mentioned earlier, this framework has been established on many other researches' work (see Table 2.8) in order to cover their gaps. In addition, comparison between existing models highlighted that most of the base models have similar activities such as identify problem, search for solution and so on. Eventually, to make this framework applicable in real projects detailed definitions have been provided for its activities. Possessing detail definition for activities is a reasonable justification for choosing this framework. These definitions are used to provide link between the knowledge and the framework activities. To provide this linkage, performed activities by concept design team members will be compared with detail definitions for Macmillan (2001) framework. In this way, the exchanged knowledge during team members' activities can be related to the Macmillan framework activities. Then, Macmillan activity-based framework will be extended to a knowledge-based framework.

As far as the problem, which this research attempts to address, is concerned, two essential issues are involved in relation with the knowledge during conceptual design stage: (1) the knowledge, and (2) the step in the conceptual design stage for which the knowledge needs to be captured. Regarding these two aspects, this study is reminiscent of the repertory grid function (See Section 2.3.3) which uses a grid to rate elements regarding their associated attributes. Using a relational-matrix, which borrows its structure from repertory grid technique, the required knowledge during conceptual design phase could be explicated. To provide this matrix, activities of Macmillan (2001) conceptual design framework will be the first entry of this matrix. To determine the second entity of the matrix, a tacit knowledge capture technique will be used to capture the experts' knowledge. Finally, the studied literature revealed that the conceptual design phase is a problematic stage in building projects. Since Macmillan framework focuses on this stage, this framework can be an appropriate choice for the study.

2.5 Theoretical Framework

Scholars such as Fenevis (2000) and Austin (2001) have emphasized on the conceptual design phase as an important phase in the design process of building projects. This phase is ideally multidisciplinary in which the flow of knowledge tends to be problematic. Moreover, the study agrees with Ibrahim and Paulson (2005) that the conceptual design stage is tacit-dominant with many professionals involved. Therefore, the purpose of this study is to focus on capturing experts' tacit knowledge during the conceptual design stage.

Nissen (2006) multidimensional model examined the movement of knowledge between experts considering knowledge typology. He has stated that experts' knowledge, which is transferred to other people to enable them to do their tasks, is of the tacit type. Then, in the next step the knowledge is converted to explicit type and formalized (Annotated as "Existing flow proposed by Nissen" in Figure 2.6). Nonaka (1995) stated that tacit knowledge is difficult to formalize and share. Considering this, the study proposes that if researcher could convert tacit knowledge when it is moving from an individual to a group, we can save the time for the next step which is the formalizing step (Annotated as "Proposed flow by this study" in Figure 2.6). Time saving causes to merge two steps and shortens the flow time (Nissen, 2006) of the explicit knowledge.

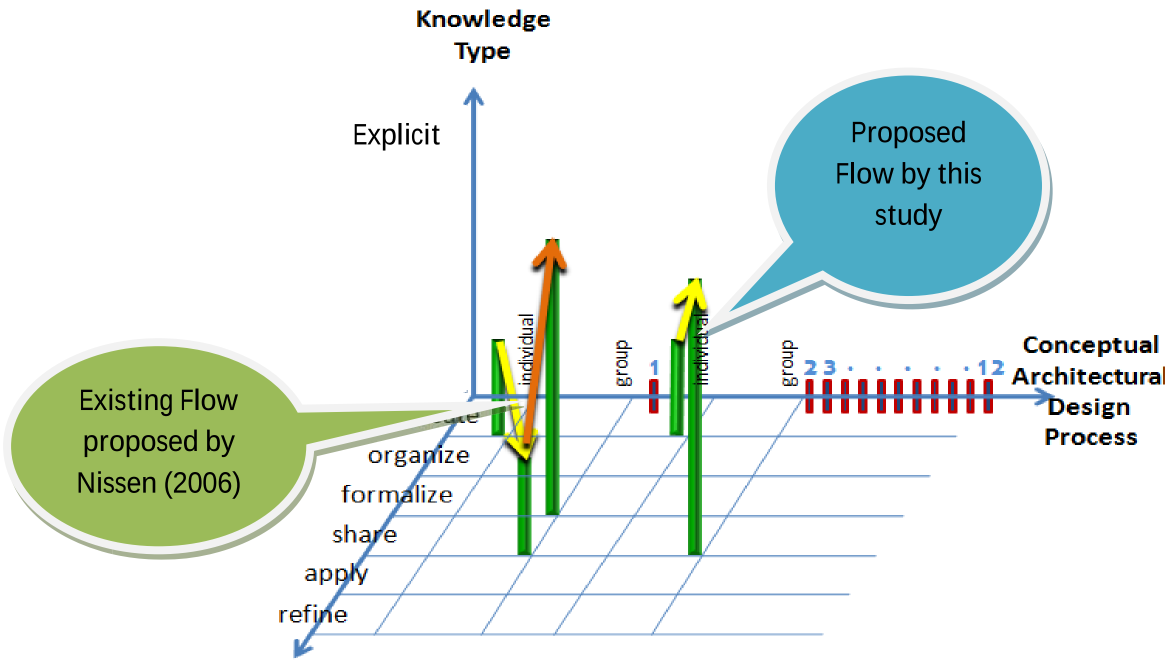

Figure 2.6. Proposed Status to Convert Tacit Knowledge to Explicit

(Source: Nissen, 2006)

Referring to the literature for knowledge conversion process (see 2.3.2), there are two main elements to capture knowledge: (1) one is the knowledge which has to be converted and, (2) a proper technique to do this conversion. Because, this study is concerned with the knowledge required during the conceptual design phase, therefore we need to be more focused on this stage. Toward this goal, existing models for this stage have been examined to choose an appropriate one. Indeed, this study attempts to provide a linkage between the required knowledge and the conceptual design activities. Therefore, selected models have to include sufficient details for the activities. To this end, after comparing existing models, Macmillan (2001) framework has been chosen as an appropriate model which was usable to make a linkage between activities and the required knowledge.

2.6 Summary

In this chapter, the literature survey about knowledge management process, knowledge flow and also design process allow the researcher to constitute a theoretical framework on the basis of the discovered related background theories concerning capturing tacit knowledge of experts during conceptual design stage. The study proposes using Nissen (2006) multidimensional model to examine the knowledge flow of different typologies and members. Since the selected area for this study is conceptual design phase of a building project, the study proposes Macmillan framework, which includes sufficient details for capturing tacit knowledge between different members. By adopting these two theories the thesis proposes two propositions for the study:

> ***Proposition 1:*** Knowledge capture can be improved when design professionals know what the required knowledge are and when they are needed during conceptual design phase.
>
> ***Proposition 2:*** With improved knowledge capture, design professionals can improve their knowledge transfer and application during conceptual design phase.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In this chapter, the performed case study research is explained. Furthermore, the researcher expresses the reasons for choosing this methodology to solve the stated problem. Then, components of selected methodology, data collection procedure, unit of analysis, and data analysis are elaborated. Objectives of this study are explained below:

Objective 1: To specify an appropriate knowledge capture technique for tacit dominated conceptual design phase.

Objective 2: To identify fundamental mechanical/electrical requirements to be considered by architects during the conceptual design phase.

Objective 3: To develop a framework for capturing fundamental tacit mechanical/electrical requirements during conceptual design phase.

3.2 Research Methodology

The selected method for this research is qualitative. Qualitative inquiry employs different knowledge claims, strategies of inquiry, and methods of data collection and analysis. Qualitative procedures rely on text and image data. Looking over the landscape of qualitative procedure shows perspectives ranging from postmodern thinking (Denzin & Lincoln, 2000), to ideological perspectives (Lather, 1991), to philosophical stances (Schwandt, 2000), to systematic procedural guidelines (Creswell, 1998; Strauss & Corbin, 1998). All perspectives are considered as "qualitative" research.

It needs to be noted that this research deals with knowledge of experts residing in their minds. Since tacit knowledge of expert is a type of thinking phenomenon, qualitative method is then proposed for this study. As Creswell (2003) stated, there are several characteristics for qualitative research: (1) Qualitative research takes place in a natural setting such as at a site, a home or an office involving the actual experience of participants to obtain details about their activities; (2) Methods of collecting data is traditionally based on open-ended observations, interviews, documents and several new methods such as sounds, emails, scrapbooks, text data and images; (3) Research questions may change or be refined; (4) Researcher makes an interpretation of data through a personal lens and cannot escape the personal interpretation risk; (5) Qualitative researcher views social phenomena holistically; (6)

Qualitative researcher reflects on who is in the inquiry; and (7) Qualitative researcher uses complex reasoning that is multi faceted, iterative and simultaneous.

Furthermore, Creswell (2003) expressed that case study is a proper strategy to explore processes, activities and events. According to Yin (2003), a case study design should be considered: (a) when we are facing "How" and "Why" questions; (b) when manipulating the behavior of the people involved in the study is not possible; (c) when there is a need to cover contextual conditions due to this belief that they are relevant to the study; or (d) when the boundaries are not clear between the phenomenon and its related context. For instance, to discover how experts know the required knowledge from different professions involved in conceptual design. Moreover, in which step of concept design they have to interact with other experts. Yin (2003) defined case study as empirical inquiry which benefits from previous theories and propositions to guide data gathering and analysis. Moreover, according to Yin (2003), the issue of generalizability is one of the challenges of case study. Case studies are generizable to theoretical propositions. Yin expressed that the generalizability issue is more theoretical and conceptual compared to experiment and survey. Based on the abovementioned reasons Yin (2003) case study research methodology is proposed as a general approach for this research. This chapter explains the case study and its required components in the following section.

3.3 Case Study Research Methodology

According to Yin (2003), there are two general analytic strategies which consist of (1) relying on theoretical proposition and, (2) developing a case description. This study chooses theoretical proposition. Yin prescribed five main components for a case study research methodology which are explained below:

3.3.1 Research Questions

Ibrahim (2008) stated that there are two ways to develop a research question: (1) knowing the problem by experience; (2) identifying gaps in the literature in the area of the research interest. This study's problem is: "Improper knowledge exchange between architects and engineers during conceptual design stage will lead to cost and time overrun in building projects."

It is found out through the previous conducted studies that many researchers such as Paulson (1976), Jin & Levitt (1996), Martinez (1998), Ibrahim (2005), Ibrahim & Paulson (2008), Ahmed (2005), Nissen (2006), and Ibrahim & Nissen (2007) believed that there is a problem with knowledge transfer in the construction industry which leads to cost and time overrun in the building projects. In addition, many other researchers including Cronik (1991), Rounce (1998), Macmillan (2001), Pektas & Pultar (2005) emphasized that the design causing wasted time and cost would form the largest category. At the same time, Ibrahim and Fay (2006) argued that the design process is a tacit dominant stage. Unfortunately, there is a lack of literature on transferring tacit knowledge according to Alavi and Leidner (2001). With support from Ibrahim & Paulson (2008) stating that knowledge type contributes to the knowledge loss phenomenon, this study posits whether or not it is possible to mitigate time and cost overrun if tacit knowledge transfer is facilitated.

Nissen (2006) further explained in his multidimensional model for product life cycle that the knowledge transferred to other experts through sharing the experience is of tacit type. According to his model, tacit knowledge comes from heavy mass and contributes to long flow time. Hence, knowledge transfer is improved through this phase by finding a way to convert tacit knowledge that has to be exchanged between experts during conceptual design stage to the explicit type. Many professionals from various fields such as mechanical, electrical, and structural professions are involved during conceptual design stage.

So far, many researchers have recognized mechanical and electrical considerations as the most problematic areas during conceptual design phase. Furthermore, this study has predominantly concentrated on mechanical and electrical considerations due to existing time limitation. Therefore, the main research question of this study is: “How can tacit knowledge of design requirements be formalized for improving knowledge flow among professionals during conceptual design phase of building projects?”

In design phase, mechanical/electrical requirements are the most problematic considerations. Thus, this study develops Sub-RQs pertaining to such considerations. The Sub-RQs of this study include:

> *Sub-RQ1:* What are techniques to formalize mechanical/electrical knowledge of design requirements during conceptual design phase of building projects?
>
> *Sub-RQ2:* What are the required mechanical/electrical knowledge during the conceptual design phase of building projects?
>
> *Sub-RQ3:* How do architects and mechanical/electrical engineers know when to transfer the required knowledge for improving conceptual design phase of building projects?

3.3.2 Theoretical Proposition

According to Yin (2003) there are two general analytic strategies. One relies on theoretical proposition and the other one develops a case description. In this study, a theoretical proposition has been utilized. Precedent literature points to incomplete knowledge flow which leads to overruns of time and cost in building projects. According to some researchers such as Rounce (1998), the considerable amount of wasted time is related to the design stage. Bearing in mind that the design stage is a tacit-dominated area and also considering the difficulty of organizing tacit knowledge, the propositions are:

Proposition 1: Knowledge capture can be improved when design professionals know what the required knowledge are and when they are needed during conceptual design phase.

Proposition 2: With improved knowledge capture, design professionals can improve their knowledge transfer and application during conceptual design phase.

3.3.3 Selection of a Unit of Analysis

The unit of analysis for this study is a team of six 4th year architectural students in a public university who won a competition to design a building project. There are some justifications to choose this unit of analysis; the reasons are:

- There are restrictions in Malaysia in attending conceptual design phase, because this stage is client-based.
- It was difficult to get real people and real projects, because they are not keen to document their activities.
- 4th year students are junior architects and therefore are able to complete medium size building projects. Furthermore, they considered 100% of mechanical and electrical requirements for concept design.
- Medium size building project is appropriate due to time limitation for a PhD research.
- Outdoor projects are risky due to the following:
    - There was no ongoing project and possibility to attend project meetings.

- It is not a common practice for architects to work with mechanical and electrical engineers in Malaysia.
- The actual professionals are not keen to be observed and also do not like recordings their activities taken.
- We had no access to a real project due to time limitation for PhD research.
- Architects are in practice for green building projects and they are not experts in this field.

For more reliability of collected data, more details about the process of improvement of skill of students are explained below. According to Nissen and Levitt (2002), skill level of team members could improve through conducting training courses. In this way, they can perform better on their tasks. Nissen and Levitt also report that the level of rework was down considerably. They used Simvision software to emphasize the improved performance of projects arising from improved skill level of team members. Their study supports the use of Simvision in this study for evaluating the workflow performance. To improve team members' skills, training courses were conducted before starting conceptual design (please refer to the technical report UPM/FRSB/EDI/TR4, 2010 – Please refer to Appendix 1 for summary of this report). Firstly, many professionals such as Associate Professor Doctor Nor Mariah Adam (mechanical/electrical expert from Mechanical Engineering Department), had lecturing sessions for required mechanical and electrical requirements. Next step was conducting research about the required technologies for green building projects. Then, students presented their literature review about abovementioned requirements (refer to the published technical report for more details). Using this process, they found all the required considerations about the required technologies. Finally, they attempted to consider all the technical requirements through conceptual design stage. Afterwards, they presented their proposed concept to the professionals in the field of architecture and also mechanical and electrical engineering fields. The professionals commented on their work based on technical requirements to revise the proposed concept. All the evidences (containing video records and also documents) have been attached to the published technical report.

The team created a concept to design a green building project for an institute in the same university. The study calls this undertaking 'ITMA' project. Figure 3.1 shows how five groups were formed to investigate green building technologies including solar assisted air conditioning, wind turbine, daylight augmented lighting strategy, building integrated photo voltaic system and rainwater harvesting and waste management (refer to the provided technical report for more details about the technologies). Then, toward the process of generating concept design proposals, three groups were formed. Each group for the design entails an expert from each five technology groups. Indeed, architectural students who had studied the required technologies played the role of mechanical/electrical experts. These three groups competed to propose a concept for the ITMA project. The winner group was the unit of analysis for this study. The process of generating conceptual design consists of three steps as shown in Figure 3.1. Explanation of the selection process shall follow afterwards.

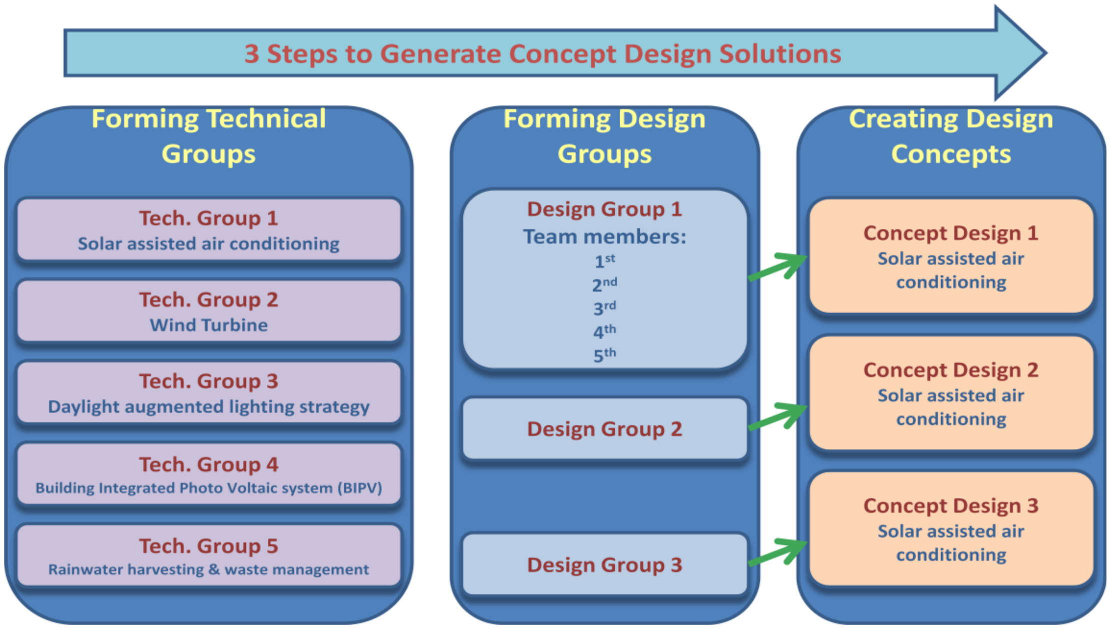

Figure 3.1. Process of Generating Design Proposals

All the three groups conducted the concept design for 6 hours on 15 March, 2010. To do data collection for this case study, the researcher recorded their activities throughout the day. The groups presented their concept proposals at the end of the same day. This research purpose is to obtain the knowledge from mechanical side which has to be considered during the conceptual design phase of building projects. The schedule for providing the concept design and presenting proposals is shown in Table 3.1.

Table 3.1. Schedule of ITMA project

Description	Due Date
Issue	23 February 2010
Brief formulation	24 February 2010
Technological seminars	03 March 2010
Concept design	15 March 2010
Design presentation	30 March 2010
Assessing Proposals	16 April 2010

A jury panel – consisting of six professional architects and mechanical/electrical engineers – commented the proposals to lead them to improve their concepts. The pre-final presentation was held on 30 March, 2010 and final presentation for final judgment took place on 16 April, 2010. All three groups presented their concept proposals specifically on how technical and architectural requirements were integrated. Assessment of the proposals was performed based on the scores shown in Table 3.2.

Table 3.2. Assessment results detail

Assessment		Group 1		Group 2		Group 3	
Factors	**Assessor**	**Score**	**percentage**	**Score**	**percentage**	**Score**	**percentage**
Design concept and strategy	1	8	16%	10	20%	3	6%
	2	9	18%	9	18%	8	16%
	3	6	12%	8	16%	6	12%
	4	8	16%	9	18%	9	18%
	5	8	16%	7	14%	7	14%
Building form	1	7	14%	10	20%	4	8%
	2	9	18%	9	18%	9	18%
	3	7	14%	9	18%	6	12%
	4	8	16%	9	18%	7	14%
	5	8	16%	7	14%	7	14%
Technological design	1	9	18%	9	18%	5	10%
	2	8	16%	8	16%	8	16%
	3	7	14%	7	14%	7	14%

	4	8	16%	8	16%	7	14%
	5	9	18%	7	14%	7	14%
Architectural aesthetics	1	7	14%	7	14%	6	12%
	2	8	16%	8	16%	8	16%
	3	7	14%	9	18%	7	14%
	4	6	12%	8	16%	6	12%
	5	8	16%	8	16%	7	14%
Presentation	1	9	18%	7	14%	7	14%
	2	9	18%	8	16%	8	16%
	3	8	16%	9	18%	7	14%
	4	8	16%	9	18%	8	16%
	5	8	16%	8	16%	6	12%
Total Average Score	1	8	16%	8.6	17.2%	5	10%
	2	8.6	17.2%	8.4	16.8%	8.2	16.4%
	3	7	14%	8.4	16.8%	6.6	13.2%
	4	7.6	15.2%	8.6	17.2%	7.4	14.8%
	5	8.2	16.4%	7.4	14.8%	6.8	13.6%

After presenting proposals by groups, the panel conducted a meeting to discuss and vote on the winning concept. Finally, Group 2 was announced as the winner. As demonstrated in Table 3.3, Group 2 had the highest mark considering the average earned marks. This result shows that voting and calculations produced similar results for this competition.

Table 3.3. Final Assessment Results

	Overall Score					Average
Groups	**Assessor 1**	**Assessor 2**	**Assessor 3**	**Assessor 4**	**Assessor 5**	
Group 1	80%	86%	70%	76%	82%	79%
Group 2	86%	84%	84%	86%	74%	**83%**
Group 3	50%	82%	66%	74%	68%	68%

According to the results in Table 3.2, most of the assessors marked the concept proposed by Group 2 as higher than the other groups. Therefore, consensus among the assessors resulted in Group 2's winning the competition. Some photos for final presentation of the three groups are displayed in Figure 3.2 to Figure 3.4.

Figure 3.2. Final presentation Green Spine by Group 1

Figure 3.3. Final presentation Green Sprawl by Group 2

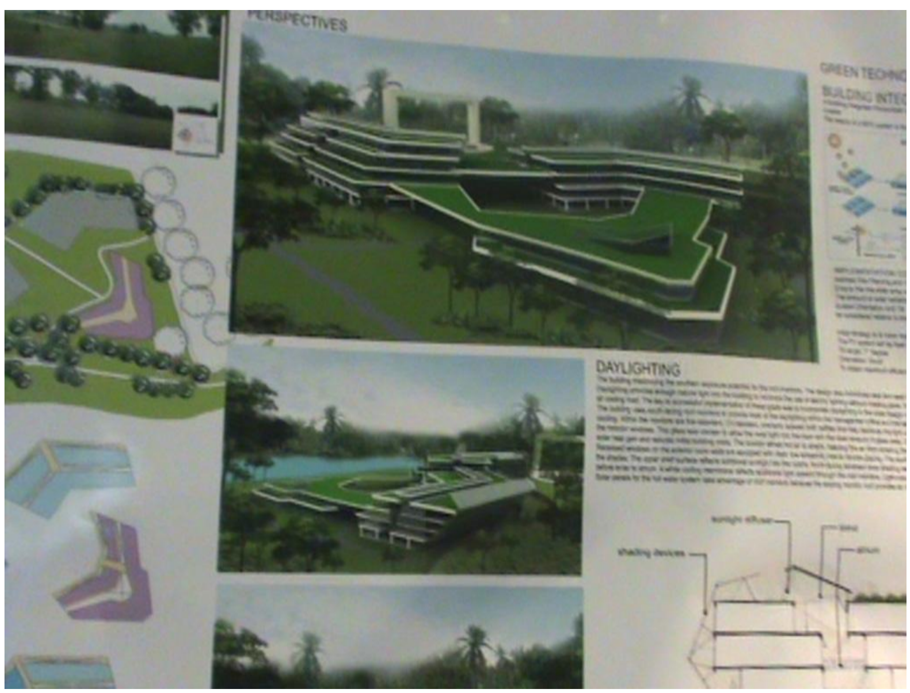

Figure 3.4. Final presentation Reciprocal lab by Group 3

Referring to the competition results in Table 3.3, Group 2' proposal was chosen as the best proposed concept. After announcing the winner, the researcher interviewed one of the panels who were expert in the context of technical requirements for Green Building projects. She also emphasized that Group 2 has considered the most technical requirements in their proposed concept. Thus, Group 2 was chosen as the unit of analysis for further analysis.

