A FRAMEWORK MODEL FOR MANAGING THE BUILDINGS COMMISSIONING PROCESS

BY

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TO ALL MY FAMILY MEMBERS

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All praise is due to Almighty Allah, whom we praise, and from who seek help and ask forgiveness. Peace and blessings of Allah be upon his slave and his Messenger, Prophet Muhammad, his family, and his companions.

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LIST OF ABBREVIATIONS

ASHRAE: American Society of Heating Refrigeration and Air-conditioning Engineers

CC®:	Continuous Commissioning®
Cx:	Commissioning
CxP:	Commissioning Provider
EMCS:	Energy Management and Control System
GSA:	General Services Administration
HVAC:	Heating, Ventilation and Air-conditioning
IAQ:	Indoor Air Quality
IEQ	Indoor Environmental Quality
LEED®	Leadership in Energy and Environmental Design
MBCx	Monitoring-Based Commissioning
M&V	Measurement and Verification
O&M	Operations and Maintenance
OOR	Owner's Operating Requirements
PM	Preventive Maintenance
RCx	Retro commissioning
ReCx	Re-commissioning
RFP	Request for Proposals
RFQ	Request for Qualifications
TAB	Testing, Adjusting, and Balancing

ABSTRACT

Full Name : Qaid Mubarak Hadhbool

Thesis Title : A Framework model for managing the buildings Commissioning Process

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Abstract: Commissioning new buildings and retro-commissioning existing construction facilities are becoming a quality assurance measure in the construction industry in many countries. The term building commissioning has gained great attention worldwide. The commissioning process enhances communication among the project team members that help to identify problems early and prevent issues from developing. Despite the huge development of the building construction industry in Saudi Arabia, there is a very little information available about the procedure of commissioning service and their benefits. The main objectives of this research are to investigate the current practice of building commissioning, and to develop a potential framework for procuring commissioning services on building construction projects, and to assess the applicability of the developed framework which implements the commissioning process on building construction projects in Saudi Arabia. Interviews were carried out with several project managers at five Saudi Arabian Universities to investigate the using of building commissioning in the educational' buildings. Framework model for building commission was developed based on knowledge from the international literature, observed professional practice and the current practice in Saudi Arabia. The assessment of the identified commissioning process is critical to investigate the applicability of the developed framework. The identified commission processes were assessed through distributing the questionnaire survey to representative sample of owners\managers, architects, and engineers in the largest cities in Saudi Arabia. The assessment results confirm the importance of the identified building commissioning process where all processes were assessed either important or extremely important. The developed framework can be applied locally in Saudi Arabia and can be updated according to the type, size, and complexity of the project.

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ملخص الرسالة

الاسم الكامل: قائد مبارك فرج هذبول

عنوان الرسالة: إطار عمل نموذجي لادارة عملية التشغيل التجريبي لانظمة المباني

التخصص: هندسة وادار التشييد

تاريخ الدرجة العلمية: محرم 1435 هجرية

أصبحت عملية التشغيل التجريبي لانظمة المباني مقياساً هاماً لضمان الجودة في صناعة البناء والتشييد في العديد من البلدان، وقد اكتسبت هذه التجربة أهتماما واسعا في جميع أنحاء العالم. لقد اشارت الدارسات الحديثه ان التخطيط المبكر لهذه العمليه يعزز التواصل بين أعضاء فريق المشروع مما يساعد على تحديد المشاكل في وقت مبكر ومنع حدوث الكثير من الاوامر التغييرية في المراحل الأخيره للمشروع. على الرغم من التطور الكبير في صناعة البناء في المملكة العربية السعودية، إلا انه ليس هناك الكثير من المعلومات المتاحة عن هذه العملية وكيفية تطبيقها. تتمثل أهداف هذه الاطروحة إلى التعرف على التجربة الحاليه للجامعات السعودية في استخدام هذه العملية لتحسين اداء المباني والتغلب على معظم المشاكل التي تواجها بالإضافة الى تطوير إطار عمل يساعد على تطبيق هذه العمليه بالشكل الصحيح من بداية المشروع وحتى مرحله التسليم النهاية للمشروع. ولتحديد مدى اهميه اطار العمل وتحديد مدى قابليه تطبيقة في المملكه العربية السعودية تم توزيع استبيان الكتروني على عدد من ملاك المشاريع ومدراء المشاريع وعلى عدد من المهندسين في المنطقة الشرقية والرياض وجده. توكد نتائج الاستبيان على أهميه المهام المعرفة في اطار العمل حيث قيمت المهام اما "مهم" او مهم جدا بقوه". ومن ذلك نستنتج ان اطار العمل المقترح يمكن تنفيذه في المملكة العربية السعودية كما ومن الممكن تحديثه حتى يتناسب مع حجم ونوع كل مشروع.