3.3.4 Linking Data to Proposition

The scope of this study is limited to the exchange of knowledge between architects and mechanical/electrical engineers. Recalling Chapter 2, the first proposition for this study is that "knowledge capture can be improved when design professionals know what the required knowledge is and when it is needed during the conceptual design phase". Since this study focuses on mechanical/electrical and architectural transcriptions, it documents and specifies:

- The required mechanical/electrical knowledge during conceptual design phase, and
- The right time to consider this required mechanical/electrical knowledge during the conceptual design phase.

To specify the required mechanical/electrical knowledge during conceptual design phase, this study needs to find an appropriate technique to capture expert tacit knowledge. Hence, sub-RQ 1- "**What are techniques to formalize mechanical/electrical knowledge of design requirements during conceptual design phase of building projects?**"- must first be addressed. Then, using the appropriate knowledge capture technique, this study would capture the required mechanical/electrical knowledge during conceptual design phase of the ITMA project. By specifying the required mechanical/electrical knowledge during conceptual design phase, sub-RQ2 is answered.

Moreover, Hari (2005) asserted that there are two main elements in capturing knowledge: (1) the technique to capture the knowledge; (2) the knowledge which has to be captured. Hence, the next step divides the task into two main parts:

Part 1a: Finding an appropriate technique to capture knowledge during conceptual design phase.

Part 1b: Determining what knowledge has to be captured;

Part 2: Capturing the required mechanical/electrical knowledge during conceptual phase of building projects.

The process of finding appropriate technique, determining the entity of the required mechanical/electrical knowledge and also capturing this required knowledge is shown in Figure 3.5.

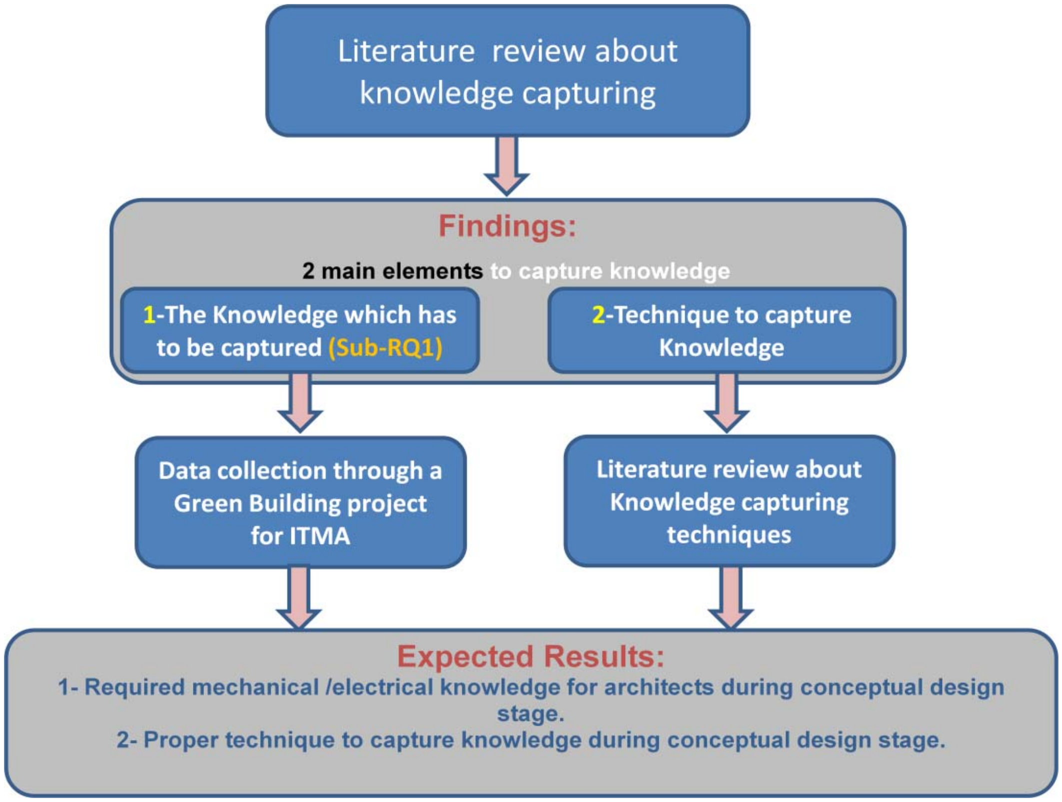

Figure 3.5. Process of Specifying and Capturing the Required Mechanical/Electrical Knowledge

For part 1a, the researcher conducted a literature survey about knowledge capture to identify the way of capturing knowledge. Then, the knowledge capture techniques were examined to find an appropriate one to capture professionals' knowledge during the conceptual design phase of building projects. As a result, the observation technique was recognized as an appropriate technique to capture mechanical/electrical tacit knowledge during conceptual design stage of a building project (See Section 2.3.5 for detail).

For part 1b, the researcher used observation technique to capture professionals' knowledge through a case study during conceptual design phase of ITMA project. Creswell (2003) stated that in observation method, the researcher takes field notes on the individual behavior and activities at the research site. Moreover, he believed that the role of researcher can be either a complete participant or an observer as participant, or a participant as observer or a complete observer. The researcher needed to be acquainted with all team members for having conversations with them to determine the considered knowledge. For this purpose, the researcher attended and observed all the activities performed by the team members to document the mechanical/electrical knowledge. Hence, the researcher was a complete observer.

Patton (1990) and Yin (2003) highlight that potential data sources may include documentation, archival records, interviews, physical artifacts and observation. The types of data resources used in this study included audio and video records from experts' activities who were involved in the case study. The audio and video records were later transcribed and analyzed to determine what the required mechanical/electrical knowledge were which need to be considered by the architects during conceptual design phase.

By answering sub-RQ2, the entity of the mechanical/electrical knowledge required to be considered by the architects during conceptual design phase was identified. By conducting both part 1a and part 1b, this study would obtain:

1. The appropriate technique/s for capturing tacit knowledge during the conceptual design, and
2. The knowledge which has to be exchanged between mechanical/electrical engineers and architects during the conceptual design phase.

The next step is to determine the third research question (i.e., **How do architects and mechanical/electrical engineers know when to transfer the required knowledge for improving knowledge flow during the conceptual design phase of building projects?**). For this purpose, the required knowledge needed to be linked to the activities of the conceptual design phase. Toward this end, this study needed to follow the steps shown in Figure 3.6. According to this figure, first step was inspecting existing conceptual design process models to find an appropriate one for the purpose of this study. Then, the collected data – the required mechanical/electrical knowledge to be considered during conceptual design phase – were assigned to the activities of the selected model for conceptual design phase. Finally, the findings – the required mechanical/electrical considerations – were checked with existing standards to ascertain the sufficiency of the considerations.

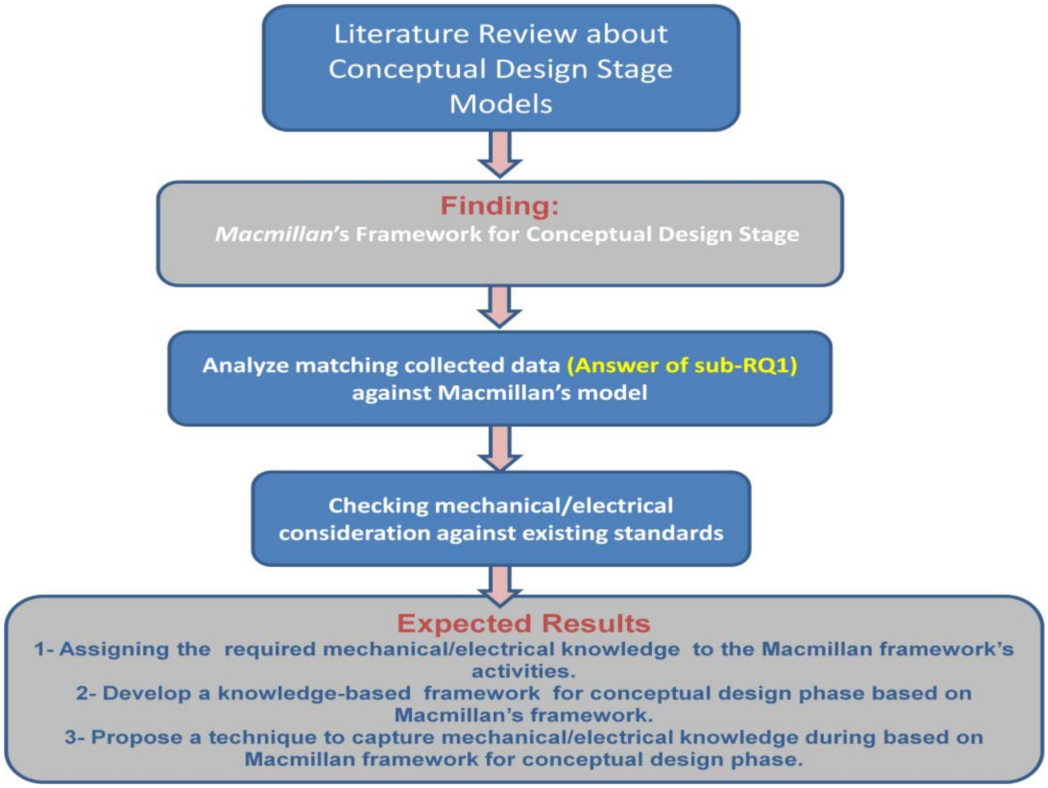

Figure 3.6. Steps to Develop a Knowledge-based Framework for Conceptual Design Phase

From Chapter 2, Macmillan (2001) framework was chosen as the appropriate framework for the conceptual design phase with sufficient details consisting the required activities and steps. Then, activities' details for Macmillan framework were used to provide a linkage between the required mechanical/electrical knowledge and the architect's activities for conceptual design phase. Thus, the required mechanical/electrical knowledge could be assigned to the related step of Macmillan framework. This proposed framework will be called Knowledge-Based framework toward the end of the study.

Based on Macmillan framework, this study faces two important issues in relation with the knowledge during the conceptual design phase. These issues include:

(1) The required mechanical/electrical knowledge, and
(2) The step of the conceptual design phase in which the knowledge has to be used.

Based on this, this study made a two-dimensional matrix using the structure of repertory grid (See Section 2.4.4). The first entity came from Macmillan (2001) framework for conceptual design phase and the second one was the required mechanical/electrical knowledge. Developing this matrix would clarify which knowledge is required to be considered through the corresponding activity of the conceptual design framework by Macmillan. By locating the required knowledge within the matrix, knowledge can be captured successfully. As a result, this study was expected to succeed in developing a technique to capture mechanical/electrical knowledge during the conceptual design phase based on the Macmillan framework.

To prove that the proposed framework can improve the flow of knowledge during the conceptual design phase, the researcher relied on Nissen (2006) multidimensional model for knowledge flow life cycle (Figure 3.7). According to Nissen, tacit knowledge contributes to long the flow time and explicit knowledge contributes to shorter flow time. Because conceptual design phase is a tacit dominated area, changing type of knowledge from tacit to explicit can then improve the knowledge flow time. At last, the existing Macmillan framework and the proposed framework were compared based on the simulation results created by SimVision. SimVision® is an agent-based computational organization theory (COT) modeling tool (Jin & Levitt, 1994), to build a high-level facility development life cycle process which includes an organization responsible over each life cycle phase to emulate the operating environment. Two studies, Nissen & Levitt (2002) and Ibrahim & Nissen (2007) have utilized this tool to evaluate and validate performance in the construction industry more specifically. Ibrahim & Nissen (2007) validated the finding of earlier qualitative ethnography to study the effects of discontinuous membership on knowledge flows in an early phase of a property development lifecycle. Ibrahim and Nissen (2005) used this method to study the amplification of tacit knowledge movement through enterprise life cycle. More details of the simulation will be explained in Chapter 5.

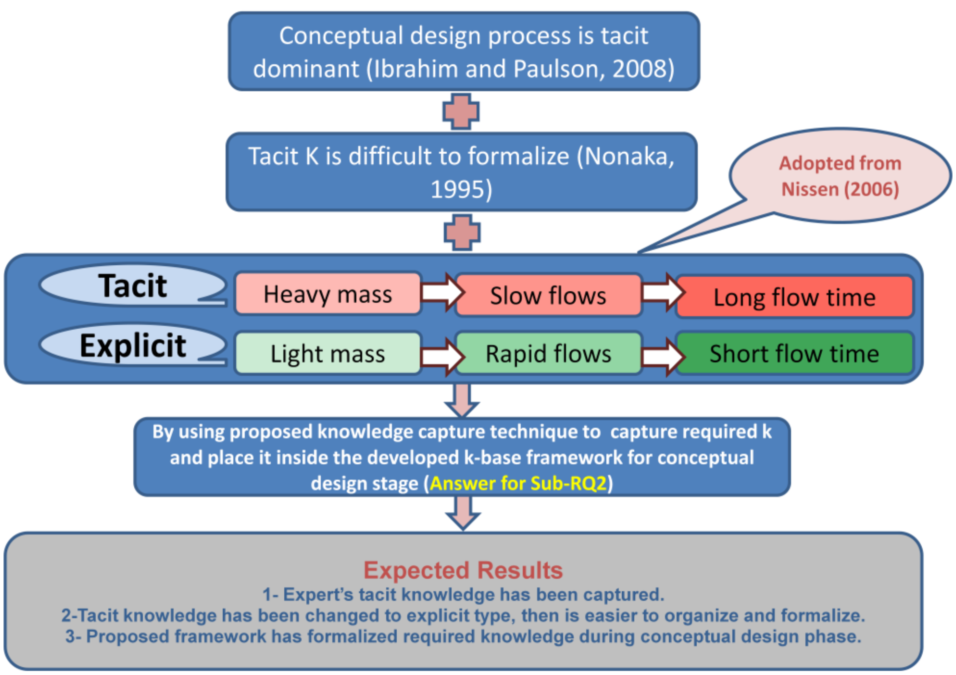

Figure 3.7. Steps to Justify the Proposed Framework for Improving Knowledge Flow

Tacit knowledge, according to Nissen (2006), corresponds to relatively "heavy mass" and accordingly contributes to slow flows and long flow time. On the other hand, explicit knowledge is relatively "light mass" and corresponds to rapid flows which contributes to shorter flow time. Furthermore, Nissen argues that the next step in knowledge flow life cycle is formalizing the knowledge based on the multidimensional model. This step deals with tacit knowledge and as a result contributes to slow flows and results in longer flow time. Knowledge movement between professional is apparently expedited by converting tacit knowledge to explicit type. Now, tacit knowledge of the experts about the required mechanical/electrical knowledge will be captured and placed in our proposed matrix by employing the knowledge-based framework for the conceptual design phase proposed by this study.

In this condition, tacit knowledge can be converted to the explicit type. In conclusion, by using the proposed knowledge-based framework of this study, the researcher expects to observe:

1. Improved the knowledge flow during conceptual design phase,
2. Higher percentage of activities to be filled with tacit knowledge,
3. Shortening the flow time (arising from explicitness of knowledge), and
4. Merging two primary steps of Nissen (2006) model into one step (capturing and formalizing the individual knowledge).

3.3.5 Criteria for Interpreting Data

In order to interpret the data, two criteria are regarded:

Criteria I:

Checking the completeness of the collected data in terms of mechanical/electrical fundamental requirements standard (Berberry, 1992), and also in terms of Green building standards for Malaysia (such as MS 1525). This study expects that more than 95% of mechanical/electrical and Green building standards are met through the proposed concept.

Criteria II:

Simulation results of FRI, PRI, work duration and cost test against the following hypotheses:

> **H1:** A building project team member who has sufficient knowledge which is required for other team members' tasks can improve performance of the receiver's task. The study expects the FRI and PRI to be less than 0.5.
>
> **H2:** A building project team member who does not have sufficient knowledge which has to be considered by other team members to do their task, by transferring incomplete knowledge can increase the risk involved in the receiver's task. The study expects the FRI and PRI to be less than 0.5.

H3: By specifying the entity of the required knowledge during conceptual design phase, performance of building project improves due to explicitness of entity of knowledge. The study expects the FRI and PRI to be less than 0.5.

Nissen (2006) identified six activities associated with the life cycle of a knowledge flow within an organization. These activities include creating, organizing, formalizing, and sharing, applying, and refining the knowledge. Nissen's work provides discrete qualitative categories for potential operationalization of knowledge flow in an enterprise. His four knowledge flow dimensions were (1) type of knowledge (tacit or explicit), (2) level of socialization associated with the knowledge (individual, group, organization, and inter-organization), (3) activities of the knowledge work (create, organize, formalize, etc.), and flow time (Nissen 2006).

Nissen's model (2006) presents flow of knowledge through three dimensions: (1) x-axis which spreads from individual to group, project team, and organization and beyond, (2) y-axis which presents knowledge type, and (3) z-axis which presents the phase within the knowledge life cycle. In this model, the speed of knowledge movement is determined by the type of knowledge (Figure 3.8).

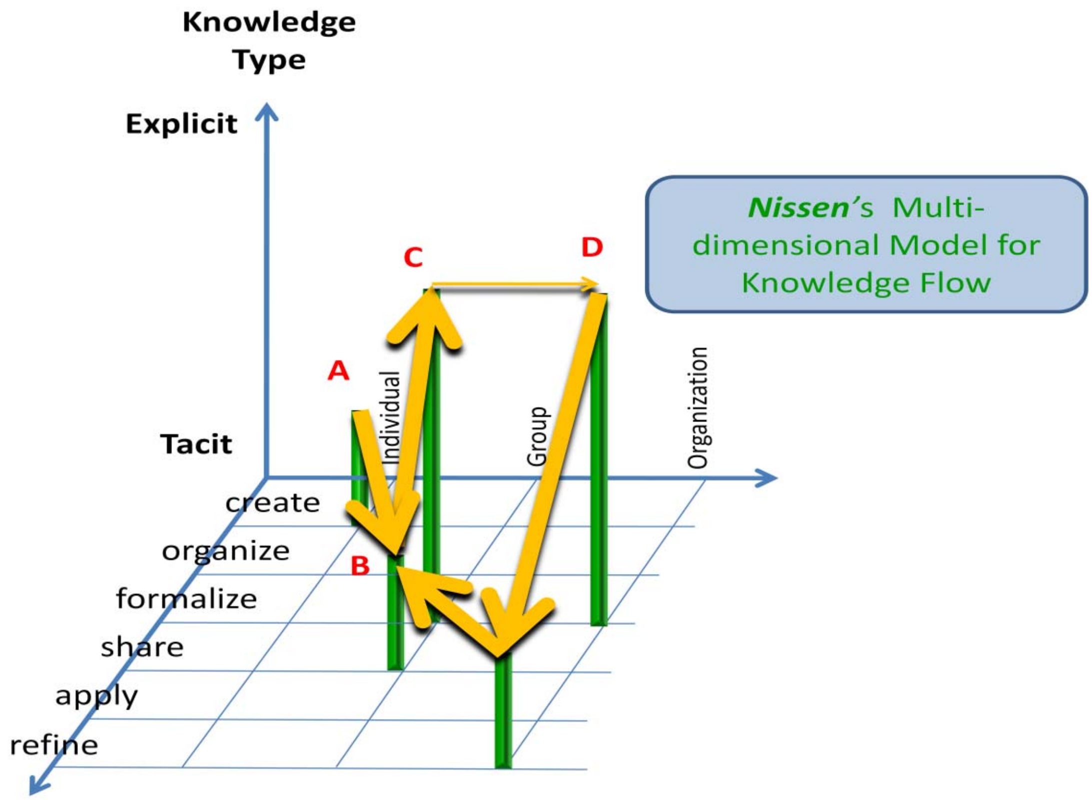

Figure 3.8. Multidimensional Knowledge Flow Visualization

(Source: Nissen, 2006)

In this diagram, the y-axis designates the explicitness of the knowledge type. By using this diagram, Nissen attempted to explain that the first step of knowledge flow lifecycle (KFLC) begins with tacit knowledge which is created by an individual. Then, the movement of tacit knowledge across the reach dimension occurs (From A to B-thick arrow) representing the flow of knowledge from the individual to group level (Socialization). According to Nissen, this kind of flow is classified as the best "share" in terms of the lifecycle dimension and for Nonaka (1998) it is "shared experience". Then a movement from tacit to explicit in group level (Externalization) happens which corresponds to the formalization stage in KFLC dimension (From B to C- thick arrow). Then, the knowledge which moves from group to organization is from explicit type (From C to D – thin arrow).

By means of this diagram, Nissen claimed that the explicit knowledge corresponds to relatively “light mass” in the context of knowledge dynamics (showed by thin arrows), contributing to rapid flows which will cause short flow time. In contrast, tacit knowledge corresponds comparatively to “heavy mass” in the context of knowledge flows (showed by thick arrows), contributing to slow flows which will lead to long flow time accordingly (Figure 3.9).

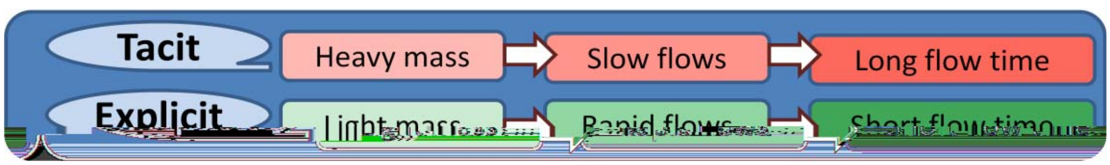

Figure 3.9. Knowledge Flow Time

(Source: Nissen, 2006)

According to Nissen’s model, the created knowledge will move from individual to group through the shared experience. If the individual’s skill matches the required experience for the related task, it means that a responsible person knows the accurate and complete knowledge which has to be transferred. Hence, the completeness and accuracy of the obtained knowledge by a receiver depends on the skill of a sender. The receiver will use this knowledge to perform his/her own task. In contrast, explicit knowledge does not depend on its owner's skill (Table 3.4). In this condition, explicitness of the knowledge leads to faster movement of the knowledge for subsequent task. As a result, explicitness of knowledge can affect performance of individual task (FRI), and also project performance (PRI). Therefore, this study hypothesizes that:

H1: A building project team member who has sufficient knowledge which is required for other team members' tasks can improve performance of the receiver's task. The study expects the FRI and PRI to be less than 0.5.

H2: A building project team member who does not have sufficient knowledge which has to be considered by other team members to do their task, by transferring incomplete knowledge can increase the risk involved in the receiver's task. The study expects the FRI and PRI to be less than 0.5.

Table 3.4. Comparing skill set and required experience

Knowledge	**Skill Level**		
	Architects	**Mechanical engineer**	**Electrical engineer**
Sufficient	High	High	High
Insufficient	Medium	High	High

This study, for example, intends to compare the results when an architect does not possess the required skill matching the required experience to participate in a project. In a tacit dominated area, the next task performance relies on the received knowledge which has been sent by a provider. Now, considering the Nissen's theory, this study establishes one more hypothesis:

> **H3:** By specifying the entity of the required knowledge during conceptual design phase, performance of building project improves due to explicitness of entity of knowledge. The study expects the FRI and PRI to be less than 0.5.

For instance, an architect obtains the knowledge about the project requirements by attending a meeting with the owners. In this condition, the architect can transfer the sufficient knowledge about the project requirements to the mechanical/electrical engineers. Then, mechanical/electrical engineers return back to the architects the considerations required for the conceptual design purpose.

To address the research hypotheses, the effects of dealing with tacit knowledge and explicit knowledge are compared through the simulation process. In dealing with tacit knowledge, project performance relies on the experience of experts; the higher the skill of the experts, the more complete knowledge is transferred/retrieved, and vice versa. In the tacit dominant area, completeness of the tacit knowledge movement relies on the skill of the experts involved. Therefore, work duration is affected by changing the skill level of the experts. On the other hand, in dealing with explicit knowledge, the entity of the required knowledge has already been specified. Therefore, the skill of experts cannot affect the completeness of the required knowledge to transfer/retrieve. In other words, in explicit dominant area, a given knowledge has to be transferred/retrieved and the activities for specifying the entity of the required knowledge are deducted. Such activities mostly belong to the tacit dominant area. According to Nissen (2006), tacit knowledge is of a heavy mass and results in long flow time while in the explicit dominant area, flow time is shorter. Therefore, the work duration of Macmillan (2001) framework for conceptual design phase and the framework proposed by this study are compared.

To validate the proposed framework, this study will test the workflow for conceptual design stage before and after assigning the required mechanical/electrical knowledge to the activities, using SimVision software. Ibrahim and Nissen (2005) had earlier employed this software as an agent-based tool that allows evaluation of multiple workflows in a single process. Using SimVision (Jin & Levitt, 2002), this study compares the results coming from simulation of these two frameworks. In this way, the study compares PRI (Project Risk Index) and FRI (Functional Risk Index) for both models. According to PM (2005), Project Risk Index (PRI) represents this likelihood that the components produced by this project will not be integrated at the end of the project, or that the integration will have defects based on rework and exception handling.

In general, rework occurs when an exception in one task requires redoing an already completed work. The driver task is usually upstream of, or roughly parallel with the dependent task in the chain of task precedence. Exceptions are errors that are localized to a task and cause rework only in that task. When project exceptions arise in a task, a certain volume of rework can be scheduled in the dependent task. For instance, in the conceptual design phase, FRI refers to the specifying and transferring the required knowledge about mechanical/electrical by engineers to architects. When the required knowledge fails to be transferred to architects, they do not consider those requirements.

Functional Risk Index (ePM, 2005) represents the likelihood that the components produced by this facility development have defects based on rework and exception handling. Therefore, PRI and FRI are related to the risk of incomplete rework according to which FRI stems from performance of individual task and PRI stems from integration of the individual task. Both of these two factors have to be under 0.5. Otherwise, the likelihood of project component and task quality failure will be high. After simulating the proposed framework of this study, the researcher uses values of FRI and PRI for the following reasons:

1- To compare the value of FRI and PRI for existing framework and the proposed framework of this study and to inspect the effects of adding the required knowledge to the Macmillan framework.

2- To ensure that their values are acceptable (FRI<0.5; PRI<0.5). In other words, to ensure that the addition of the required knowledge to the existing work flow does not have negative effects on the results.

3.4 Validation

The study follows Yin (2003) in validating the study's construct validity, internal validity, external validity, and reliability. More details about validation procedure of this study are explained below:

3.4.1 Construct Validity

The construct validity ensures that the collected data represent a logical chain of evidence and consistency from the initial research question to conclusions. As Yin (2003) stated, construct validity is performed through the data collection step. According to Yin, using triangulation method can address construct validity in case study approach. Also, the multiple sources of evidence provide multiple measurements of the same phenomenon; hence, construct validity and reliability will be addressed by applying this method (Yin, 2003). Patton (1987) also expressed that triangulation is rational for using multiple sources of data. Furthermore, Yin (2003) believed that in triangulation method, findings are more convincing and accurate since different data sources are utilized. For this reason, the study confirms the construct validity with multiple sources of data. First, the data collection was conducted through the observation process. Then, the researcher attempted to elicit the same data from literature. Finally, the collected data were compared with existing standards for fundamental basic requirements and Green Building Index.

3.4.2 Internal Validity

The internal validity interprets data for pattern matching and determining causality. According to Yin (2003), to address internal validity, the researcher needs to recognize the real and actual conditions which lead to a fact or other conditions. Furthermore, Lewin (2005) expressed that the internal validity is related to explaining the effect of changing independent variable to dependent variables. This research explains the relation between independent and dependent variables through the simulation of the proposed model. For instance, the effect of changing the skill of people (as an independent variable) will be examined on the functional risk index (FRI) and the project risk index (PRI) as two dependent variables (See Chapter 5).

3.4.3 External Validity

Data are tested through the external validity in which the results of the case studies are applied to a broader set of circumstances. External validity refers to the possibility of expanding any claims of causality from a studied sample to other ones. Lewin (2005) asserts that the obtained results should be the same results which have come from the sample in order to be able to generalize the findings. Moreover, Yin (2003) expressed that external validity depends on possibility of generalizing the findings of a study to an immediate case study.

This study uses theories and models from prior literature to extend propositions for this study. Some of these opinions are explained below:

- Paulson (1976), Jin & Levitt (1996) and Ibrahim and Paulson (2008) stated that incomplete and inefficient knowledge transfer causes unnecessary rework delay and lost revenue in the construction industry.
- Valkenburg (1998) expressed that lack of synchronization causes serious problems for team members in both interactions and communications, and results in misunderstandings and uncoordinated actions.
- Martinez (1998) stated that when an organization lacks a heightened degree of knowledge sharing, knowledge leaks are the results which cause repeated mistakes, dependence on a few key individuals, duplicated work, lack of sharing of good ideas, and slow introduction of new products or market solutions.
- Macmillan (2001) believed that the conceptual stage of the design process is particularly difficult to be specified because its phases cannot be described as isolated activities. Additionally, the way in which the activities are described

is highly ambiguous, with individuals from various disciplines using a variety of terminology to recount the same occurrence.

- Shelborn (2006) highlights that effective knowledge management can reduce project time and cost, improve the quality, and provide a major source of competitive advantage for the construction organizations.
- Ibrahim and Paulson (2008) and Ibrahim and Nissen (2007) found that one characteristic which contributes to the knowledge loss phenomenon is the different dominating knowledge type for each lifecycle phase.

According to the findings from the abovementioned studies, the researcher attempted to apply such findings to the conceptual design stage of a building project. To evaluate applicability of the generalized proposition, the proposed model will be simulated using SimVision tool.

3.4.4 Reliability

As mentioned before, Yin (2003) reasons that the use of multiple resource of evidence which provides multiple measurements of the same phenomena, can address construct validity and also ensure reliability. Since multiple sources of data are employed in this research, reliability is addressed sufficiently. The first source of data was the data collected through a case study during the conceptual design stage of a building project. As mentioned earlier in section 3.3.3, the study follows Nissen and

Levitt (2002) to have the 4th year students trained on the green building technologies to improve knowledge of team members about mechanical and electrical requirements.

The second source of data was basic mechanical/electrical requirement standard (Burberry, 1997) for building projects. Because the selected case study was a green building project, green building index (GBI Assessment criteria for Non-Residential New Construction, 2009) was also used as the third source of the data to ensure the completeness of mechanical/electrical considerations for the proposed concept design. Finally, computational organizational tool was utilized to compare the results after simulating Macmillan (2001) framework and the framework proposed by this study.

3.5 Limitation of Study

This study is limited to the 4th year architect students in a public university. Team members are led by professionals and experts from architectural and mechanical/electrical field. Indeed, architect students play the role of mechanical/electrical experts by studying the required technologies for Green Building projects (See section 3.3.3). Moreover, this research focuses on the conceptual design phase of a Green building project. Therefore, this study is limited to the A/E/C field. Finally, for reliability validation, computational modeling has been used for this study which is a simulated model, not a real one to ascertain the applicability to the real world.

3.6 Summary

In this chapter, the case study research methodology with sequential mixed-method for data collection was explained as the design of this study. Regarding the stated problem, the selected methodology for this research was qualitative. Based on the research question, case study was chosen as the general approach for this research. Then, according to Yin (2003), case study components were explained. Furthermore, for linking the collected data to the research propositions, this study used a sequential mix method. In fact, to answer the first and second sub-RQs, the case study was employed. Answering the first two research questions will lead to proposing a knowledge-base framework for the conceptual design phase. Evaluation of the proposed knowledge-based framework is performed through the simulation process using computational modeling (using Simvision). Moreover, according to Yin (2003), four validation steps (construct validity, internal validity, external validity and reliability) for case study were explained.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

In this chapter, the data obtained through the case study is explained and analyzed. In the procedure of data collection, the primary method was observation during the conceptual design phase of a Green building project for Institiut Teknologi Maju (ITMA). The purpose here was to identify the required mechanical/electrical knowledge for being considered during this stage. Then, the observation method and also observation protocol are explained.

Later in this chapter, observation results elicited from the video records are elaborated. Next step will be to compare the collected data with existing standards for fundamental mechanical/electrical requirements and Green Building Index. Finally, in view of detailed definitions for activities of Macmillan framework for conceptual design phase, the required mechanical/electrical knowledge is assigned to the activities of this framework.

4.2 Observation

According to Creswell (2003), data collection procedure consists of three steps: (1) setting boundaries for study; (2) collecting data through unstructured/semi-structured observation, interviews, documents and visual materials; and (3) establishing protocol for recording information. The observation method has been chosen as the method in this research to collect data. Hence, next section deals with this method in more details.

Creswell (2003) stated that in observation method the researcher takes field notes on the individual behavior and activities at the research site. As mentioned earlier in Chapter 3, this researcher needed to have conversation to find out the considered knowledge, he/she had to be introduced to the conceptual design team members to discuss with them. In fact, the researcher of this study needs to attend and record activities of team members through a case study to discover the mechanical/electrical knowledge. Therefore, the researcher functions as a complete observer.

4.2.1 Observation Protocol

After collecting the data, the recorded videos needed to be transcribed to discover the exchanged knowledge through the performed activities by group members. The following steps to collect and interpret data have been shown in Figure 4.1. The researcher attended all class sessions to inspect pre-design activities. To be more familiar with green building projects, the researcher also accompanied students in site visits. Then, the main step was to attend a one-day effort of team members to perform the concept design. The whole day activities by groups to design concepts were observed and recorded. Then, all the records were transcribed by the researcher of this study. Then the transcriptions were confirmed with group members.

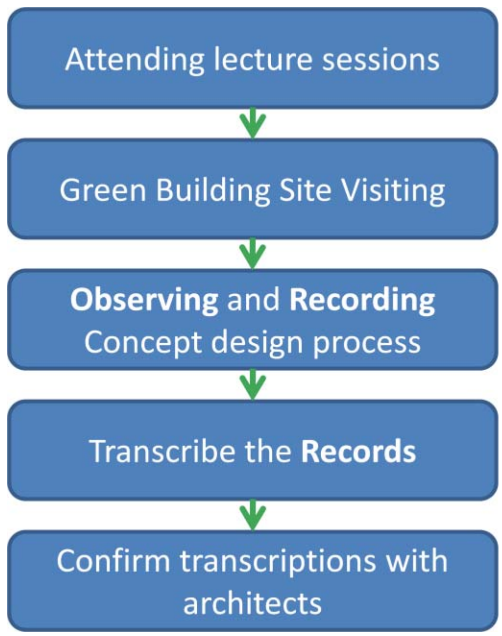

Figure 4.1. Steps to Collect and Interpret Data

4.2.2 Case of Observation

There were three project teams which competed in preparing the proposal for the concept for Green Technology Park for UPM Institiut Teknologi Maju (ITMA) project. The process of generating conceptual design consists of three steps which were explained in Chapter 3 (see section 3.4.3). As mentioned earlier, three groups competed to propose their concepts. The observation results for these groups are explained in part I. Part II is for analyzing mechanical/electrical knowledge based on winning the proposal.

4.2.2.1 Part I- Observation Results

In this part the details of the performed activities by Group 2 for developing the concept design are explained. From records and informal conversations with Group 2 team members, the study found out their approach to the concept design. Figure 4.2 demonstrates their approach which is based on their explanations. As it is clear they examined the problems associated with the existing building. Some members interviewed the current users and observed their activities to obtain information about the problems with the existing buildings. In the meantime, some other team members performed site analysis. They examined sun path movement, wind speed and direction, existing structures and views. In view of the abovementioned activities, they created a passive design. Then, they attempted to complete the concept design while keeping in mind the technical and sustainable device requirements. The details of the performed activities of Group 2 are shown in Table 4.1.

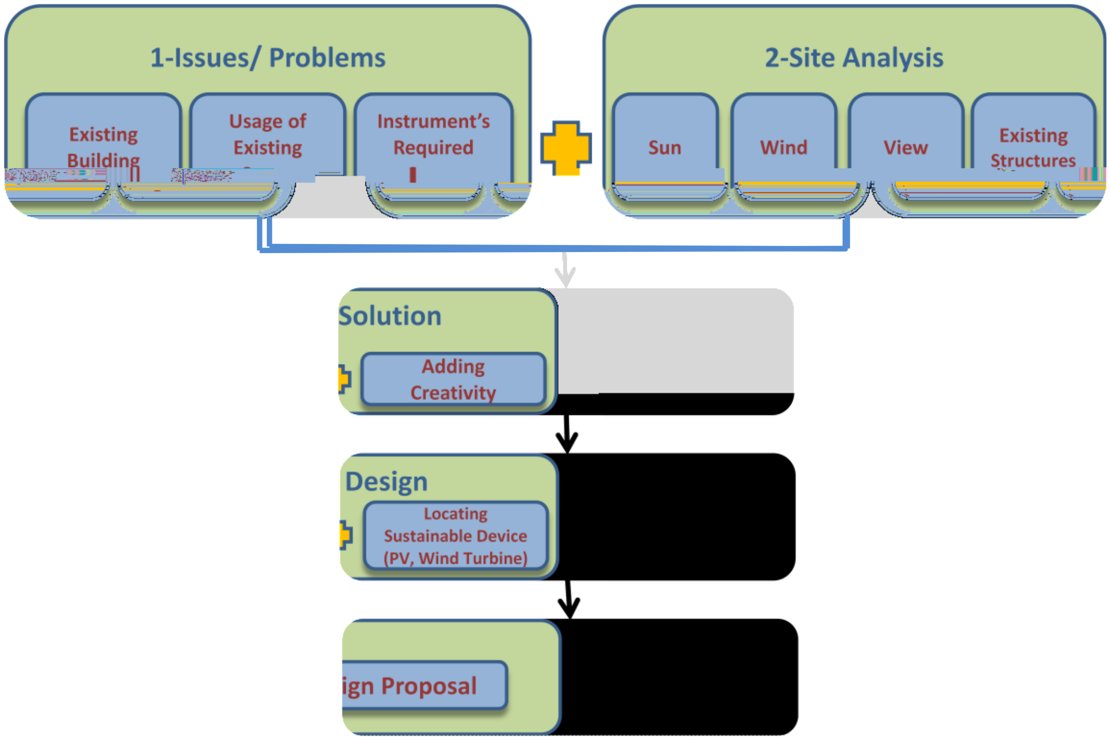

Figure 4.2. Approach to Concept Design by Group 2

According to Figure 4.2, Group 2 firstly inspected the existing building problems. Then, they interviewed and observed current users and equipments about usage of existing spaces. Indeed, these activities constitute pre-design studies. Because this study tends to focus on the concept design stage, therefore the recorded activities in Table 4.1 start from the second step in Figure 4.2. According to the group 2's approach, the second step is site analysis. Therefore, as it is evident in Table 4.1 the first activity concerns analyzing the sun path movement, inspecting wind direction and so on.

Table 4.1. Detail of activities for concept design by Group 2

Video Segment Refer No.	Activity Description
18	- Analyze sun path diagram, wind direction and views as important issues to specify building orientation
19	- Sketching passive design to use maximum daylight, optimum orientation and so on.
28	- Discuss about spaces planning, lobby and their sizes
37	- Discuss about space requirements - Analyze the site analysis design - Inspect required technologies - Acknowledge existing issues and problem, find better solution
53	- Make decision about technology requirements: • Building Integrated Photo Voltaic system (BIPV) • Solar air conditioning system • Wind turbine • Rainwater harvesting, waste management system • Daylighting
80	- Discuss about office module and labs - Discuss about Building Integrated Photo Voltaic system alternatives - Discuss about rainwater usage (for filtration, landscape, shading device, cool down roof); why they want to catch rainwater and where they want to use it - Inspecting necessity of using clerestory and light shelve to control sky light - Locate wind turbine on top floor at cooling tower to generate wind to help turbine. - Inspect space function and requirements - Create standard modules - Discuss about natural daylighting and ventilation requirement - Site issues , solar bowl - Inspect space info - Start design process - Discuss about using solar bowl to generate electricity - Discuss about indoor or outdoor environment for labs, roof provision - Contour issues and utilization - Use typical modules for office labs*5 - Try to match buildings with the existing solar bowl
85	- Marking guidelines (give value percentage for each subject in design)
88 89	- Specify drawing requirements consist of: • Diagrams • Plan • Section • Elevation • Concept
90	- Recognizing that East-west oriented gets more heat and daylight - Provide courtyard for better distribution of daylight (self shaded courtyard by buildings) - Specify BPIV (Building Integrated Photo Voltaic) location, vertical PV solar panel - Discuss about wind turbine location

	- Recognize low wind on the ground and high speed wind on top - Recognize that solar assisted turbine air conditioning need heat - PV (providing electricity)need cooling (so it should be cooling down) - Recognize that solar assisted air conditioning and PV cannot put together
91	- Inspecting PV efficiency for light shelves and shading devices and recognizing that the answer is negative - Create design module alternatives
97	- Inspecting circulation for main access and services
98	- Relocate trees and landscapes
99	- Specify size for labs, width and length - Using daylight rule of thumb
103	- Try to size building based on paper cut
104	- Standardized space size
111	- Form design alternatives for labs and office
116	- Decide that PV will be located on the roof - Section design
120	- Specify height of office and labs and double volume requirement
125	- Draw required plans - Draw the diagram for rainwater catchment
126	- Draw section
127	- Perform estimation for rainwater harvesting system - Calculate water storage tank size based on roof area - Specify location of pump and rain water tank

Some photos in Figure 4.3 to Figure 4.6 are archival documents for performed activities of the second group during the process of producing the concept for ITMA project.

Figure 4.3. Discuss about Design Drawings (Plan, Section, Elevation, Diagrams) by Group 2

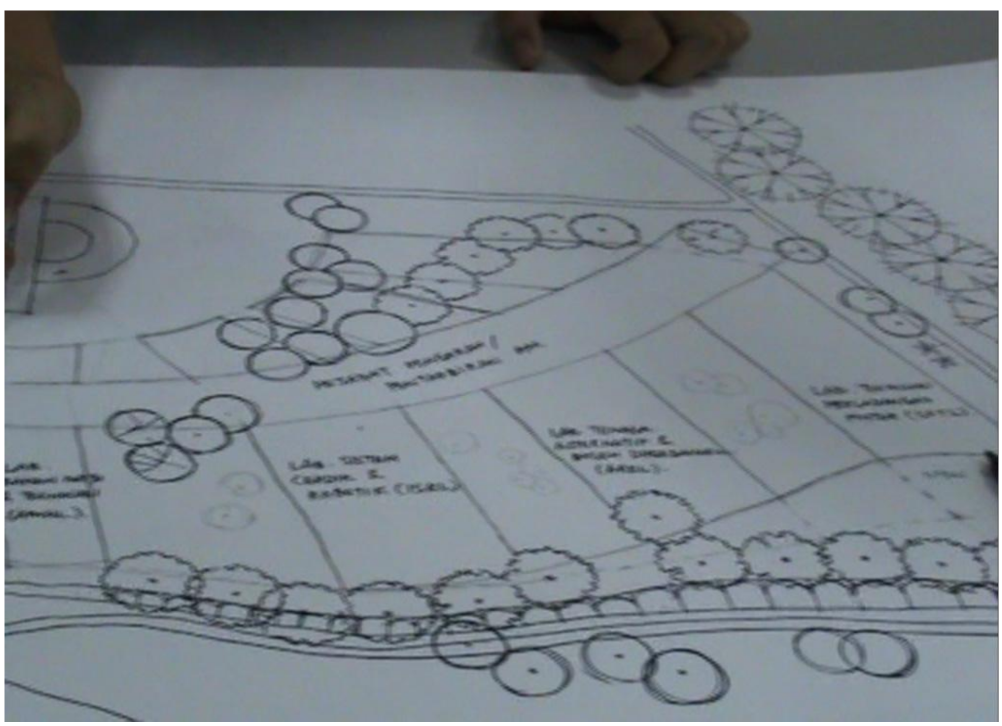

Figure 4.4. Massing Blocks of Building inside the Site by Group 2

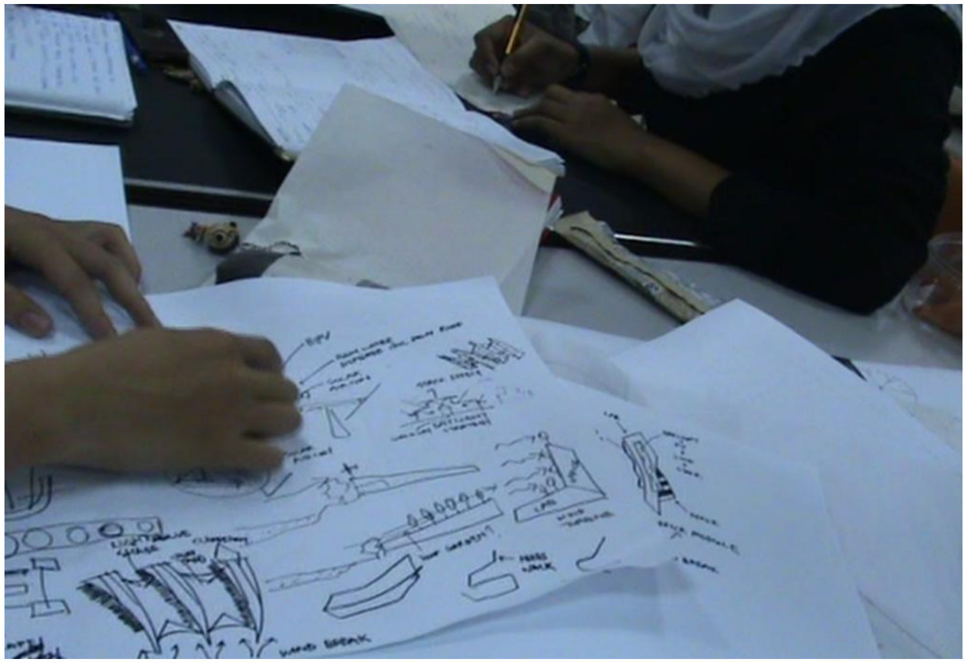

Figure 4.5. Discuss about Technical Requirements (PV Panels, Wind Turbine and etc.)