درجة الماجستير في العلوم
جامعة الملك فهد للبترول والمعادن
الظهران, المملكة العربية السعودية
محرم ١٤٣٥

CHAPTER 1 INTRODUCTION

1.1 Background

Most of the existing buildings have many problems with the performance and operations of the systems, as well as many structural and electrical problems. A building that performs poorly can have many other consequences. It can result in excessive repair and replacement costs, employee absenteeism, indoor air quality problems, increased construction team liability, and unnecessary tenant turnover which in turn cost building owners, employers a lot of money each year. However, there is one process that can help ensure that many of these problems can hopefully be avoided. That process, known as building commissioning, is a quality-assurance process that increases the possibility that a newly constructed building will meet owner requirements (Claridge, 2003).

A study of 60 commercial buildings indicated that more than half suffered from control problems, 40% had heating, ventilation and HVAC equipment problems, 15% of the buildings had missing equipment, and 25% had energy management systems problems (Energy, 2005). Another study by the Energy Center of Wisconsin (1998), found that 81% of building owners surveyed encountered problems with new heating and air conditioning systems (Claridge, 2003).

Building commissioning as a general term is the quality assurance process which aims to ensure that the building performance will meet the owner's requirements. Building commissioning is not an additional phase of the building process, but runs in parallel with the phases in the building process (Grondzik, 2009). Currently, USA, Canada. China,

Hong Kong, and the United Kingdom are the countries that have issued guidelines, standards, publications and research reports on the subject (HKBCcC, 2006).

Several issues will be discussed in this thesis including the concept of building commissioning, the benefits of building commissioning in building construction projects, cost of commissioning, and international practices of building commissioning as well as the current local practice.

This chapter presents the background for the research subject along with the problem statement, the objectives, the significance of the study, it's scope and limitation and the structure of the thesis.

1.2 Statement of the Problem

Building systems are becoming more complex than before and are continually developing. The construction industry is continually striving to keep up with these changes to meet the needs of owners who expect more out of their buildings than ever before. Unfortunately, many owners are finding that they are not getting the desired performance they expect from their buildings (Energy, 2005).

Despite the huge development of the building construction industry in Saudi Arabia, there is very little information available about the procedure of the commissioning service as well as a lack of detailed guidelines for managing the building commissioning process. Direct implementation of the commissioning process according to international practices may not be practical for the local industry.

Some of the questions that will be highlighted in the research include the following:

- What is the concept of building commissioning?
- What are the benefits that can be achieved by using building commissioning?
- What is the current local practice of building commissioning and how can it be improved to keep up with the rapidly developing construction industry?

1.3 Research Objectives

The main objectives of this study are:

a) To investigate the current practice of building commissioning in Saudi Arabia.

b) To develop a potential framework for procuring commissioning services on building construction projects in Saudi Arabia.

c) To assess the applicability of the developed framework which implement the commissioning process on building construction projects in Saudi Arabia.

1.4 Significance of the Study

The importance of this study arises from the fact that no researches have been done to comprehensively evaluate the commissioning process in building construction projects in Saudi Arabia. Additionally, this research will look into the methodology of the commissioning that the building construction industry in Saudi Arabia uses in practice and compare that with current guidelines as well as the best practice to keep up with the rapidly developing construction industry, as well as to maximize the benefits of the commissioning process. The findings of the study will be directly relevant and applicable to building projects in Saudi Arabia. Also, the outcome of the study could be used in future research in this area.

1.5 Scope and Limitations

This research will help to identify the current practice of using building commissioning in Saudi Arabia, and to develop a potential framework for managing this service.

There are some limitations of this work which are mentioned here:

- The study will be limited to the building construction projects in Saudi Arabian Universities. To have a focus group, the preliminary survey and information collection is limited to university projects, because the number of universities has increased and there are huge developments in construction projects in the university cities.
- The study will be limited to the building commissioning process of the new construction projects.
- The development of the framework will be limited by the previous studies, best practices, international guidelines and the current practice.