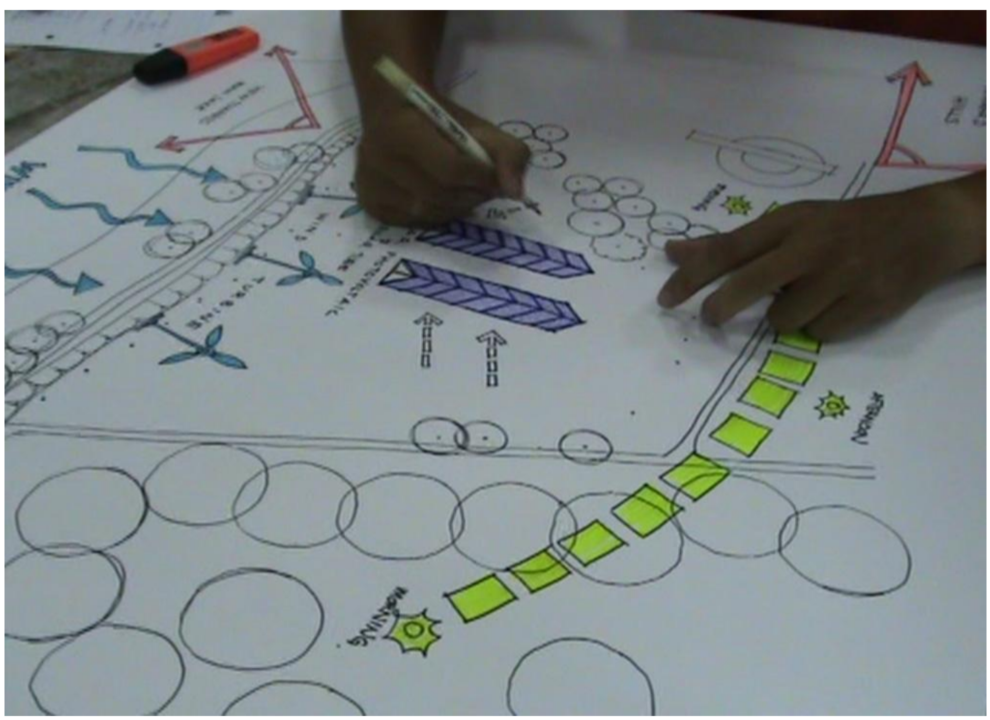

Figure 4.6. Drawing PV Panels Considering Sun Path Movement by Group 2

4.2.2.2 PART II-The Analysis of Knowledge Movement between Architect and Mechanical/Electrical Engineers during the Concept Design

In this part, the process of matching design team activities with the Macmillan framework for conceptual design phase is explained. In fact, through the case study the researcher discovers the details of the performed activities by team members and also the required mechanical/electrical knowledge. As a result, by matching team members' activities and Macmillan framework activities this study will be able to provide a linkage between the abovementioned activities. Then, this study needs to be ensured about the completeness of mechanical/electrical considerations against the related standards for the basic mechanical/electrical requirements and also the green building projects. Finally, this research counts the proposed concept design for achieving the standard requirements. The abovementioned process is explained in the following two sections:

4.2.2.2.1 Matching Design Team Activities with Macmillan Framework for the Conceptual Design Phase

To provide a linkage between activities during the conceptual design stage and the Macmillan framework activities the researcher attempted to elicit details of the second group's activities. Considering the recorded videos and also the report provided by group 2, we obtain details of the performed activities from two different points of view. For the selected methodology of this study we used pattern matching method to provide the linkage. As mentioned before, Macmillan framework for the conceptual design stage was chosen to be matched with the activities performed by the design groups. The matching process between the performed activities by group 2 and Macmillan framework for the conceptual design stage has been explained hereunder. Since most activities during the design stage included drawing (plans, section and etc.) and calculating (required spaces and capacity), we took the following steps to analyze those design outputs which were obtained:

- Transcribing the video records which contain team members' activities.
- Asking students to explain their activities since they were drawing most of the time.
- Organizing the description of activities into Table 4.2.
- Checking and affirming that how each activity can be related to any steps of the Macmillan (2001) framework for the conceptual design stage.

Empty cells in Table 4.2 point to the fact that there is some knowledge which the study did not document and can be considered lost during the process of documentation. Indeed, empty cells support Ibrahim and Paulson (2005) who had identified how environmental characteristics causes knowledge loss phenomenon. As such, the knowledge obtained from transcriptions derives from the tacit dominated area during the conceptual design phase. As a matter of fact, by transcribing video records, the researcher attempted to convert experts' tacit knowledge to explicit type. The right side column in Table 4.2 refers to the knowledge documented by team members and submitted in the report which contains the explicit knowledge. Indeed, empty cells of Table 4.2 shows that some knowledge corresponding to the steps 1, 3, 4, 5, 6 and 10 has been lost. It means that team members have lost some knowledge through the documentation process. In other words, team members through the conceptual design used some knowledge which has not been documented. All the mechanical considerations by group 2 during concept design are summarized in Table 4.2.

Table 4.2. Matching complete list of activities for concept design by 2nd group with Macmillan framework

Macmillan Framework steps		Supporting evidence for specific conceptual design framework activities		
No.	**Correspond name**	**Video Segment No.**	**From Transcriptions**	**From Submitted Report**
1	**Specify the business needs**	53	Make decision about technology requirements : - BIPV - Solar Air-Con - Wind Turbine - Rainwater harvesting, waste management - Daylighting	
2	**Assessing stakeholders requirements**	80	-Office module -Labs + office - Discuss about BIPV alternatives - Discuss about rainwater usage (for filtration, landscape, shading device, cool down roof); why they want to catch rainwater and where they want to use it - Daylighting- clerestory sky light-light shelve - Wind turbine location (on top floor), locate at cooling tower (because it can generate wind to help turbine)	Specifying solar cooling system needs: - Specify type of solar collector - Storage tank - Control unit - Pipes & pumps - Thermally driven cooling machine Discuss about components of rainwater harvesting system: -Catchment location (roof) -Conveyance (by gutters and downpipes) -Filtering (first flush) -Storage tank -Booster pump

				-Roof tank -Distribution (plumbing to toilets, general use) BIPV implementation on site: - Integrated with roof of each lab, - tilt angle:10 degree, - direction: south Location of BIPV system on the roof of administration office. instead of locating on façade due to maximize the exposure to the sun: - Office is on higher level hence there will be no obstructions or shaded by nearby buildings or trees - Wind flow through channel from the pond to up the hill between lab buildings will provide appropriate ventilation behind the PV panels to dissipate heat and increase the efficiency - PV panels at canopy walkway (beside being shading device, semi- transparent character of PV provides appropriate daylight penetration)
3	**Identify problems with existing solutions**	18 19 28 37	- Analyzing sun path diagram, wind direction and views as important issues to specify building orientation - Discuss about spaces planning, lobby and their sizes - Discuss about space requirements - Site analysis design - Technology for form design - Acknowledge existing issues and problem, find better solution	
4	**Developing requirements**	80	Space function and requirements - Standard module - Natural daylighting and ventilation requirement - Site issues , solar bowl - Space info acquired - Design process design	

			- Solar bowl to generate electricity - Indoor or outdoor environment for labs, roof provision - Contour issues and utilization - Use typical modules for office labs*5 - match building with the existing solar bowl	
5	**Setting requirements**	88 89	Specify drawing requirements - Diagrams - Plan - Section - Elevation - Concept	
6	**Determining project characteristics**	85	Marking guidelines (give value percentage for each subject in design)	
7	**Generating initial concepts**	90	- East-west oriented gets more heat and daylight - Provide courtyard better distribution of daylight - Self shaded courtyard by buildings - BIPV location - Discuss about wind turbine location(Low wind on the ground, high speed wind on top - Solar assisted air conditioning needs heat - PV need cooling (so it should be cooling down)	2 separate zoning for orientation of building For zone 1: - Opening are more facing north and south - Sun control due to hot climates since late afternoon sun will penetrate the north-side spaces - Vertical elements to control direct glare and aesthetic For zone 2 - Opening are more facing east-west - Difficult to shade due to angle of sunlight which is almost perpendicular to the glass - Opening glass: 1- bottom window heavily tinted,2- top window slightly clear glass, 3- manual window to reduce glare. Considering longest façade facing the north-south. Long façade shade the below courtyard PV modules calculation: - Sizing and amount of PV modules - Area needed

				Specifying location of solar evacuated tubes (at the top of office building) Inspecting wind speed to know possibility of meeting basic requirements Using cooling tower if it is needed Specify wind turbine location
8	**Transformation/ Combination of concepts**	91 97 98 99	- PV not efficient for light shelves and shading device - Design modules alternatives - Circulation for main access and services - Relocate trees and landscapes - Size for labs (width and length)	- Considering main access road from east - Provide adequate ventilation (appropriate ventilation behind the modules is required) - Consider integrating daylighting (BIPV elements can help to reduce glare associated with architectural glazing) - Incorporate PV modules into shading devices. PV arrays at glass areas can provide passive solar shading. - Considering local climate and environment on the array output - Address site planning and orientation issues. To ensure about receiving maximum exposure to the sun and not be shading by site obstructions+ physical orientation of BIPV system and tilt angle should be considered relative to the geographical location of the building site
9	**Selecting suitable combinations**	103 104	- Sizing blocks based on paper cut - Space size standardize	- Considering Width of spaces 20m and more - Upper clerestory windows with extension of roof to: (1) Prevent risk of water leakage, (2) can be used to diffuse direct sunlight with exterior sun control devices, and (3) providing day light to the lower floor level in a 2 storey facility
10	**Firming up into**	111	- Design for labs, office,	

	concept proposals	116 120	alternative forms - PV will be located on the roof - Section design - Height of office, and labs, double volume requirement	
11	**Evaluating and choosing proposal**	123 126	- Plan Drawing - Section drawing	
12	**Improving detail and costing proposal**	127	- Estimating for rainwater harvesting system - Water storage tank size based on roof area - Location of pump and water tank	- Calculating number of needed air conditioner (75 m2=1 unit of A/C) - Calculating cooling capacity - Calculating roof spaces for - solar evacuated tube - Initial cost needed for BIPV system - Life cycle calculation for BIPV usage - Calculation of life cycle cost assessment - Calculating conventional and solar A/C system - Comparison of energy consumption between conventional and solar air conditioning system - Calculating operating cost saving - - - Location of rainwater tank and the filter - Calculating area for roof catchment - Estimating rainwater yield - Estimating storage tank size - Calculating water saving - - Calculating output energy produce by wind turbine - - Calculating life cycle cost for wind turbine

4.2.2.2.2 Analyzing Design Team Activities against Macmillan Framework Activities

According to Macmillan framework, there are twelve activities for conceptual design phase of any building project. In this section, the researcher explains referring the definitions for Macmillan framework activities attempts to illustrate the exchanged knowledge between team members through the case study.

1- Specify the Business Needs

The first activity "Specify the business needs" aims at recognizing business needs which must be fully understood by interdisciplinary design team before taking any actions. Moreover, regarding this activity definition team members have to gather available information and generate mission statement to define what is required. Referring to the video segment no. 53, the "Specify the business needs" activity Group 2 focused on discussing the required technologies such as BIPV, solar air conditioning, wind turbine, rainwater harvesting system and daylighting strategy and their requirements. For instance, they attempted to know how to calculate rainwater tank size and other technologies likewise. Going through the Table 4.2 which shows correspondent knowledge for the conceptual design activities, it is realized that team members discussed these requirements. However, they did not write anything in their submitted report about their discussions to make decision about the required technologies. Indeed, video records contain tacit knowledge and the submitted report includes formalized knowledge. In this way, we find that some knowledge is lost when formalized through the first activity.

2- Assessing Stakeholders' Requirements

Second activity of Macmillan (2001) framework is "Assessing stakeholders' requirements". According to Macmillan definition through this step team members have to try to elicit information from client aspiration in terms of requirements for functionality. In connection to this, ITMA project team members attempted to discuss office module and labs to satisfy stakeholders' needs. Additionally, they examined Building Integrated Photo Voltaic system alternatives. Then, they investigated rainwater usage to know why they want to catch rainwater and where they want to use it: for filtration, landscape, shading device, cool down roof. Then, they attempt to make decisions about control devices to prevent glazing. As a result, they proposed to contrive clerestory and light shelves. After that, considering that stakeholders' tend to use natural energies completely, they decided to locate wind turbine on the top floor. Under such conditions and due to the insufficiency of wind sped on the ground, they proposed to use cooling tower to generate wind to help the turbine. In addition, they attempted to use maximum natural daylight and ventilation.

The abovementioned considerations were elicited from video records. However, they had more considerations through "Assessing stakeholders' requirements" activity which were realized through documenting the concept design. Indeed, the submitted report revealed that more details are needed to be considered during this stage. For instance, team members through this activity specified the type of solar collector, storage tank size, piping and pumping system and so on. To perform this activity, mechanical/electrical experts needed to have sufficient information about the free spaces inside the site to position the storage tank and other equipment. Referring to the submitted report, they provided more details for the components of rainwater harvesting system, BIPV implementation. By means of this, they decided to locate BIPV system on the roof due to the maximum the exposure to the sun. Indeed, locating BIPV system on a higher level prevented obstructions or shade caused by nearby buildings or trees. Furthermore, wind flow could provide appropriate ventilation behind the PV panels to increase the efficiency. These considerations were essential issues which were transferred to the architect during the concept design.

3- Identify Problems with Existing Solution

For the third activity based on Macmillan framework team members needed to specify the constraints of the problem. Then, they had to guide the design by setting some design drivers and constraints. To this end, they found out space requirements. Then, they attempted to study the function of labs. Therefore, two members of Group 2 went to visit and examine lab functions, and the space required. Then, they investigated how the iconology and the form of the site can be integrated. By gaining this information they could start designing the shape of the buildings. Thus, they attempt to know:

- What do the buildings require?
- How do the buildings operate?
- What is the relationship between the offices and the labs?

- Do they relate to each other?
- Do they need each other's support?

Using the abovementioned issues, the team members could decide the shape and the size.

Then to start the design, they attempted to analyze sun path diagram, wind direction and the views as important issues to specify the building orientation. They had site plan and had visited site location. The next step was to start the design and to discuss the spaces required. Indeed, they had a table for the required spaces and their size. Considering these information they had to locate the building blocks inside the site. There were some problems with the existing building namely the insufficient space for laboratories, for number of users and also the required technologies. Regarding this problems they had to find the best solution for the design. All the performed activities through the concept design elicited from video records. Going through Table 4.2, the corresponding cell to this activity that refers to the documented knowledge in the submitted report shows that nothing about these considerations were documented. In other words, this part of the required consideration is absent in formalization. For instance, the required technologies such as using solar bowl to generate electricity are essential in the shape of the buildings. Recalling the performed activities of Group 3 for concept design, their first design entails more than 12 blocks. At that time, mechanical experts in their team stated that they could not have many blocks due to the high cost of generating electricity from solar bowl. In this situation, they had to redesign to decrease the number of blocks.

4- Developing Requirements

Referring to the details of this activity, team members have to extend acceptable solution boundary by identifying real users of the facility and interviewing them in order to understand their value requirements. Then they have to combine experience and expertise into the design environment. Finally, both the convention and client wishes have to contest to develop the building structure. In this connection, team members attempted to specify space function and its requirements. Then, they attempted to develop standard modules. They decided to use typical modules for office and labs. After that, in order to obtain maximum natural daylight and appropriate ventilation they attempted to locate the modules inside the site while paying attention to the sun path movement and wind direction. Furthermore, they decided to consider solar bowl as the focus point in the site. Therefore, they arranged the modules inside the site so that the building blocks could surround the solar bowl. Finally, they examined indoor or outdoor environment for labs and roof provision. Considering the situation, they discussed the way they can use the roof area for technologies such as rainwater harvesting system and photo voltaic system. To this end, they needed to consider these issues to contour the design. Going through Table 4.2, correspondent cell from submitted report shows that there is no documentation for the abovementioned activities which were elicited from video records. Similar to the first and third activities, there was some knowledge through forth activity which missed to be formalized.

5- Setting Requirements

Referring to the detail definition for this activity, the team members had to produce a list of all requirements which was specified by the client and the design team. In this respect, they attempted to provide a list for drawing the requirements which consisted of: diagrams, plans, section plan, elevation plan and the concept. The diagrams were necessary for the required technologies such as rainwater catchment system, photo voltaic system, wind turbine and the cooling tower and so on. In this way, all team members were informed about what they had to provide through the following steps. Going through Table 4.2 it becomes clear that there were no documentation for the things team members performed during this activity.

6- Determining Project Characteristics

Through this activity team members had to define the boundaries of the research by using pre-set requirements. The requirements have to be ranked in order of their perceived value. In this way, the characteristics of project are defined by using value datum which is determined to assess the conceptual design proposal. To this end, team members studied the values assigned to the required technologies for ITMA green building project. In this way, they could make decisions about incorporating technologies to benefit from their advantages. For instance, through the next steps team members propose to use photo voltaic panels for shading device on the walkway, as well as its semi-transparent character to provide an appropriate daylight penetration. As it is apparent in Table 4.2, team members did not document anything about how they assigned values to different aspects and also about their decisions related to gaining more benefit from incorporating technologies into the design concept.

7- Generating Initial Concept

This activity is for generating initial solutions based on the existing solutions or abstract ideas, then using creative thinking in conjunction with experience and the prior knowledge. To this end, they used their findings about daylight and wind direction to orient the building. They considered two separate zoning for orientation of buildings. For the first zone, openings were faced north-south. Therefore, in response to the need to control the direct glare from the north side late in the afternoon, they used vertical elements. For zone 2, openings faced more the east-west which gets more heat and daylight. Moreover, this orientation was difficult to shade due to the angle of sunlight. Hence, they proposed three types of opening glass: heavy tinted bottom window, slightly clear glass for top window and manual window to reduce the glare. Therefore, as regards the building orientation, they used appropriate strategies to overcome the problems with sun light, heat, and glare. They also considered the longest façade facing north-south which shades the courtyard underneath. The courtyard improved the distribution of daylight. At this stage, they discussed more about PV panels. Since they decided to locate PV panels on the roof - through the second activity of Macmillan framework- they needed to estimate the area needed for PV modules to ensure that there is sufficient accessible area on the roof. Through this activity team members specified the location of the solar evacuated tubes at the top of the office building. They also made decisions about the location of the wind turbine and also the cooling tower which is used to compensate for the insufficiency of wind speed. Table 4.2 shows that all the considerations made by the team members through this activity have been documented in the report submitted.

8- Transformation/Combination of Concepts

Through the eighth activity of Macmillan framework team members have to produce a number of holistic solutions which derives from the uninhibited thought. Then, they have to develop, transform and combine individual proposals in order to mould them into usable proposals. Therefore, team members through this activity attempted to arrange alternative modules inside the site in view of the need to provide adequate ventilation behind the modules. After that, they considered the main access road from the east. Then, they incorporated PV modules into the shading devices. PV arrays at glass areas could provide passive solar shading. Team members also addressed site planning and orientation through this activity. In this way, they made sure that there is maximum exposure to the sun and there is no shading caused by the site obstructions of BIPV system. All the discussions between team members through this activity were documented in the submitted report.

9- Selecting Suitable Combinations

According to the detailed definitions for this activity, team members have to eliminate unsuitable proposals. Thus, team members attempted to specify the proper size of the building blocks. They determined that width of spaces be 20 meters and more. Additionally, they used upper clerestory windows with the extension of the roof to prevent the risk of water leakage and also to diffuse direct sunlight. In this way, team members could finalize the space size of the building blocks. All the performed activities through this step were documented.

10- Firming up into Concept Proposal

Through this activity team members have to reveal the gaps in the information on the important elements of the design. Team members also had to take into consideration the necessity of knowing the working principles such as performance, space requirements, pinch-points in the structure, services, co-ordination etc. approximately. Through this activity ITMA project team members designed alternative forms for labs and office. Then they discussed the height of office and labs, and the double volume requirements. They performed section design through this activity. Team members did not document what they performed during this activity.

11- Evaluating and Choosing Proposal

This activity is for evaluating the solution proposal. To this end, they needed to gauge the concept variants against one another, an imaginary ideal and/or pre-set value hierarchy of the characteristics and requirements of the design. Owing to the fact that ITMA project team members had a unique proposal, they had no to choose any other proposal. They developed their design based on the pre-defined requirements for Green Building project. Through this activity they drew plans, section and so on. Similar to the previous activity, there was no document for this activity in the submitted report.

12- Improving Detail and Costing Proposal

According to the detailed definition for this activity, team members had to estimate cost of the proposals and develop the chosen proposal to a level that allows the critical unknowns to be improved to the point where they pose little or no risk to the subsequent development and the success of the project. Going through Table 4.2 reveals that team members performed some calculation for rainwater harvesting system, storage tank size based on the roof area that was elicited from video records. Further calculations for calculating the area needed for roof catchment, rainwater yield, water saving were documented in the submitted report. Moreover, some other calculations were conducted to determine the number of the needed air conditioners and cooling capacity. Then, they compared energy consumption between conventional and solar air conditioning system. Team members also performed similar calculations for the wind turbine. All these calculations were fully documented in the submitted report.

In conclusion, it is realized that some knowledge which was used to perform activities such as “Specifying the business needs”, “Identifying problems with existing solutions”, “Developing requirements”, “Setting requirements”, “Determining project characteristics”, “Firming up into concept proposals” and “Evaluating and choosing proposals” was lost to be documented in the submitted report. Considerable amount of this knowledge was related to the fundamental requirements which have to be considered through the concept design. Mechanical/electrical experts were present during the entire process of concept design; therefore their presence decreased the probability of the required mechanical/electrical knowledge being ignored through the conceptual design. Many reasons such as the long distance between the experts involved in concept design may increase the probability of failing to consider the required mechanical/electrical knowledge. Therefore, by explicating the entity of the required knowledge this problem can be obviated. To achieve this goal, during the next sections the researcher attempts to elicit the required mechanical/electrical knowledge which was used for the purpose of the concept design.

4.2.2.2.3 Checking Mechanical/Electrical Considerations against Existing Standards

As mentioned before, after providing a linkage between the obtained knowledge during the concept design, this study needs to specify the mechanical/electrical considerations made by group 2. In this way, the researcher attempted to elicit these considerations through the performed activities by group 2. These considerations have been summarized in Table 4.3.