1.6 Organization of the Thesis

The thesis is divided into seven chapters to achieve the main research objectives. The first chapter gives general background information about building commissioning, a statement of the problem, the research objectives, and its scope and limitations. Chapter two summarize the literature related to building commissioning. Chapter three presents the research methodology. Chapter four presents a comprehensive coverage of local current practices of the commissioning process in Saudi Arabian universities. Chapter five presents a development of the framework for identifying the main commissioning process and functions that should be carried out during the life cycle of the project. Chapter six presents the analysis of the data received from experts about the new framework. Chapter seven presents the conclusions and summary of the study and recommendations for future studies.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter covers the literature related to the objectives of this thesis. The areas covered include: the project life cycle, the closing phase, definitions of commissioning, previous studies about commissioning, what building commissioning can do and cannot do, types of commissioning, the commissioning team, the commissioning process, commissioning documentation, commissioning costs, and the general benefits of commissioning.

2.2 The project life cycle

The project life cycle is a collection of the project phases, in which each project is divided into several phases to provide better management control and appropriate links to the on-going operations (PMI, 2008).

The project life cycle assists in the performance of the following activities:

- To outline the beginning and the end of a project.
- To explain what technical work should be done in each phase and who should be involved in each phase.
- To draw up a description for the activities that may be very general or very detailed.

According to the project management institute (2008) all the project can be divided into the following project life cycle structure (see Figure 2.1):

- Starting the project
- Organizing and preparing.
- Carrying out the project work
- Closing the project

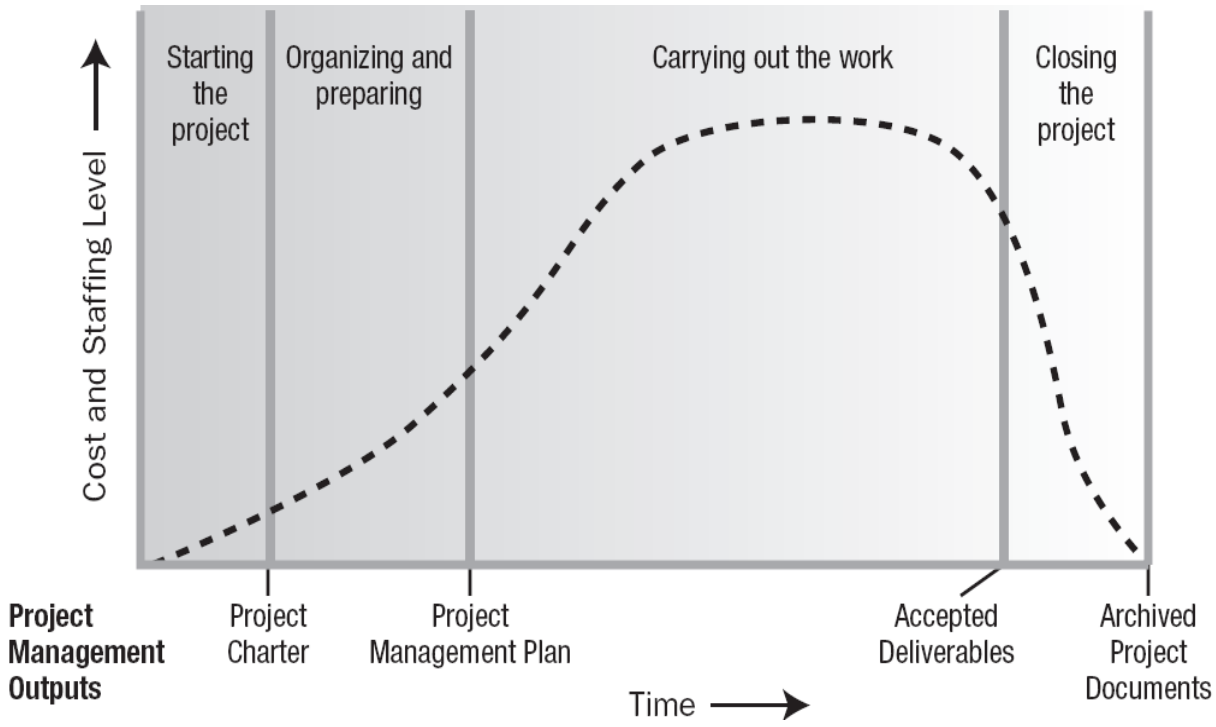

Figure 2.1: typical cost and staffing level across the project life cycle (PMI, 2008)

2.2.1 Process groups

There are many steps in the project management processes starting from the beginning of the project and going through to the project termination. The processes are concerned with describing and organizing the work of the project. They are applicable to most projects, most of the time.