Table 4.3. Mechanical/electrical requirements for architect consideration during concept design by group 2 (from transcription of video segments)

#	Consideration Description	Reference	
1	**Daylighting Considerations**	**Video Segment No.**	**Report Page No.**
1-1	Facing side for openings	18	12
1-2	Using some way to control direct glare (such as vertical elements on façade)	80	12
1-3	Propose sun control devices to diffuse direct sunlight	90	12
2	**Building Integrated Photovoltaic System considerations**		
2-1	PV location	90,116	----
2-2	PV tilt angle (should be considered in regard with the geographic location of the building site)	----	29
2-3	PV direction	90	29
2-4	Module calculation: - Size and amount of modules - Area needed - Initial cost needed - Life cycle calculation for BIPV usage	80 90	30 31
2-5	Possibility of incorporating PV modules into shading devices - PV panels on canopy walkway - PV panels on glass areas	80 91	29
3	**Rainwater Harvesting System Considerations**		

3-1	Catchment location	123	32
3-2	Required components: - Way of conveyance (by gutters/ downpipes) - Filtering (first flush) - Storage tank - Booster pump - Roof tank - Distribution (plumbing to toilets/general use)	80	32
3-3	Location of rainwater tank and filter	----	34
3-4	Calculating area for roof catchment	127	
3-5	Estimating rainwater yield	127	
3-6	Estimating storage tank size	127	
3-7	Calculating water saving	127	
4	**Wind Turbine**		
4-1	Inspecting possibility of meeting basic requirements (such as wind speed) for using wind turbine	18	40
4-2	Specify wind turbine additional requirements (such as cooling tower) against lack of requirements	80	40
4-3	Calculating output energy produced by wind turbine	80	44
4-4	Calculating life cycle cost	127	44
4-5	Specifying wind turbine location	80 90	46
5	**Solar Assisted Air Conditioning System Considerations**		
5-1	Specify solar air conditioning requirements: - Collector (such as solar evacuated tube) - Storage tank - Control unit - Pipes and pumps - Thermally driven cooling machine	90	15
5-2	Specify type of collector	----	15
5-3	Calculating number of needed air conditions	----	19
5-4	Calculating cooling capacity	----	19
5-5	Calculating roof space for collector	----	20
5-6	Calculating life cycle cost	----	20
5-7	Calculating result of comparison between energy consumption for conventional and solar air conditioning system	----	22

Table 4.3 is the summary of the mechanical/electrical considerations by group 2. There is a standard for the basic mechanical and electrical considerations during the concept design, so we did literature review to find the required considerations. The summary of the basic mechanical requirements for the building projects (Burberry, 1992) is shown in Table 4.4. Then, we confirm the completeness of the mechanical and electrical requirements which have to be considered by architects against these basic requirements.

Table 4.4. Comparison of mechanical/electrical basic requirements (adopted from Burberry, 1992) and their correspond reference through case study

Requirements	#	Mechanical/Electrical Requirements (Burberry, 1992)	Reference	
			Video Segment No.	Report Page No.
Wind	1	Avoid effects of wind velocity in buildings with different heights at ground level by contriving wind tunnel	90 120	8 37
Daylight	1	Considering minimum daylight standards for spaces	80 99	6
	2	Considering daylight reflection factors for dwellings	----	9 13
	3	Control the spacing between the height of blocks when laying out groups of building to catch reasonable daylight	80 120	----
	4	Considering sun movement path, solar heat gain and sunlight criteria	18 90	----
Ventilation	1	Considering pressure variants and stack effects by contriving controllable opening lights or mechanical ventilation	----	12 13 14
Energy conservation	1	Site selection	----	3 9
	2	Grouping individual building to composite blocks	103	----
	3	Shape and size(small heat loss ratio 1:1 to 1:3- long side : short side)	99 104	12 13
	4	Orienting windows as far as possible toward south	18	9

The two right side columns in Table 4.4 display the mechanical/electrical considerations which correspond to the standard for these requirements by Burberry (1997). Indeed, these two reference columns demonstrate that almost all the requirements have been taken into account throughout the proposed concept by group 2. Empty cells in "report page no" column show that some of the mechanical/electrical requirements have been considered from the early steps of concept design, but they have not been documented in the submitted report. These part of knowledge which has been lost before formalization is evident for knowledge loss phenomenon. In reverse, there was some knowledge which was not acquired during concept design, but team members documented them in their submitted report.

ITMA project is a Green Building project. Hence, we need to look into the green building standard from a technical point of view such as MS1525 for 'Energy Efficiency and Renewable Energy', MS 1752 for 'Method for measuring performance of electric toasters for household and similar purposes' and also MS 1751 for 'Methods of measuring the performance of electric ironing machines for household and similar purposes'. A summary of technical requirements stipulated by Green Building Index for Malaysia (MS1525) is shown in Table 4.5. Since this study is concerned with the conceptual design of building projects, "Architectural and passive design strategy" part of MS 1525 is followed. The two left columns of Table 4.5 show the architectural and passive design strategies. Similarly, the two right columns are evidences from the data recorded during the data collection process and also from the report submitted by the team members of the project.

Table 4.5. Summary of Green Building requirements (adopted from MS 1525)

Architectural and passive design strategy		Reference	
Strategy	**Description**	**Video Segment No.**	**Report Page No.**
Site planning and orientation	- Avoid direct sun light - Providing for the possibilities of day lighting (most of the windows facing either north or south)	80 ----	9 12
Daylight	- Try to create a better uniformed daylight distribution in a room (by using light shelf or split window) - Appropriate glazing area	80 ----	13 12,13
Natural ventilation	Not recommended for office building in Malaysia	----	----
Lighting			
Energy consumption	Reduce energy consumption for lighting	80	12
Energy efficiency			
Building related factors	- Size and shape - Orientation - Planning and organizing - Window system	104 19,90 80,99 ----	14 12 14 13
Building orientation	- Solar radiation and its heating effects on walls and room which face different directions - Ventilation effects associated with relation between the direction of the prevailing winds and the orientation of the building	---- 90	12,13 9
Planning and layout	- Grouping of spaces - Interaction of spaces - Ceiling height and space volume	103 104 120	12 8
Window system	- Size, location, shape and orientation of glazed areas affect on heat gain and solar gain - Heat gain influenced by type and design of shading system - Heat gain influenced by composition and type of glass - Obstruction and shading by surrounding buildings, structures and trees	80 90 ---- 90	13

Referring to Table 4.5, it is clear that all the green building strategies have been considered in the proposed concept design by group 2.

According to Green Building Index (GBI) criteria MS 1525, energy efficiency, environmental quality and water efficiency are factors that are assessed through Green Building projects. In this regard, the recognized technologies such as Daylighting and Building Integrated Photovoltaic System and their requirements which have been elicited from MS1525, MS1837 and the literature review related to them are shown in Table 4.6. In this table the four left columns show the required technology, standard/reference which are the stem of the correspondent technology. The forth column is associated with the description of technology. The two right columns of this table show corresponding evidence from the proposed concept design by group 2.

Table 4.6. Summary of required technologies for Green Building project-Adopted from MS 1525, MS 1837 and literature

Green Building Technologies	Standard No./ Reference	#	Description	Reference	
				Video Segment No.	Report Page No.
Daylighting	MS1525	1	Choosing proper side for openings	----	12
		2	Control direct glare	80	12
		3	Sun control devices to diffuse direct sunlight	80	13
Building Integrated Photovoltaic System	MS 1837	1	PV location	90,116	----
		2	PV tilt angle	----	29
		3	PV direction	----	29
		4	Module calculation: - Size and amount of modules - Area needed - Initial cost needed - Life cycle calculation for BIPV usage	----	30
		5	Incorporating PV modules into shading devices	----	28
Rainwater Harvesting System	Li (2010)	1	Catchment location	123	32
		2	Required components: - Way of conveyance (by gutters/ downpipes) - Filtering (first flush) - Storage tank and filter size and	127	32

			location - Booster pump - Roof tank - Distribution (plumbing to toilets/general use)		
		3	Estimating rainwater yield	127	34
		4	Calculating water saving	----	34
Wind Turbine	Frost (1994)	1	Basic requirements such as wind speed	90	39
		2	Specify wind turbine additional requirements	----	40
		3	Calculating output energy produced by wind turbine	----	43
		4	Calculating life cycle cost	----	44
		5	Specifying wind turbine location	80	46
Solar Assisted Air Conditioning System	Renewable Heat in Europe (K4RES-H) + Solar Cooling, ASEAN Energy Efficiency and Conservation (EE&C)	1	Solar air conditioning requirements: - Type of collector - Storage tank - Control unit - Pipes and pumps - Thermally driven cooling machine	90	15
		2	Calculating number of needed air conditions	----	19
		3	Calculating cooling capacity	----	19
		4	Calculating life cycle cost	----	20
		5	Comparison between energy consumption for conventional and solar air conditioning system	----	22

A comparison was made between what is required to do according to the existing standard for green building and technology requirements, and what has been performed by Group 2 team members through the case study. With the help of the comparison, we found out that they had considered all the requirements.

4.3 Development of knowledge-based framework for Conceptual Design Phase

In this research, we attempted to elicit the exchange knowledge between multidisciplinary experts during the concept design in the selected case study. The elicited knowledge associated with Macmillan steps for the conceptual design stage is shown in Table 4.7. Regarding the evidences from case study, the required knowledge has been provided by different experts. Therefore, the required knowledge regarding the person who is responsible to provide it has been locates in the related column. The two left columns of Table 4.7 (No. and Macmillan Conceptual Design Framework Steps) refer to the steps of Macmillan conceptual design framework (2001). The two right side columns of this table show the exchanged knowledge between architects and mechanical/electrical engineers corresponding to the performed activities by group 2.

Table 4.7. Recommended knowledge movement between architects and mechanical/electrical engineers according to Macmillan conceptual design framework (2001) steps

		Movement of Knowledge Expected to Reside in	
No.	**Macmillan Conceptual Design Framework Steps**	**Architectural Knowledge**	**Mechanical/Electrical Knowledge (to be transferred to the architects side)**
1	Specify the business need	- Specify kind of building (function) - Site characteristics - Owner aspirations - Exist building problems - Defining a mission about requirements	- Specify required technologies: - BIPV - Solar air conditioning - Wind turbine - Rainwater harvesting system - Waste management - Daylighting
2	Assessing stakeholders requirements	- Building modules regarding defined mission	- BIPV location, tilt angle and direction - Rainwater usage, location and storage tank requirements - Daylight strategy to catch optimum sky light - Solar air conditioning area needs - Wind turbine location and requirements
3	Identify problems with exist solutions		- Sun path movement - Wind direction

			- Constraints arising from technologies such as wind velocity points
4	Developing requirements	- Space function and requirements - Standard modules - Height of buildings	- Minimum daylight standard for spaces - Ventilation requirements (such as required space between blocks) - Pressure variants - Necessity of mechanical ventilation due to stack effect (caused by height of building)
5	Setting requirements	- Specify drawing requirement and diagrams	- Solar collector location - Water catchment location - PV panels location, tilt angle and location - Wind turbine location
6	Determining project characteristics		
7	Generating initial concepts		- Specify effect of courtyard for better distribution of daylight - Use of building shade - Specify PV panel location base on need to cool
8	Transformation/ Combination of concepts	- Design alternatives for building modules - Specify width and length of buildings	
9	Selecting suitable combinations	- Specify size of blocks of buildings - Specify space between buildings	
10	Firming up into concept proposals	- Alternative forms of design - Specify height of buildings	- Finalize PV location
11	Evaluating and choosing proposal	- Specify chosen alternative	- Rainwater catchment diagram
12	Improving detail and costing proposal		- Estimating storage tank base on roof area - Specify location of pump and water tank - Estimation of needed air condition - Cooling capacity - Estimation of needed space needed for solar requirements - Life cycle cost - Estimation operating cost saving

As mentioned earlier, Table 4.7 shows the required knowledge which has been exchanged between architects and mechanical/electrical engineers during the concept design of ITMA project. As it appears through many steps, some knowledge has to be exchanged between professionals. As we experienced through the inspecting group 3 activities, the failure to consider the required knowledge at the right time leads to reworking. Exchanging the right knowledge at the proper time can decrease the wasting of time and boost teamwork performance.

This study has acquired the required knowledge which has to be exchanged during the conceptual design phase of building projects. By establishing the linkage between Macmillan (2001) framework for conceptual design and the required knowledge, the appropriate time to exchange the knowledge has been discovered. For instance, through the observation of three groups' activities which competed to propose their concept for ITMA project, the effect of exchanging knowledge at the right time was achieved. Team members in group 3 spent a long time to design and locate the blocks inside the site. When they finalized their design, mechanical/electrical experts attempted to consider technology requirements for building block. At that time they realized that due to the need to use solar bowl to generate electricity they must reduce the number of blocks. They also needed empty space to locate rainwater storage tank. The designed blocks covered the whole available space of the site. In this way, they lost their time for concept design which could be considered one of the reasons to fail this group.

In conclusion, the proposed knowledge-based framework by this study contains the required mechanical and electrical knowledge during conceptual design phase. Precedent model and framework for design process such as Macmillan (2001) framework and Eilouti (2009) included required activities for design purpose. As Nissen (2002) stated knowledge flow enables workflow. Therefore, this study attempted to add knowledge flow beside the workflow of Macmillan framework.

4.4 SUMMARY

This chapter was divided into two main parts: (1) to explain the results of the observation, (2) to analyze the knowledge movement between architects and mechanical/electrical engineers. For part 1 we explained the activities of three cases. Indeed, the cases consisted of three teams that competed to propose the concept design for ITMA project. At the end of part 1 the process of winning the concept was illustrated. In part 2, we analyzed the winning group activities (group 2) during concept design. To this end, we attempted to transcribe video records which were provided through concept design stage of ITMA project. Then, transcriptions were verified by team members. To validate the collected data we had a comparison between mechanical/ electrical considerations through the case study, exiting standard for basic mechanical/electrical requirements and also green building technology requirements. It was realized that all the requirements have been considered by group 2 during concept deign of ITMA project.

Thus the study confirmed the internal validity its constructs. To achieve objective 2 which is to develop a framework for capturing the expert knowledge during the conceptual design stage, this study attempted to provide a linkage between the obtained data from the case study and Macmillan conceptual design framework. To this end, team members' activities were compared and contrasted to the pre-defined activities for Macmillan framework. In the end, this study managed to provide a linkage between the required knowledge during conceptual design phase and the selected conceptual design framework. By revealing the entity of knowledge which has to be exchanged between experts, this study succeeded in converting tacit knowledge to the explicit type. Consequently, the researcher wants to propose that by converting the tacit knowledge of an expert to the explicit one, the performance of the project will improve. To prove this, three hypothesizes are developed in the next chapter. Then, computational organizational tool is used (SimVision) for the intellectual validation of the developed hypothesis.

CHAPTER 5

VALIDATION

5.1 Introduction

In this chapter we are going to explain the procedure of validating the extended model of the conceptual design phase. The proposed model by this study has been established on Macmillan (2001) conceptual design framework. Macmillan framework entails a workflow for the concept design. Indeed, this study proposed the framework, which attempted to extend the activity-based Macmillan framework, by adding the required mechanical/electrical knowledge during the conceptual design phase to the existing framework. Nissen and Levitt (2004) stated that since knowledge flows enable workflows, they are indispensible to organizational performance. Nissen (2006) also emphasized that accompanying the required knowledge with the workflow can improve the performance. In this chapter, we attempt to prove that the extended knowledge-based model improve the performance of the project through intellective validation by using Simvision.

5.2 Model Simulation

We employed SimVision educational version 4.2.0 which was developed by Vite Corporation with a license from PM. SimVision® is an agent-based computational organization theory (COT) modeling tool (Jin & Levitt, 1994), to build a high-level facility development life cycle process which includes an organization responsible over each life cycle phase to emulate the operating environment, hence validating the ethnographic findings. Ibrahim and Nissen (2005) using this method amplified tacit knowledge movement through enterprise life cycle.

Ibrahim (2005) stated that there are three items which are of significance in studying knowledge flow in any organization. They include: the process under study, the organization, and their connections. Since the flow of knowledge is engaged with the passage of time as the process progresses, SimVision links process and to organization. Indeed, Nissen and Levitt (2002) for the first time attempted to simulate knowledge flow in the design of the organization by using a computational method (Simvision). They used the theory for multidimensional conceptualization of the knowledge-flow phenomenon to develop the dynamic models of knowledge flow dynamics. They illustrated their research approach and the modeling environment through formal representation and simulation of several knowledge-flow processes by means of SimVision.

Moreover, Ibrahim and Nissen (2007) extended the organization theory by integrating it with knowledge-flow theory. Their research used computational methods and tools to understand how discontinuous membership affects organizational performance. Similarly, since this study is concerned with knowledge flow during the conceptual design process, we followed Ibrahim and Nissen (2007) to inspect effectiveness of the proposed knowledge-based framework for conceptual design phase.

The base case for this study is Macmillan (2001) framework for the conceptual design phase. The process of choosing this framework was based on the comparison made among the existing models for this stage (See 2.4.4). Using this software we attempted to create the conceptual design process adopting Macmillan (2001) framework for this stage. Although Macmillan (2001) conceptual design framework has 12 main activities, there are some implicit activities which work to specify the required knowledge and also to exchange of the required knowledge. Therefore, we have added two activities following each activity from Macmillan framework. In conclusion, the process of the concept design has 36 activities which stem from Macmillan model and 24 more additional activities for identifying and exchanging the required knowledge for each activity. To simulate the base Macmillan framework through SimVision, the following steps must be considered. After launching SimVision, a default program opens that contains a default project1 and two milestones namely Start and Finish (Figure 5.1).

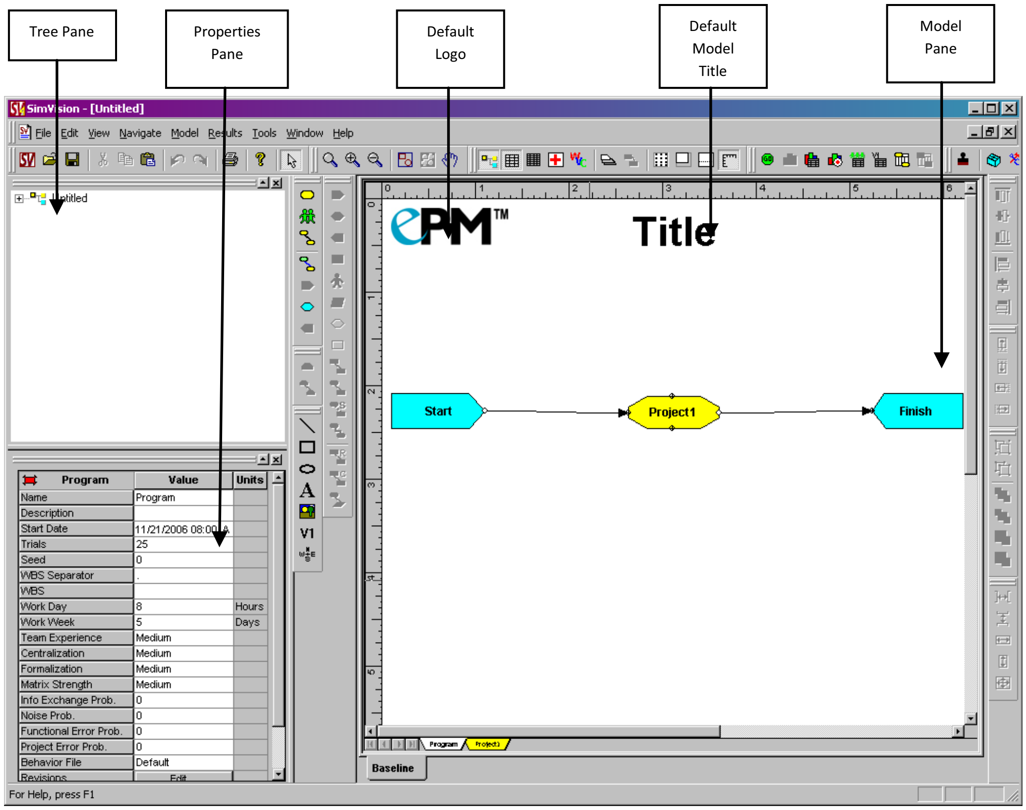

Figure 5.1. Default Workspace for Opened Program in SimVision

A program is a set of related projects that together meet the business needs of a client. The default project and milestones are displayed in the Model pane. Then, by clicking on the Project1tab at the bottom of the default workspace, the default project elements are viewed in the model pane (Figure 5.2).

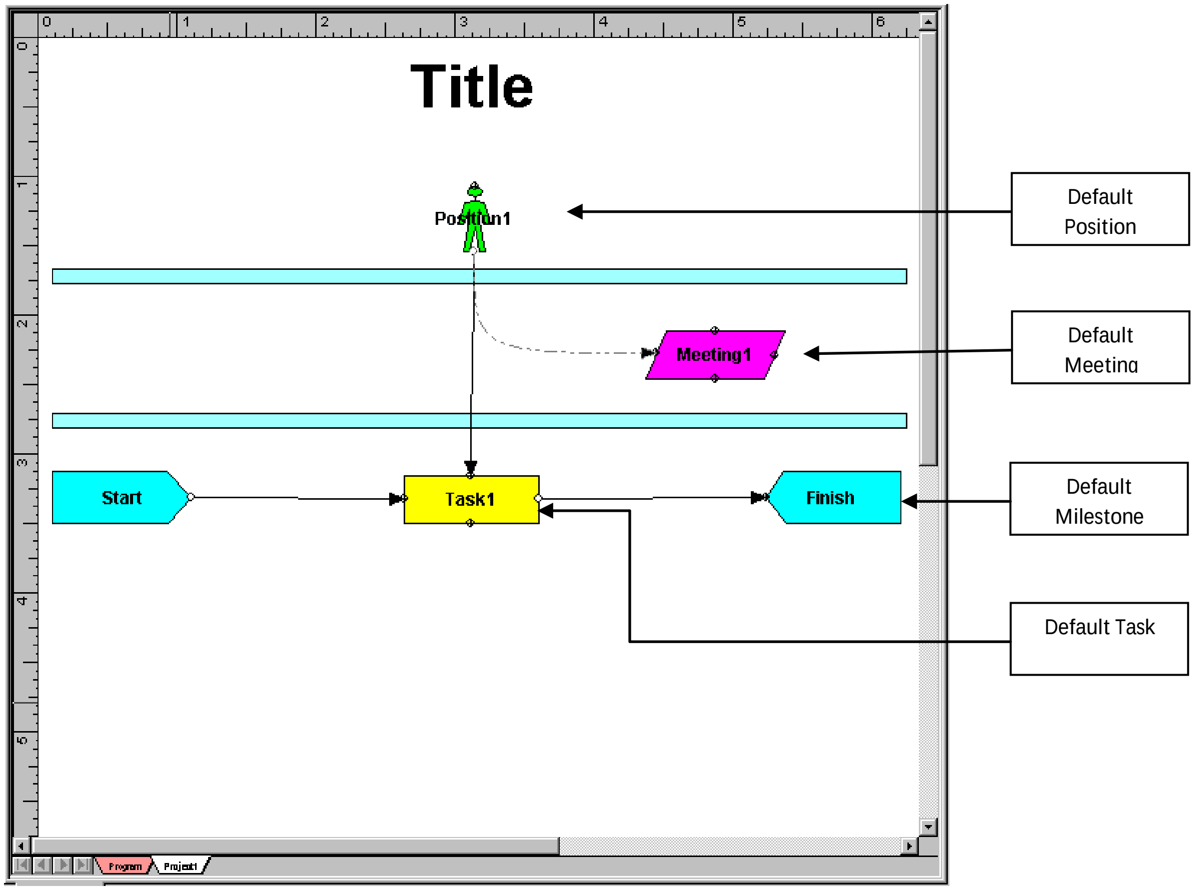

Figure 5.2. Default Project elements

Like the program, the project also has two default milestones: Start and Finish. The project's start and planned end dates can be set by setting dates for the Start and Finish milestones. It also has a default task, position, and meeting. The next step is adding Macmillan activities as tasks between the first and second Milestones. Then the task precedence has to be defined by linking the tasks to each other and to milestones by means of successor links. As a result of which every task and milestone must have both a predecessor and a successor. The Start milestone only has a successor; the Finish milestone only has a predecessor. Successor links can be one of the three types: (1) finish-start, (2) start-start, (3) finish-finish.

Once the project tasks are in place, the positions are required to be added. A position is an individual or a group of individuals with a responsibility for one or more tasks. Like all other objects, positions have a set of properties. These properties which are called micro-behaviors are composed of: (1) Name, (2) role, (3) application experience, (4) FTE, (5) salary A name is a short label for the position. A Role is the position's function in the organizational hierarchy. Each position fulfils one of the three functions: Sub-team (ST), Sub-team Leader (SL), or Project Manager (PM). Project Manager is the position that tends to make many of the decisions, and to whom others usually go with questions. Typically only one person per project has this role. Sub-teams generally do most of the work. Usually sub-team leaders' position is between PM and ST. In this tutorial, we use only PM and ST roles. Application Experience concerns the degree of the experience the position with respect to this type of project. FTE is the number of full-time equivalent persons represented by the position. Salary is the position's hourly wage, measured in currency units. After creating a hierarchy of positions, the tasks can be assigned to these positions. Each task must have a single primary responsible position. More than one position can work on a task, but only one position is primarily responsible for it. Tasks can only have a single primary responsible position, but positions can have multiple primary tasks. Tasks can have any number of secondary responsible positions. Positions are available to work on secondary tasks only when they are not working on primary tasks. There are two kinds of assignment links with which you can assign tasks to positions: (1) primary assignment link which links a position to a primary task, (2) secondary assignment link which links a position to a secondary task.

Using the said steps, the researcher attempted to implement Macmillan framework as the base case for this study. As it is shown in Figure 5.3, Macmillan main activities are in white color. Activities have been ordered in columns. For instance, the first activity is “specifying the business needs”. The next activity in the first column is for identifying the required knowledge. The following activity is for “exchanging the required knowledge”. Other activities have been ordered consequently. In SimVision we have to assign activities to project team members. Many experts such as the project manager, architect and mechanical/electrical engineers are involved in the concept design phase; therefore each activity is assigned to all these experts. In this way, we can examine the effects of these experts’ skills on the project performance.

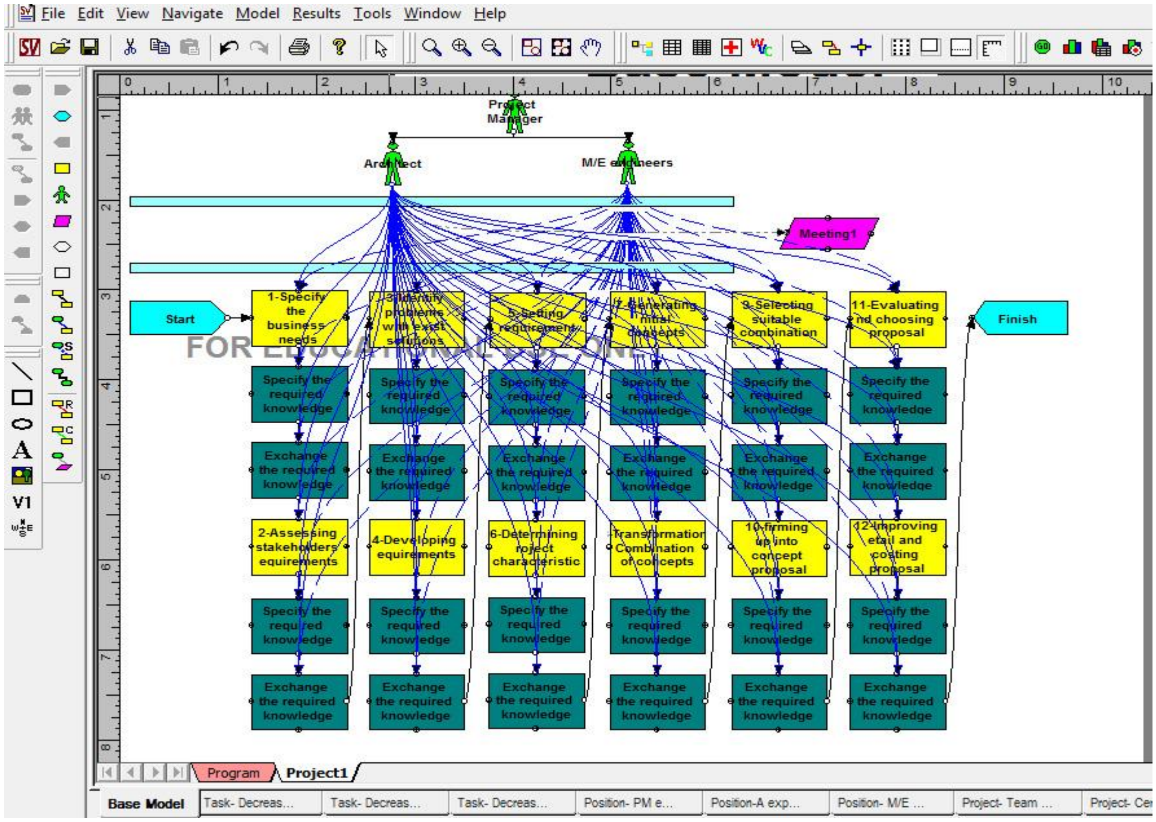

Figure 5.3 Base Framework for Conceptual Design Phase

(Source: adopted from Macmillan, 2001)

According to Nissen's (2006) multidimensional model, the knowledge move from the individual to the group through the shared experience. Now, if experts' skill matches the required experience for the related task, the person in charge will know the accurate and complete knowledge which has to be transferred. As a result, the completeness and the accuracy of the knowledge obtained by the receiver depend on the skill of the sender. In a tacit dominant area such as the conceptual design phase, the performance of successor's task relies on the received knowledge which has been sent by a provider. Therefore, the skill of all the team members involved can affect the knowledge exchanging process between experts and by extension the project performance. Considering these experts' skill (experts' tacit knowledge) has an undeniable effect on the performance of the project (See Table 5.1). According to this table the required skills for team member consist of Medium level for Project Manager (PM), High level for Architect (AR) and High level for Mechanical/Electrical engineer (ME). These experts possess the required skill, therefore they are able to provide the required knowledge at the right time. If an expert such as an architect does not possess the required level of skill, other team member's task through will suffer through his/her incomplete knowledge transfer. Therefore, this study hypothesizes that:

> **H1:** A building project team member who has sufficient knowledge which is required for other team members' tasks can improve performance of the receiver's task. The study expects the FRI and PRI to be less than 0.5.
>
> **H2:** A building project team member who does not have sufficient knowledge which has to be considered by other team members to do their task, by transferring incomplete knowledge can increase the risk involved in the receiver's task. The study expects the FRI and PRI to be less than 0.5.

To prove the abovementioned hypothesis, what the researcher does is compare and contrast the results when a team member -- such as architect -- possesses the required skill which matches the required experience to participate in a project with the situation in which the same person does not.

Table 5.1. The awareness of team members about the required knowledge

Awareness	PM	AR	ME
Sufficient	Medium	High	High
Insufficient	Medium	Medium	High

For example when mechanical/electrical engineers (ME) do not possess the sufficient knowledge for using the solar bowl to generate electricity, they may let the architects (AR) design many blocks for the building. The researcher experienced a similar problem with Group 3 concept design. In the middle of the day set for doing the concept design, mechanical/electrical experts stated that due to the high cost of generating electricity by means of solar bowl, they would not approve of the presented concept design. Thus, they lost their time through redesigning their concept. Similarly, if architects had sufficient experience about the solar bowl requirements they could have prevented the loss of time. If they knew that they had to allow for specific requirements for various kinds of technologies, they would have demanded these requirements from mechanical/electrical experts.

In such a situation, of the project manager's skill (PM) as the leader of the design team has a great impact on knowledge exchange process. If the project manager knows that some knowledge is required to be exchange at a given time, he will facilitate this process. Therefore, explication of the entity of the knowledge required to be considered during the conceptual design phase can affect project performance. In other words, when the entity of the required knowledge has been specified, we can avoid spending time on identifying it. In such a situation, team members deal with the explicit knowledge which does not depend on the skill of the experts involved. Therefore, this study has one more hypothesis to offer as regards Nissen theory (2006):

> **H3:** By specifying the entity of the required knowledge during conceptual design phase, performance of building project improves due to explicitness of entity of knowledge. The study expects the FRI and PRI to be less than 0.5.

For instance, when an architect knows about the entity of the required mechanical/electrical knowledge which has to be considered through each step of the conceptual design, the time needed to determine the knowledge required is reduced.

Test case 1: Base Case (Sufficient Awareness)

Following Ibrahim and Nissen (2005) example for the situation in which there is a small number of task volumes in the base case, the behavior parameters are set higher than the normal in construction industry to amplify the effects of knowledge flow on the outcome. According to SimVision a project represents a work process when it must be performed by the project team members to achieve an outcome. Each project is composed of tasks, positions, milestones, meeting and also links among components. We set the parameters for project, positions and tasks as stated here: Medium level for team experience, Low for centralization, Medium for formalization, Medium for matrix strength, 0.7 for communication probability, and finally 0.15 for noise problem, project error probabilities and also for functional error probability. As mentioned before, the values of the above parameters have been set in accordance with the normal construction industry values.

Position parameters for experts (including of the project manager, architect and mechanical/electrical engineers) are shown in Table 5.2. The micro-behaviors include fulltime-equivalent (FTE), role, application experience (App. Exp.) and salary.

Table 5.2. Baseline parameters for team members

#	Position	FTE	Role	Application Experience	salary	Knowledge Skill
1	Project Manager	0.3	PM	Medium	100	Medium
2	Architect	1	SL	High	80	High
3	Mechanical/Electrical Engineer	2	ST	High	70	High

In the base case, all team members' skill satisfies the required skill for carrying out the job. For instance, the required skill for architect and mechanical/electrical engineers is high. In case base these experts' skill satisfies the required skill. In other words, architects and mechanical/electrical experts are fully aware of the knowledge which has to be exchanged between the experts.

Test case 2: Proposed Case (Insufficient Awareness)

The second case test is about insufficient awareness for experts. All the project, position and tasks parameters are similar to the case test. To represent the effect of insufficient awareness of the experts on performance we changed their skill. Accordingly, the skill of architect changed from High to Medium so as to gauge the effect of the experts' skill on project performance (Table 5.3). As it is shown, the skill of the architect has not fulfilled application experience requirements. It means that the architect does not have the sufficient knowledge to accomplish his/her own task.

Table 5.3. Changed parameter for architect skill

#	**Position**	**FTE**	**Role**	**Application Experience**	**Salary**	**Knowledge Skill**
1	Project Manager	0.3	PM	Medium	100	Medium
2	Architect	1	SL	High	80	**Medium**
3	Mechanical/Electrical Engineer	2	ST	High	70	High

5.3 Case Analysis

We made 3 simulations for base case, changing experts' skill and also setting "Identify Knowledge" activities' duration to 0. By setting trials to 50, we ran 150 trials. The simulator default for running is 25 trials. When the number of simulation trials increases, the small difference between the mean of the two project teams becomes significant. Following Ibrahim (2005) work to make the simulation more accurate, this study has done the same tests with 50 trials. Different simulations were made because these experts have different roles and this study needs to study the effect of changing each condition. The first simulation was for the base model in which the skill of experts met the application experience requirements. Next simulation was for changing the architect skill from High to Medium. The last simulation was for setting the duration of "identifying knowledge" activities to 0 which stemmed from explicating the required knowledge. All simulations showed similar results to changing micro-behavior parameters.

Now, we explain the effect of each parameter change on the work volume, rework, coordination and decision wait. In stated hypothesis we claimed that in the tacit dominant area changing the skill of the experts involved would affect the performance. Therefore, we examine the difference between the values of parameters before and after changing the architect's skill level. In this way, we intend to demonstrate when an experts' skill level can affect some parameters such as rework, coordination and etc.

According to the results obtained by changing the level of the architect's experience from High to Medium rework (12.8 days to 18.23days), coordination (22.63 to 30.43) and decision wait (14.70 to 22) increase. Statistics also shows that by changing the skill level of the architect from High to low, duration increases from 11 days to 13.5 days and the total work cost increases from 98941 to 120324 (Table 5.4). The right side column of Table 5.4 shows the amount of increase in the percentage resulting from changing the architect's skill. Indeed, Table 5.4 refers to hypotheses 1 and 2 that are related to the skill level of team members. The considerable effect of changing the architect's skill level on the parameters of the project performance is revealed after comparing project parameters with one another.

Table 5.4. Effect of changing architect skill level on project performance parameters

Affected Item	Parameters' Value Base on Architect Skill Level		Difference %-Arising from Changing Level of Skill
	High	Medium	
Work Duration	11	13.5	22.7%
Total work cost	98941	120324	21.6%
Rework	12.8	18.23	42.4%
Coordination	22.63	30.43	34.5%
Decision wait	14.70	22	49.6%

The abovementioned results are related to the first and second hypothesis of this study which pertains to the characteristics of the tacit dominant area. We claimed that changing the skill of the experts involved in the project could affect the performance of team members while dealing with tacit knowledge. The diagram of differences resulting from changing the architect's skill is shown in Figure 5.4. This diagram shows that there is a relation between the level of the architect's skill and project parameters. By changing the skill level from High to Medium value of parameters i.e. work duration, rework, coordination and decision wait increase. In other words, the completeness of sent/ received knowledge by the architect depends on his/her skill. Architect's awareness of the type of the knowledge required to be sent or received, considerably decreases the parameters of the project.

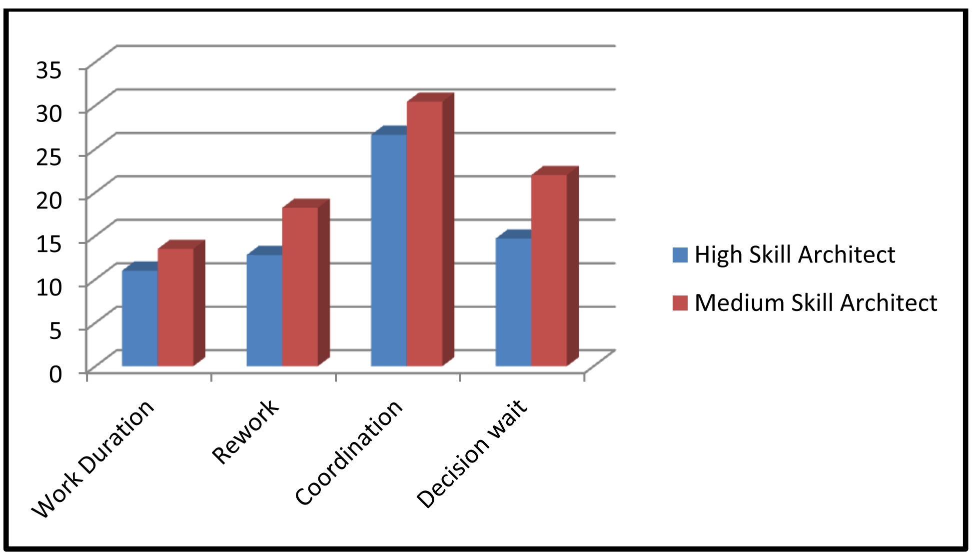

Figure 5.4. Parameter Changes Arising from Changing Architect Skill

As mentioned earlier, the last simulation was for setting duration of “identifying knowledge” activities to 0 which stemmed from explicating the required knowledge. This simulation was related to the third hypothesis. We made three more simulations in connection with the properties of the explicit dominant area. According to the third hypothesis, adding knowledge to Macmillan (2001) framework for conceptual design phase eliminated the need for identifying the required knowledge. The obtained results from this simulation are shown in Table 5.5. In this table “Base Case” column contains the simulation values for Macmillan conceptual design framework. Next right side column is for changing “Identify Knowledge” activities to 0. Comparing these two columns indicates that work duration and total work cost have decreased considerably. Referring to the results it becomes clear that adding knowledge flow to the work flow in Macmillan model reduces work duration (by 33.6%), total work cost (by 33.3%) and also FRI (by 3.3%). For instance, work duration of base case decreases from 11 days (SD=0.5) to 7.3 days (SD=0.3). Although functional risk has increased by 3.3%, its value is still under 0.5. Based on SimVision FRI<0.5 is an acceptable range for this parameter. Values above 0.5 indicate a very high likelihood of project component or task quality failures if the facility developer does not take any action to lower the risks. FRI and PRI values of above 0.4 mean that many failures are not going to be reworked, and values that are above 0.7 are unacceptable level of risk for any organization. More discussion about the results will be presented in the next section.

Table 5.5. Effect of removing "Identify Knowledge" activities due to adding knowledge flow to Macmillan (2001) conceptual design process

Affected Item	Base Case		"0" Duration for "Identify Knowledge" Activities		Difference %
	Value	SD	Value	SD	
Work duration	11 days	o.5	7.3 days	0.3	-33.6%
Total work cost	$98941	0.0	$65967	0.0	-33.3%
Process quality risk	0.28	0.027	0.29	0.033	+3.6%
Product quality risk	0.15	0.014	0.15	0.018	0
Functional risk index	0.30	0.029	0.29	0.036	-3.3%

Note: SD stands for Standard Deviation for simulation trials

Indeed, Table 5.5 contains the values to prove hypothesis 3 whereby we claimed that explicating the required knowledge during the conceptual design phase can improve project performance. As demonstrated, work duration and total work cost have reduced considerably.

5.4 Discussion and Conclusion

Recalling chapter 2 we had two propositions:

> ***Proposition 1:*** Knowledge capture can be improved when design professionals know what the required knowledge are and when they are needed during conceptual design phase.

Proposition 2: With improved knowledge capture, design professionals can improve their knowledge transfer and application during conceptual design phase.

From the case study we elicited the knowledge such as the proper space between the blocks for proper ventilation which is required to be exchanged among experts for the purpose of concept design. In this way, we found out that specifying the proper space between blocks is an essential mechanical consideration by which the need for proper ventilation is satisfied. Also, responsible experts have been identified to provide and apply this knowledge. Therefore, by knowing the entity of knowledge -such as the required space for rainwater storage tank- and also by identifying the responsible expert -architect or mechanical/electrical engineers- who can provide it, the necessary considerations can be made at the proper time. For instance, sun path is a mechanical requirement which must be noticed by architects for orienting buildings and openings. The proposed pattern shows that this knowledge has to be sent from the mechanical side to the architect side in the third step - to identify problems through the existing solutions- of Macmillan (2001) model. In such a situation, we are able to elicit the expert tacit knowledge. In other words, by this we can convert expert tacit knowledge to explicit type. Therefore, this study claims that by explicating the entity of the required knowledge during the conceptual design phase – according to Macmillan (2001) framework-, movement of knowledge between architects and mechanical/electrical experts is facilitated. Thus, project team performance is improved.

As mentioned earlier, Macmillan (2001) framework contains 12 explicit activities and 24 implicit activities. Implicit activities correspond to explicit ones to identify and exchange the required knowledge which is required to be considered through the activities. For instance, sun path movement is one of the basic mechanical requirements which have to be considered to orient the building. In this respect, a novice architect has to talk with mechanical/ electrical engineers to identify the required considerations. Then, he has to ask for the identified knowledge at the proper time. In such a situation, explicating the entity of the required knowledge can reduce the required time for the implicit activity to identify the required knowledge. Moreover, the explication of the required knowledge reduces the probability of identifying incomplete knowledge.

To prove these propositions we used computational organization tool (SimVision). We simulated Macmillan framework as the base model and presented the framework of this study as the proposed model. Then, we tabled the results of the base model with different skill levels of the architect to display the impact of skill in tacit dominant area on project performance in Table 5.3. The results of changing the level of the architect's skill indicate lower organizational performance in terms of the parameters of the project namely work duration and rework. By changing the level of the architect's skill from High to Medium work duration increases from 11 days to 13.5 days. This result is equivalent with the rework, where the Medium level skill of architect has more rework than the High level skill. The estimated rework with a High skill architect is 12 day, while with a Medium level skill it rises to 18 days. The work duration also concurs with the coordination, where the Medium level of the architect needs further coordination than the High level skill for an architect (22 days are needed for coordination in comparison with 30 days). Finally, the work duration concurs with decision wait, where Medium level skill of architect causes more decision wait than High level skill (14.5 days is required for decision wait in comparison with 22 days).

To conclude, increasing work duration after changing the architect's skill from High to Medium amplify rework, coordination, and decision wait volumes. The abovementioned results show that the performance of the project in a tacit dominant area can be affected by the skill of experts involved. For instance, an experienced architect's knowledge about mechanical consideration during a concept design may prevent rework caused by the lack of them. For instance, architects in Group 3 created the concept design in terms of the required space which had been specified by stakeholders. However, they did not have the sufficient knowledge about technology requirements for ITMA green building project. Thus, they did not considered technology requirements like the existence of enough space for locating rainwater storage tank. They also did not know that they had to minimize the number of blocks due to the high cost of generating electricity via solar bowl.

According to the simulation results, after changing the skill of the architect, work duration, total work cost, rework, coordination and decision wait parameters were all affected in a negative way. Indeed, by decreasing architect' skill level all the above-mentioned parameters increased considerably. The results obtained reveal that there is a negative relationship between these parameters and experts' skill. In conclusion, this study finds out that the level of experience of the architect during the concept design has a conspicuous effect on project performance. In other words, when an architect has sufficient knowledge about the technology requirements such as the positioning of the building blocks with respect to the existing structures –for example a solar bowl-, the time needed to identify and obtain these results from mechanical/electrical engineers is saved. As a result, this saving of time reduces the total work duration of the project. These results support hypotheses 1 and 2:

> **H1:** A building project team member who has sufficient knowledge which is required for other team members' tasks can improve performance of the receiver's task. The study expects the FRI and PRI to be less than 0.5.

> **H2:** A building project team member who does not have sufficient knowledge which has to be considered by other team members to do their task, by transferring incomplete knowledge can increase the risk involved in the receiver's task. The study expects the FRI and PRI to be less than 0.5.

Nissen (2006) had claimed that explicit knowledge contributes to a shorter flow time. Thus, we attempted to simulate an ideal condition in which duration of "Identify Knowledge" activities is set to 0 through adding knowledge flow to the existing work flow for Macmillan (2001) model for the conceptual design phase. As mentioned earlier, setting “Identify Knowledge” activities to ‘0’ points to the time saving which was affected by explicating the entity of the knowledge in the proposed framework of this study. In conclusion, based on the results obtained (See Table 5.4), work duration and total work cost for the conceptual design phase of ITMA project decrease considerably. Finally, the results together with the comparison made between similar parameters for base case and simulated cases, this study revealed that explicating the required professionals’ tacit knowledge results in the improvement of the performance of the project.

Nissen (2006) in his multidimensional model attempted to examine knowledge movement among experts through a project life cycle in terms of knowledge typology. This study attempted to utilize Nissen theory to detect the knowledge movement between experts during the conceptual design phase. According to Nissen the knowledge that moves from an individual to a group is of the tacit type. For instance, mechanical/electrical engineers, using their experience, can raise architects’ awareness of rainwater harvesting system components such as the storage tank. Then, they propose possible positions to locate the storage tank based on its required size. It is the mechanical/electrical tacit knowledge which is communicated to architects through the shared experience. This knowledge is of the tacit type. Then, According to Nissen’s multidimensional model, this knowledge through formalization step goes to the explicit level. Indeed, this study attempts to explicate knowledge when it moves from an individual to a group. In this way, the first two steps of knowledge life cycle that are based on Nissen theory are simultaneously implemented. According to

Nissen's multidimensional model, knowledge after creation moves from an individual to a group through the shared experience. This knowledge is of tacit type. Through the next step this tacit knowledge is formalized. Therefore, it goes to the explicit level. However, using the proposed framework of this study the required knowledge is formalized while it moves from the individual to group. Thus, the first two steps of Nissen's model are applied simultaneously which leads to a decline in the required time.

The proposed framework includes the entity of the required mechanical/electrical knowledge. Therefore, using this framework results in saving the time for perform "Identify Knowledge" activities -which was implicit with conceptual design activities. In this way, this study expects shortening of work duration of the project. The results in Table 5.5 are indicative of the fulfillment of the expectations. In other words, these results support hypothesis 3. According to hypothesis 3, this study claimed that by specifying the entity of the required knowledge during the conceptual design phase the performance of the project improves owing to the reduction of time. The result has proved that by applying the proposed framework of this study which demands the explication of the experts' mechanical/electrical tacit knowledge, knowledge movement among experts during the conceptual design phase is expedited. Therefore, the two propositions of this study are supported.

5.5 Summary

In this chapter, we attempted to substantiate our proposed knowledge-based framework for the conceptual design phase of the building project. To do so, we developed three hypothesizes:

> **H1:** A building project team member who has sufficient knowledge which is required for other team members' tasks can improve performance of the receiver's task. The study expects the FRI and PRI to be less than 0.5.
>
> **H2:** A building project team member who does not have sufficient knowledge which has to be considered by other team members to do their task, by transferring incomplete knowledge can increase the risk involved in the receiver's task. The study expects the FRI and PRI to be less than 0.5.
>
> **H3:** By specifying the entity of the required knowledge during conceptual design phase, performance of building project improves due to explicitness of entity of knowledge. The study expects the FRI and PRI to be less than 0.5.

Then, by using SimVision, different hypotheses arising from tacitness and explicitness of knowledge were simulated. Results suggest that in tacit dominated area the experts' level of skill affect the performance of the project considerably. Therefore, the conceptual design phase of building projects as a tacit dominated area is subject to the skill of the experts involved. In other words, the completeness of the exchanged knowledge is dependent on the skill level of experts. Experienced experts by drawing on their experience may know the required considerations in different professions. While, novice team members may not possess the sufficient knowledge on these considerations. The insufficient knowledge of novice team members may result in the failure in considering the requirements. This leads to rework. Indeed, by specifying the entity of the required knowledge, there is no need to identify what knowledge is required through each activity. Therefore, a great deal of time is saved through eliminating activities related to "identify knowledge". The results from simulation corroborated this statement.

Moreover, conceptual design phase as a tacit dominated area is subject to the loss of knowledge. We explained this phenomenon by analyzing the data collected from the case study. As demonstrated in Table 4.2., many considerations by Group 2 team members during the concept design were not documented by the report submitted. By specifying the entity of the required mechanical/electrical knowledge through the conceptual design phase, the formalization of the required knowledge is effected when it moves from an expert to the other team members. As a result, the probability of losing knowledge declines. The results of simulation confirm the applicability of the proposed tacit knowledge capture technique by this research.

Recalling the stated problem of this study it was mentioned that over time and over cost can arise from design stage as a tacit-dominated area. Therefore, this study attempted to discover the entity of the required mechanical/electrical knowledge during the conceptual design phase. To make this knowledge applicable a connection was established between the required knowledge and its correspondent activity in Macmillan framework. Thus, a framework was proposed by this study to formalize the required mechanical/electrical knowledge while it moves among the professionals. The simulation revealed that by adopting the proposed framework by this study which embraces the entity of the required mechanical/electrical knowledge during the concept design phase, cost and duration of the project decrease. According to this study, it can be concluded that by employing the proposed framework, knowledge flow can be improved. As a result, overrunning of time and cost will be reduced.

CHAPTER 6

CONCLUSION, KNOWLEDGE CONTRIBUTIONS, BENEFITS AND FUTURE STUDIES

6.1 Introduction

This chapter summarizes and concludes the whole thesis. It first reviews the research questions and objectives of the study and then summarizes the results of the data which were collected through observing concept design process of ITMA project. Later, the proposed knowledge-based framework for the conceptual design stage is presented. The limitation of the study and also knowledge contributions follow and finally, recommendations for future research are made.

6.2 Research Question and Objectives

The main research question of this study is:

> Main-RQ: How can tacit knowledge of design requirements be formalized for improving knowledge-flows among professionals during conceptual design phase of building projects?

To address the main research question, we had to answer three sub-RQs including:

Sub-RQ1: What are techniques to formalize mechanical/electrical knowledge of design requirements during conceptual design phase of building projects?

Sub-RQ2: What are the required mechanical/electrical knowledge during the conceptual design phase of building projects?

Sub-RQ3: How do architects and mechanical/electrical engineers know when to transfer the required knowledge for improving conceptual design phase of building projects?

To address the main research question, we had to achieve three objectives which consist of:

- To specify an appropriate knowledge capture technique for tacit dominated conceptual design phase.
- To identify fundamental mechanical/electrical requirements to consider by architects during conceptual design phase.
- To develop a framework for formalizing tacit mechanical/electrical knowledge during conceptual design phase.

6.3 Summary of the Findings

Findings of this study are divided into two sections:

1- Findings from literature review, and

2- Findings from observation of the case study.

6.3.1 Summary of the Findings from Literature Review

Based on literature about knowledge management process, knowledge flow, and the design process, this study attempted to constitute a theoretical framework based on discovered and relevant background theories. Referring the studied literature, conceptual design phase of building project is the most problematic area from knowledge flow point of view. Despite the intense flow of information between professionals involved in design process, as Pektaş (2006) stated there is a lack of research to better understand and manipulate these flows. According to Nissen (2006) knowledge flow enables workflow. He also maintained that knowledge flows always lie on the critical paths of workflows and the associated organizational performance. Hence, knowledge flows should be planned and managed like workflows.

Regarding Nissen (2006) multidimensional model for knowledge flow, tacit knowledge which flows from individual to group contributes to long flow time. Nonaka (1995) stated that tacit knowledge is difficult to formalize and communicate. Therefore, this study attempted to explicate the required knowledge during conceptual design phase. To do this, Macmillan (2001) framework was recognized as an appropriate choice which had deeply focus on conceptual design phase and also had sufficient activities' definition for this study purpose. Then, this study extended Macmillan framework for the conceptual design phase by adding the required knowledge to it.

By assimilating the two abovementioned theories for the conceptual design phase (by Macmillan, 2001) and the knowledge flow life cycle (by Nissen, 2006), this study proposed two propositions which are stated below:

> ***Proposition 1:*** Knowledge capture can be improved when design professionals know what the required knowledge are and when they are needed during conceptual design phase.
>
> ***Proposition 2:*** With improved knowledge capture, design professionals can improve their knowledge transfer and application during conceptual design phase.

6.3.2 Summary of Findings from Observation

The findings from the case study observation process were analyzed in chapter 4. This study needed to find the mechanical/electrical knowledge which are required to be considered during the conceptual design phase among professionals including BIPV, solar system, wind turbine, etc. This knowledge was identified through ITMA project in the case study. At the same time, the required knowledge was linked to the activities of Macmillan framework for the conceptual design phase. For instance, architects have to specify kind of building for mechanical/electrical experts to enable them to decide about the required technologies. The complete matching is presented in Table 6.1.

6.4 Knowledge-based Macmillan (2001) Framework for Conceptual Design Phase

With the collected data from the case study, this research matched the activities performed during the case study with the activities from Macmillan framework. As a result, a relationship was established between the required mechanical/electrical knowledge and activities of the Macmillan framework for conceptual design phase. These are presented in Table 6.1. For readers' information, the empty cells in the proposed framework indicate that this study could not match any obtained knowledge to the corresponding activity during the conceptual design phase. With the completed matching exercise, this study claims to have extended Macmillan (2001) activity-based framework to a knowledge-based framework, thus combining both workflows and knowledge flows. The study posits that empty cells in Table 6.1 are evidences which suggest that nil knowledge exchange occurred among experts for those activities. Going through Table 6.1, "Architects" column is for the information from architects which has to be allocated to mechanical/electrical experts, in return of effect on design. Similarly, "Mechanical/electrical Engineers" column contains mechanical/electrical information which these experts must know to be allocated to architects.

Through some activities, the professionals perform their tasks based on the knowledge obtained from their previous activities. These observations supported Ibrahim and Nissen's (2007) study. They mentioned that team members would use their prior knowledge during the design phase. However, there is no reason to ensure that their prior knowledge is accurate. Therefore, the extended Macmillan framework made explicit the required knowledge for both architect and mechanical/electrical experts to perform their work with reliable information.

Table 6.1. Findings from observation process

#	Macmillan Activities	Knowledge From: Architects	Knowledge From: Mechanical/Electrical Engineers
1	Specify the business need	- Specify kind of building (function) - Site characteristics - Owner aspirations - Exist building problems - Mission statement about requirements	Specify required technologies: - BIPV - Solar air conditioning - Wind turbine - Rainwater harvesting system - Waste management - Daylighting
2	Assessing stakeholders requirements	- Building modules regarding defined mission	- BIPV location, tilt angle and direction - Rainwater usage, location and storage tank requirements - Daylight strategy to catch optimum sky light - Solar air conditioning area needs Wind turbine location and requirements
3	Identify problems with exist solutions		- Sun path movement - Wind direction - Constraints arising from technologies such as wind velocity points
4	Developing requirements	- Space function and requirements - Standard modules - Height of buildings	- Minimum daylight standard for spaces - Ventilation requirements (such as required space between blocks) - Pressure variants - Necessity of mechanical ventilation due to stack effect (caused by height of building)
5	Setting requirements	Specify drawing requirement and diagrams	- Solar collector location - Water catchment location - PV panels location, tilt angle and location - Wind turbine location

Table 6.1. Findings from observation process

#	Macmillan Activities	Knowledge From	
		Architects	**Mechanical/Electrical Engineers**
6	Determining project characteristics		
7	Generating initial concepts		- Specify effect of courtyard for better distribution of daylight - Use of building shade - Specify PV panel location base on need to cool
8	Transformation/ Combination of concepts	- Design alternatives for building modules - Specify width and length of buildings	
9	Selecting suitable combinations	- Specify size of blocks of buildings - Specify space between buildings	
10	Firming up into concept proposals	- Alternative forms of design - Specify height of buildings	- Finalize PV location
11	Evaluating and choosing proposal	- Specify chosen alternative	- Rainwater catchment diagram
12	Improving detail and costing proposal		- Estimating storage tank base on roof area - Specify location of pump and water tank - Estimation of needed air condition - Cooling capacity - Estimation of needed space needed for solar requirements - Life cycle cost - Estimation operating cost saving

The structure of this knowledge-based framework for the conceptual design phase was borrowed from repertory grid (Liou, 1992; Boose, 1989-See Section 2.4.4 for more details) where rows are activities of Macmillan (2001) framework for conceptual design phase, and columns are the required knowledge for this stage. Thus, the study proposed this knowledge-based conceptual design framework as a technique to capture expert knowledge. Using this framework, project managers know what knowledge each expert needs in order to perform his/her own activity more efficiently. Finally, this framework can be used to create a user interface for a knowledge portal. Knowledge portals make an important contribution in enabling knowledge management by providing users with a consolidated, personalized user interface that allows efficient access to various types of (structured and unstructured) information. Therefore, it can be used to develop a user interface in which the required knowledge can be exchanged among experts through a knowledge portal.

6.5 Limitation of Study

This study is limited to the activities of 4th year architect students as team members of a Green building project in UPM. Data collection took place through the conceptual design phase of this project.

6.6 Knowledge Contribution

There are three knowledge contributions for this study which are stated as follows:

1- **Extending Macmillan's conceptual design framework to include explicit required knowledge during the conceptual design phase.** According to Nissen (2006), knowledge flow rest on the critical paths of workflows and the associated organizational performance. Hence, knowledge flows should be planned and managed like workflows. Macmillan (2001) framework for the conceptual design phase includes just the sequence of activities for achieving the concept design of building projects. This study had discovered the required knowledge during the concept design and provided a linkage between the steps of the existing Macmillan framework and the required knowledge. To this end, this study used detailed definitions for Macmillan's step. The proposed knowledge-based framework is displayed in Figure 6.1.

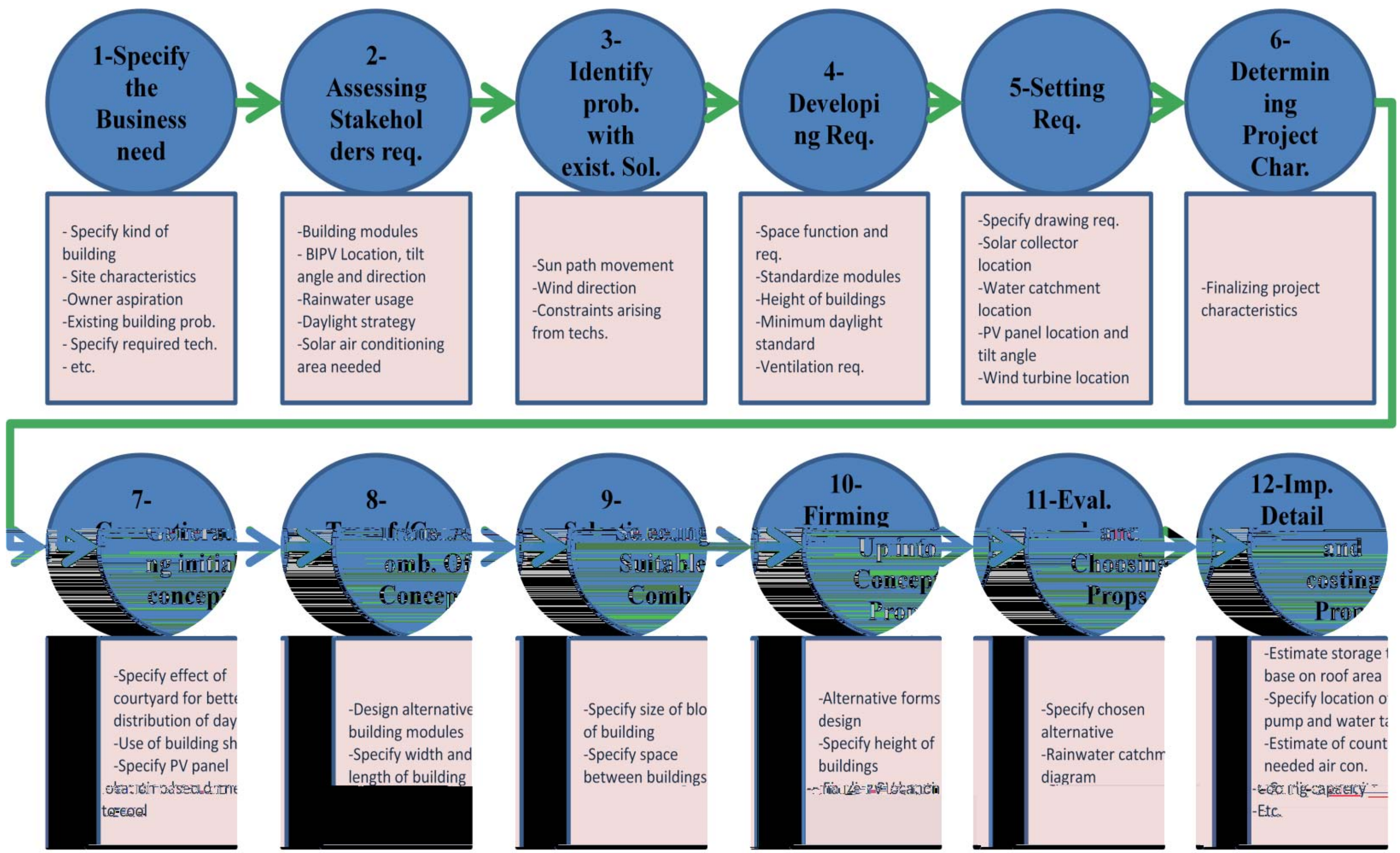

Figure 6.1. Proposed Knowledge-Based Framework for Conceptual Design Phase

2- **Developing a tacit knowledge capture technique by combining tacit observation and explicit repertory grid documentation.** The aim is simultaneous conversion of tacit knowledge to explicit knowledge. Indeed, the proposed framework of this research includes the required knowledge which has to be exchanged through each step of the concept design. For instance, specifying minimum daylight standard in the forth step of Macmillan framework ("Developing requirements" step) is essential to determining the size of spaces. Therefore, to specify the required tacit knowledge during the conceptual design phase we used observation knowledge capture technique. Then, as mentioned earlier (See 2.4.4), the structure of the repertory grid knowledge capture was borrowed to develop a tacit knowledge capture technique during the conceptual design phase. Rows of the grid indicate the activities of Macmillan (2001) framework. Columns of grid constitute the knowledge which was discovered through observing the conceptual design phase. Using this grid, the required knowledge for each step of the concept design can be captured and converted to explicit type. According to many researchers such as Nonaka (1995), tacit knowledge is difficult to share and formalize. Using the proposed technique of this research, capturing expert tacit knowledge can be facilitated during the conceptual design stage. Other researchers such as Ibrahim and Nissen (2008) found that tacitness of the knowledge can augment the probability of knowledge loss. Using the proposed technique of this study, the required knowledge is converted to the explicit type. Therefore, the probability of knowledge loss through concept design stage is reduced.

In summary, the study claims novelty on the developed knowledge-based framework for the conceptual design phase and the proposed technique to capture experts' tacit knowledge.

6.7 Benefits of Study

The knowledge-based Macmillan framework is able to:

1. Facilitate the knowledge flow during the conceptual design phase;
2. Facilitate expert tacit knowledge capture by using the proposed technique of this research;
3. Facilitate expert tacit knowledge conversion to the explicit type (formalizing) using the proposed technique of this research;
4. Speed up the flow of knowledge which arise from the explicitness of knowledge; and
5. Shorten the flow time which arise from explicitness of knowledge.

6.8 Recommendations for Future Study

This study attempted to find out the required knowledge which has to be exchanged between architects and mechanical/electrical engineers during the conceptual design phase. There are many other aspects associated with the building projects. Thus, the following studies are recommended:

1- This study attempted to propose a knowledge-based framework (See details in Table 6.1) for the conceptual design stage. A future study can be conducted to measure the efficiency of knowledge flow improvement by using the proposed framework of this study.

2- This study just focused on the interactions between architects and mechanical/electrical engineers. Many other experts from various disciplines such as the structural engineer who are involved in building project researches can study this aspect.

3- Similar researches can be conducted to discover the required knowledge through the project life cycle phase.

4- This study was conducted to discover the required knowledge for green building project. There are many different kinds of buildings such as commercial building, hospital and so on; therefore, this study can be performed for different kinds of buildings.

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APPENDIX 1

Case Study Detail For

Green Technology Park for UPM Institiut Maju (ITMA)

1. Executive Summary

This project investigates various building technologies that help reducing the impact of buildings on the environment. Through this project conceptual design for a green technology park for ITMA will be proposed. First step for the class to come up with a proposal for a technology park meant for ITMA's laboratory divisions is investigating sustainable building technologies.

For the development of the park, it is targeted that the proposal of the technology park with all the technologies investigated being used in its development. Final presentation for the proposals will be consists of 4×A0 paper, showing the site plan, floors plans, sections, elevations and 3D perspectives. Additionally, each group will produce an A4 bound report of the various technical details of the technology they focused on.

2. Background of Project

Green buildings are designed to save energy and resources, recycle materials and minimize the emission of toxic substances throughout its life cycle Green buildings harmonize with the local climate, traditions, culture and the surrounding environment. Green buildings are able to sustain and improve the quality of human life whilst maintaining the capacity of the ecosystem at local and global levels Green buildings make efficient use of resources, have significant operational savings and increases workplace productivity Building green sends the right message about a company or organization – that it is well run, responsible, and committed to the future. Green buildings make efficient use of resources; have significant operational savings and increases workplace productivity. This project investigates various building technologies that help reducing the impact of buildings on the environment.

2.1 Objectives

The objectives of this project were consists of:

- To investigate the various building technology that help reduce the impact of buildings on the environment.
- To propose a conceptual design for a green technology park for ITMA in UPM, as a showcase for implementing green technology.

2.2 Requirements

The Green Building Index is an environmental rating system for buildings developed by PAM (Pertubuhan Arkitek Malaysia / Malaysian Institute of Architects) and ACEM (the Association of Consulting Engineers Malaysia). The Green Building Index is Malaysia's first comprehensive rating system for evaluating the environmental design and performance of Malaysian buildings based on the six (6) main criteria of Energy Efficiency, Indoor Environment Quality, Sustainable Site Planning & Management, Materials & Resources, Water Efficiency, and Innovation. The Green Building Index is developed specifically for the Malaysian tropical weather, environmental and developmental context, cultural and social needs.

The GBI initiative aims to assist the building industry in its march towards sustainable development. Sustainable building technologies are consists of:

- Solar assisted air conditioning
- Wind turbine
- Daylight augmented lighting strategy
- Building Integrated Photo Voltaic system
- Rainwater harvesting and Waste management

Hence, the class divided into five groups to investigate about green building technologies.

2.3 Program

All the groups supposed to do conceptual design during 6 hours on 15 March 2010. To do data collection for this case study we recorded their activities for whole day. The groups presented their concept proposals at the end of the same day. Panels commented their proposal to lead them to improve their concepts. The pre-final presentation was on 30 March 2010 and final presentation for final judgment happened on 16 April 2010.

3. Design Milestones

As mentioned before the architects have to do some studies about required technologies. Then they have to present their findings. Tentative schedule for design process has been shown in Table 1.

Table 1- Tentative Schedule

Description	Due Date
Issue	23 Feb 2010
Brief formulation	24 Feb 2010
Technological seminars	03 Mar 2010
Design presentation	30 Mar 2010
Assessing Proposals	16 Apr 2010

4. Results

4.1 Technological studies

The class regarding the schedule presented their investigations about the technology which they have to study. Grouping detail to investigate about technologies is shown in Table 2. All the lecture sessions for this course which entails technological presentations by 5 formed groups have been recorded by this researcher.

Table 4- Grouping for seminar for Green Building Technologies

Student Name	Group No.	Technology
- Tee Khay Mee - Saiful Azam bin Azizan - Zarina BT Bachok - Ng Han Luong	1	Solar assisted air conditioning
- Haw Yoke Ah - The Soon Beng - Nurul Ain Ahmad - Mohd Faizal bin Razali	2	Wind turbine (WM)
- Gan Poh Tin - Goh Yin Chuan - Noor Adili bin Kamarudin - Mohd Safarin Savikon	3	Daylight augmented lighting strategy (WS)
- Muhammad Fairuz bin Ahamad - Loo Jie Hsin - The Min Shen	4	Building Integrated Photo Voltaic System (DD)
- Teoh Lee Moi - Tan Khang Hung - Fadzil Ikhwan bin Ismail - Daphne Lian Fang Siew	5	Rainwater harvesting and Waste management (MF)

During each presentation some photos have been taken as additional evidences for this process.

4.2 Design Process

Process of generating conceptual design is consists of 3 steps and is shown in Figure 1.

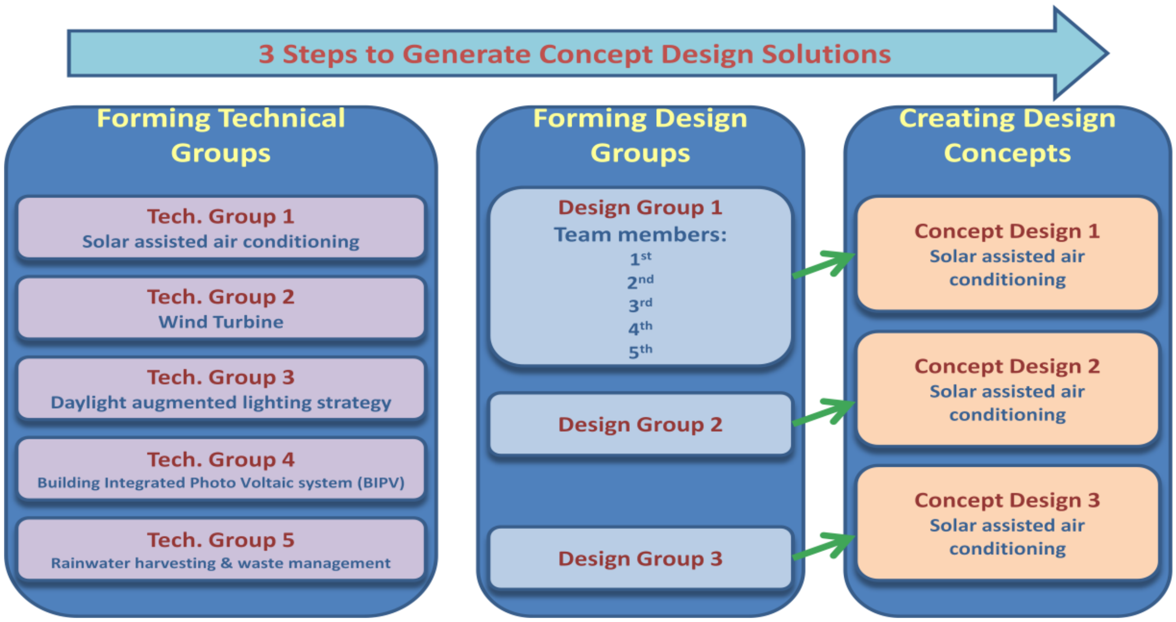

Figure 1- Process of generating design proposals

As it has shown in Figure 1 and mentioned before, the class divided into five groups to investigate about green building technologies. As it is apparent in Figure 1, next step in the process of generating proposals was forming the groups to do concept design. Each group for design purpose entails experts from all five technology groups. List of student and their expertise is shown in Table 3.

Table 5 - List of Design Groups

Name	Technological expertise	Design Group
Goh Yih Chuan	Daylight augmented lighting strategy	1
Muhammad Fairuz Bin Ahamad	Building Integrated Photo Voltaic System	
Teoh Lee Moi	Rainwater harvesting and Waste management	
Daphne Lian Fang Siew	Rainwater harvesting and Waste management	
Zarina BT Bachok	Solar assisted air conditioning	
Ng Han Luong	Solar assisted air conditioning	
Mohd Faizal bin Razali	Wind Turbine	
Noor Adili bin Kamarudin	Daylight augmented lighting strategy	2
Loo Jie Hsin	Building Integrated Photo Voltaic System	
Tan Khang Hung	Rainwater harvesting and Waste management	
Saiful Azam bin Azizan	Solar assisted air conditioning	
Haw Yoke Ah	Wind Turbine	
Gan Poh Tin	Daylight augmented lighting strategy	3
Mohd Safarin Savikon	Daylight augmented lighting strategy	
The Min Shen	Building Integrated Photo Voltaic System	
Fadzil Ikhwan bin Ismail	Rainwater harvesting and Waste management	
Tee Khay Mee	Solar assisted air conditioning	
The Soon Beng	Wind Turbine	

As it is apparent each group entails experts from different technology study groups. In this way, each group at least has one member from each expertise associated with Green Building requirements. More details about groups' activities to produce concepts explain in the follow.

4.2.1 Group 1

Detail of performed activities for this group has been shown in Table 4. Left side column is the number of recorded video for group activities and next column is for description of performed activities by architects. Whereas architects through the concept design stage mostly were drawing, therefore through an informal conversation we asked them to explain what they were doing.

Table 4- Detail of Group 1 activities for concept design

Video Segment Refer No.	Activity Description
22	- Talking about boundaries of site - Is there enough space required blocks and buildings? - What kind of strategy they want to choose
24	- Deciding about kind of approach to design. It can be crazy design, but this is a real project.
27	- Identifying what kind of the space is required - What they want to put inside the site - Discuss about the spaces - Organization of the layout
31	- Kind of form - How they want to put the buildings inside the site to use maximum daylight - Which direction is optimum to put PV (No east-west. From south is ok)
33	- Need to do more research to find better direction - Discuss about exist labs, exist machines inside the labs and etc.
38	- Make decision about putting each lab on which space regard to their function and regard to the condition of existing labs.
44	- Specifying kind of sections - Drawing sections - Choosing daylight strategy regard to the sections (side light rather than top lighting - Glare problem
47	- Try to fit layout regard to the condition of the site such as Slope and Exist trees - Try to leave more space in the site to catch rainwater - Try to capture max. lake view - Try to use green trees (sustainable strategy) - Schematic layout- not considering function yet - Drop off, loading(estimation), circulation
55	- Providing 3d model for sketches to provide best view and outlook of the building. After doing this if they found that its outlook is not good maybe they change it.

60	- Explaining time management
62	- Try to think about rainwater harvesting system - How this system work in ITMA project : (1) collecting rainwater, (2) store in tanks, (3) clean the water to use for flush toilet or landscape
77	- Discuss about daylight strategy (light shelf/shading/green spine) - Organization of all the strategy locations (solar assisted tube and PV) - How put all strategies together?
82	- Layout done with all proposed strategies - Team members attempt to combine and arrange drawings for presentation
87	- Finalize the design to present - Solar assisted tube on the roof - PV on the roof (green spine roof) - Rainwater system underground - Specify the lab locations regard to their size and function - Try to fix space for labs - Adjust shape and size to fix the function - Specify the location for rainwater storage tank/pump - Specify location of tanks underground of each building / labs - Discuss about solar assisted air conditioning systems - Adjustment for solar evacuated tube (rough calculations- required area=900 m2
109	- Discuss about the material to be used

4.2.2 Group 2

In this section we explain about 2nd group activities. Regarding records through our informal conversation we found out that they have had an approach to concept design. According their explanation their approach has been shown in Figure 2.

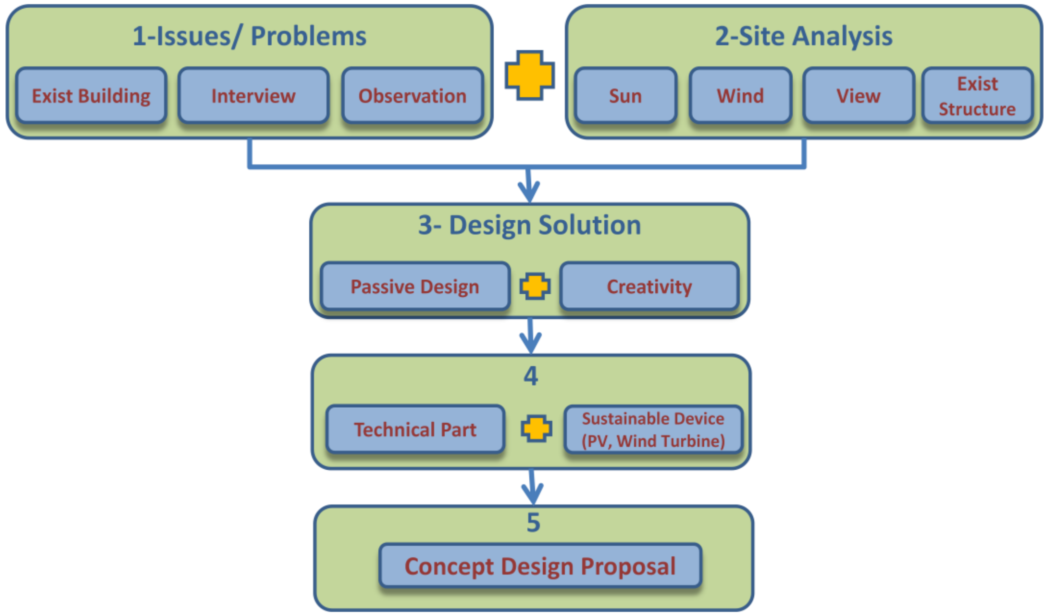

Figure 2 - 2nd Group Approach to Concept Design

Detail of performed activities for 2nd group has been shown in Table 5.

Table 5 - Detail of activities for concept design by 2nd group

Video Segment Refer No.	Activity Description
18	- Analyzing sun path diagram, wind direction and views as important issues to specify building orientation
19	- Doing passive design
28	- Discuss about spaces planning, lobby and their sizes
37	- Discuss about space requirements - Site analysis design - Technology for form design - Acknowledge existing issues and problem, find better solution
53	- Make decision about technology requirements - Building Integrated Photo Voltaic system (BIPV) - Solar air conditioning system - Wind turbine - Rainwater harvesting, waste management system - Daylighting
80	- Discuss about office module and labs - Discuss about Building Integrated Photo Voltaic system alternatives - Discuss about rainwater usage (for filtration, landscape, shading device, cool

	down roof); why they want to catch rainwater and where they want to use it - Daylighting- clerestory sky light- light shelve - Wind turbine location (on top floor), locate at cooling tower (because it can generate wind to help turbine) - Space function and requirements - Standard module - Natural daylighting and ventilation requirement - Site issues , solar bowl - Space info acquired - Design process design - Solar bowl to generate electricity - Indoor or outdoor environment for labs, roof provision - Contour issues and utilization - Use typical modules for office labs*5 - match building with the existing solar bowl
85	- Marking guidelines (give value percentage for each subject in design)
88 **89**	- Specify drawing requirements - Diagrams - Plan - Section - Elevation - Concept
90	- Recognizing that East-west oriented gets more heat and daylight - Provide courtyard for better distribution of daylight (self shaded courtyard by buildings) - Specify BPIV (Building Integrated Photo Voltaic) location, vertical PV solar panel - Discuss about wind turbine location - Recognize low wind on the ground and high speed wind on top - Solar assisted turbine air conditioning need heat - PV (providing electricity)need cooling (so it should be cooling down) - Recognize that solar assisted air conditioning and PV cannot put together
91	- Inspecting PV efficiency for light shelves and shading devices and recognizing that the answer is negative - Design module alternatives
97	- Inspecting circulation for main access and services
98	- Relocate trees and landscapes
99	- Specify size for labs, width and length - Daylight rule of thumb
103	- Try to size building based on paper cut
104	- Standardized space size
111	- Design alternative forms for labs and office
116	- Decide that PV will be located on the roof - Section design
120	- Specify height of office and labs and double volume requirement
125	- Plan drawing - Draw the diagram for rainwater catchment
126	- Section drawing

127	- Estimation for rainwater harvesting system - Calculating water storage tank size based on roof area - Specify location of pump and rain water tank

4.2.3 Group 3

Activity of this group such as other groups was observed and recorded. Like what we did for 1st and second groups we did informal conversation with 3rd group team members to discover detail of their activities to perform concept design. Detail of their activities is shown in Table 6.

Table 6 - Detail of activities for concept design by 3rd group

Video Segment Refer No.	Activity Description
14	- Calculation for devices - Estimating return period for cost - Daylight construction
15	- Need to know gap size between the building for ventilation and daylight (by research) - Talking about room, labs and office size requirement
17	- Structure - Loading - Size of blocks
20	- Orientation of blocks - Gap between the buildings - Building setback (services and fire break)
25	- Explaining calculation for PV panels
26	- Talking about sun orientation
29	- Discuss about gap between buildings
30	- Central circulation spine
32	- What kind of experiment and machine will be used in the labs - Function of spaces
34	- Size of building blocks - Number of blocks need to reduce
35	- Making decision about used techs. - Discuss about orientation of the building to catch more daylight to reduce active

	system
45	- Discuss about building height, 2-3 storey
49	- How they want to orient the blocks
51	- Talk about car park
56	- They have done the massing, orientation and size. Now they want to pass design to mechanical experts and other ones.
57	- Explaining justifications for performed design - They are talking about circulation, car park, strategies, views and focus point. They are explaining their design for other team members - Concentrate building rather than scatter building blocks, because they need open space to catch rainwater
58	- They were talking about rainwater catchment(more space is better for it), natural ventilation and natural daylight problem with exist design(because of lots of number of blocks)
59	- Again talking about rainwater catchment system - They want to put tanks to store rainwater under the earth and therefore need more empty space in the site - They have accepted that exist design (so far) is not proper for this purpose
63	- Talking about orientation of the buildings
64	- Talking about building height - Try to connect the blocks through a bridge or roof garden
65	- By using higher buildings in west side they can provide good shadow from west(in the evening) on the centre space - Proposing roof garden for connecting the buildings
66	- Explain about strengths of new design over old design (orientation and daylight gain)
67	- Repeat building orientation regarding the stated problem from technical members
71	- Design changed because they have a lot of blocks - They have to design with passive design approach - They need to integrate rainwater catchment system and ventilation requirements(such as required gap between buildings
72	- Discuss on how to make whole buildings efficient in order to bring in daylight - Discuss about proportion between allocated spaces and gaps
73	- Whether building fulfills requires space or not
74	- Explain how the design should be - Talking about space planning - What has to be on the ground and what on top floors - What between buildings
76	- Clarifying boundary of site by coloring
81	- They did not consider slope in their design (just a little- hence site analysis has not done completely)
86	- They completed section of building and conception - Talk about what they need for presentation - What is good about their design - Try to find what is strong point in their design to say in their presentation
92	- Look at the actual lab on the photo and size of machines - They found out that exist labs can be a reference (Now it's a little tight) - They try to optimize exist problems (its tight and not enough space for students) - Try to solve problems in exist buildings
96	- Try to identify the most suitable main entrance and loading entrance
105	- Try to connect the solar bowl to the building by having green spine from the solar bowl straight to building courtyard

110 **113**	- Playing with the shape - How the shape should be looked in proportion
117	- Redefine the shape
118	- Drawing diagram of how building respond to the sun light
119	- Sun respond diagram
122	- Try to identify which space for which requirement(labs / office) regarding the required size
124	- Coloring – make design presentable

4.3 Assessment

All three groups competed to propose the concept regarding technical and architectural requirements. Assessing proposals was based on some has been summarized in Table 7. Assessment procedure is explained in the next section.

Table 7 - Summary of Assessing Factors for Concepts

Items	**Item Description**	**Score**									
		Very Poor		**Poor**		**Ok**		**Good**		**Very Good**	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Design Concept and strategy	Overall concept and design										
Building Form	In response to the site dynamics and orientation										
Technological Design	Incorporation of technology into overall design concept. Technical component sizing and location										
Architectural aesthetics	Form, spatial quality, visual clues, etc.										
Presentation	Boards layout, thematic, clarity, animation, perspective, 3D, sketches.										

5. Assessment Procedure

As mentioned in tentative schedule, final presentation for judgment was on 16 April 2010. Judgment was performed regarding aforementioned assessing factors. Completed forms by panel have been attached to this report (appendix III). In the procedure of assessing groups conducted an exhibition from their proposals. They supposed to present their work just in five minutes. Then, the panel has 30 minutes to inspect proposals and ask probable questions from groups about their justifications about considerations. Then they marked the proposals. Results of assessment regarding assessing factors and 5 panel member judgment have been summarized in Tables 8 & 9.

Table 8- Assessment Results' Detail

Assessment		Group 1		Group 2		Group 3	
Factors	**Assessor**	**Score**	**percentage**	**Score**	**percentage**	**Score**	**Percentage**
Design concept and strategy	1	8	16%	10	20%	3	6%
	2	9	18%	9	18%	8	16%
	3	6	12%	8	16%	6	12%
	4	8	16%	9	18%	9	18%
	5	8	16%	7	14%	7	14%
Building form	1	7	14%	10	20%	4	8%
	2	9	18%	9	18%	9	18%
	3	7	14%	9	18%	6	12%
	4	8	16%	9	18%	7	14%
	5	8	16%	7	14%	7	14%
Technological design	1	9	18%	9	18%	5	10%
	2	8	16%	8	16%	8	16%
	3	7	14%	7	14%	7	14%
	4	8	16%	8	16%	7	14%
	5	9	18%	7	14%	7	14%
Architectural	1	7	14%	7	14%	6	12%

aesthetics	2	8	16%	8	16%	8	16%
	3	7	14%	9	18%	7	14%
	4	6	12%	8	16%	6	12%
	5	8	16%	8	16%	7	14%
Presentation	1	9	18%	7	14%	7	14%
	2	9	18%	8	16%	8	16%
	3	8	16%	9	18%	7	14%
	4	8	16%	9	18%	8	16%
	5	8	16%	8	16%	6	12%

Table 9- Final Results of assessment

	Overall Score					Average
Groups	Assessor 1	Assessor 2	Assessor 3	Assessor 4	Assessor 5	
Group 1	80%	86%	70%	76%	82%	79%
Group 2	86%	84%	84%	86%	74%	**83%**
Group 3	50%	82%	66%	74%	68%	68%

Then, they had a meeting to discuss and vote for choosing winner concept. Finally, they acclaimed 2nd group as winner group. As it is apparent in Table 9 regarding the average earned marks by groups 2nd group has the highest mark. This result shows that voting and calculations produced the unique result for this competition.

6. Design Proposals

In this section we have some photos from Board layout for 3 proposed concepts which have been presented is final session.

Figure 3 - Final presentation Green Spine (1st Group)

Figure 4 - Final presentation Green Sprawl (2nd Group)

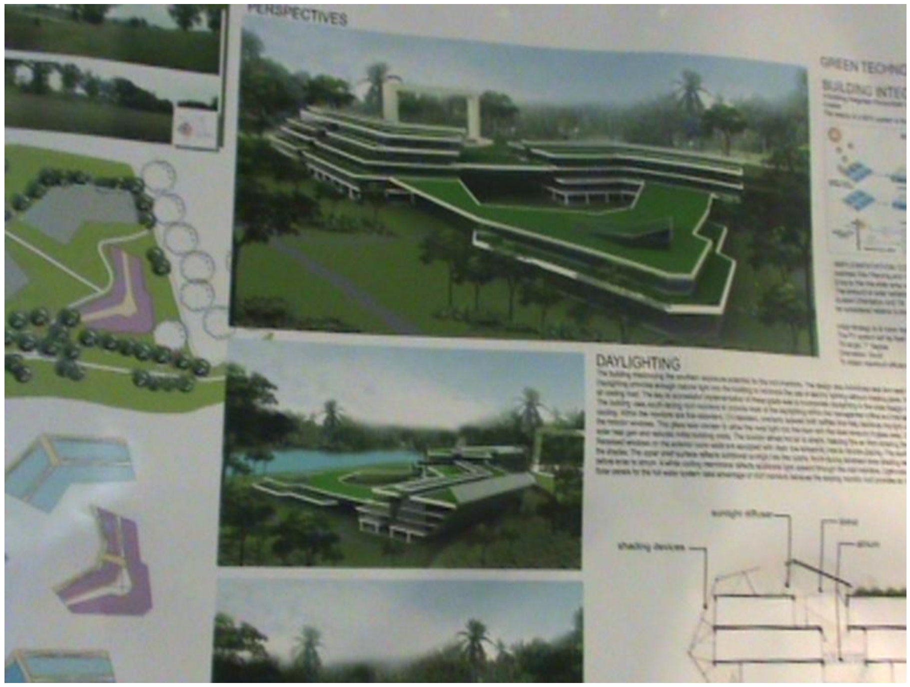

Figure 5 - Final presentation Reciprocal lab (3rd Group)

7. Conclusion

As it is apparent in Table 9, second group proposal was chosen as the best proposed concept. Hence, we focused on the activities of 2nd group for analyzing and interpreting collected data. Regarding this issue we tried to explain approach of 2nd group to concept design schematically in Figure 6.

After collecting data we needed to transcribe recorded videos to discover the exchanged knowledge through the performed activities by group members. The followed steps to collect and interpret data have been shown in Figure 6.

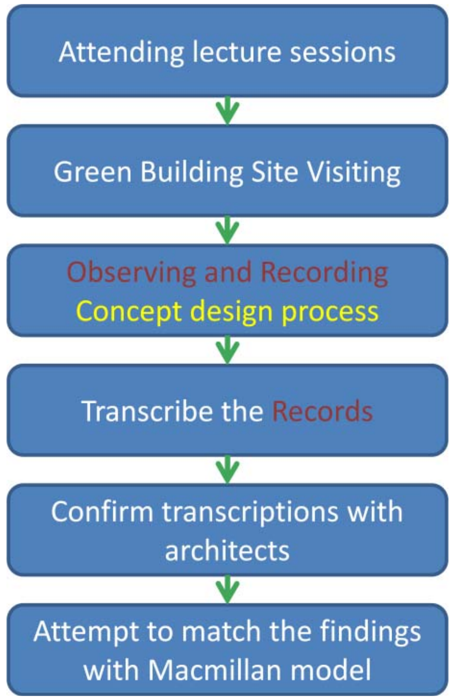

Figure 6- Steps to Collect and Interpret Data

Whereas most activities through design stage is drawing and calculating, to confirm transcribed data we tried to discuss with architects. Then, regarding the selected methodology for this study we used pattern matching method. As mentioned before Macmillan framework for conceptual design stage has been chosen to match performed activities by design groups and predefined activities for conceptual design by Macmillan. Provided match between performed activities by groups and Macmillan framework for conceptual design stage has been shown in the follow.

APPENDIX 2

PUBLICATIONS

Pourzolfaghar, Z., Ibrahim, R., Abdullah, R., Adam, N. M. Potential Technique for Capturing Building Design Tacit Knowledge to Decrease Cost and Time Overruns. Submitted to 10th European Conference on Research Methodology for Business and Management Studies (ECRM 2011), In Press.

Pourzolfaghar, Z., Ibrahim, R., Abdullah, R., Adam, N. M., Abang Ali, A. A., Green Technology Park for UPM Institiut Maju (ITMA): A Case Study to Capture Mechanical and Electrical Tacit Knowledge during Conceptual Design Phase of Building Projects, Technical Report Ref. UPM/FRSB/EDI/TR4, June 2010.

ONGOING PUBLICATIONS

Pourzolfaghar, Z., Ibrahim, R., Abdullah, R., Adam, N. M. Developing Knowledge-Based Framework for Conceptual Design Phase for mitigating Knowledge-Loss through a building lifecycle (Design Studies, In review).

Pourzolfaghar, Z., Ibrahim, R., Abdullah, R., Adam, N. M. Development of a knowledge capture technique for use in a Tacit-Dominated lifecycle phase of a discontinuous enterprise (KMRP, In review).

Pourzolfaghar, Z., Ibrahim, R., Abdullah, R., Adam, N. M. Impacts of Adding Knowledge Flow to an Activity-Based Framework for Conceptual Design Phase on Performance of Building Projects(IJKM, In review)

BIODATA OF STUDENT

Zohreh Pourzolfaghar Ph.D. received her doctoral degree in Project Management from Universiti Putra Malaysia. She received the M.Sc. in Industrial Engineering, Management System & Productivity from Industrial Management Institute, Tehran branch in 2007. Her Master's thesis was titled "Motivational Model for Team Working in Project Management". She also received B. Sc. In Software Engineering from Azad University, Mashhad branch in 1995. Pourzolfaghar worked for 6 years in hardware, software and network field. She also worked 3 years as software programmer and also 6 years as teacher in the field of computer software. Pourzolfaghar regarding her M.Sc. degree worked 5 years as a control manager in several private consulting and construction companies. She had two research projects for Xenix and Unix operating systems, involving in theoretical and practical aspects of these operating systems.