The process groups are divided into five categories known as project management processes groups as shown in Figure 2.2 (PMI, 2008):

1. **Initiation processes**. Those processes implemented to recognize the new project or phase that should be begun.

2. **Planning processes**. Those processes implemented to identify the owner's project requirements and to improve the objectives of the work.

3. **Executing processes**. Those processes performed to coordinate human and other resources to carry out the plan.

4. **Monitoring processes**: Those processes necessary to review and control the progress of the project to ensure that project objectives are according to the project plan and specifications, and to take corrective action when necessary.

5. **Closing processes**: Those processes implemented to terminate all activities to formalize acceptance of the project or phase.

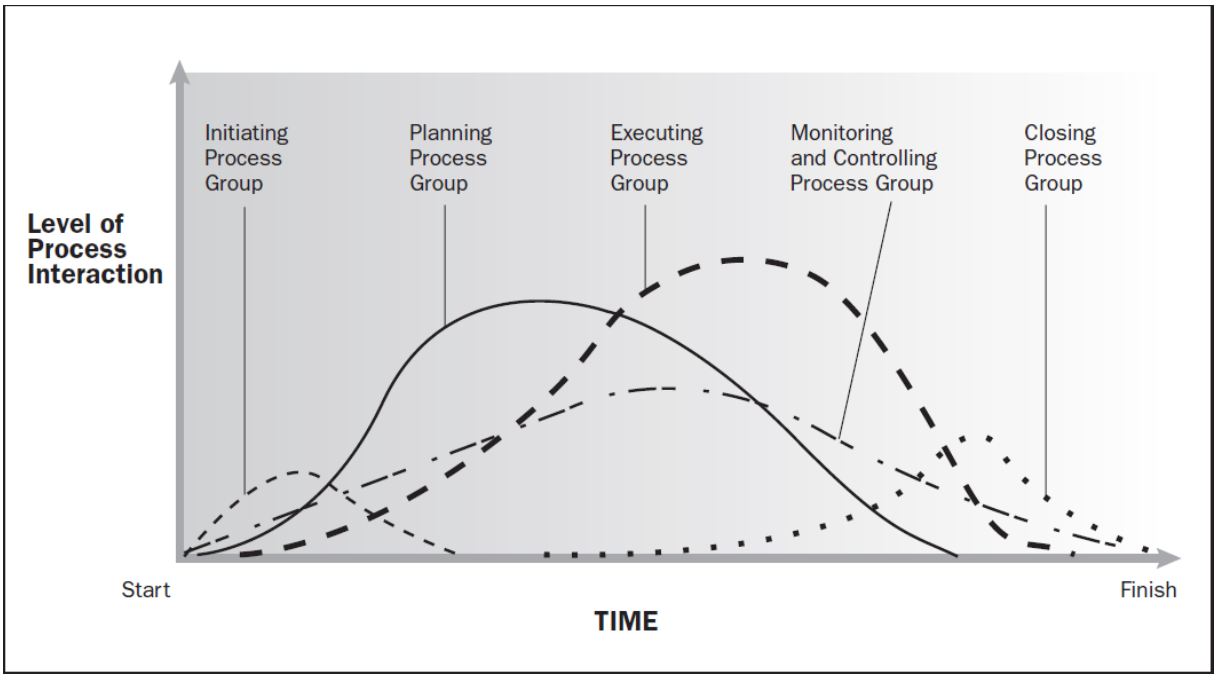

Figure 2.2: process groups interact in a phase or project (PMI, 2008)

2.3 Closing the project

Closing the project is as important as project startup. Experience shows that many projects are delayed due to lack of proper project closing procedures. Project closeout is defined as "the period of construction that provides the systematic transition of the project to the owner until the cessation of all construction activities on the project site" (Geren, 2012). The closing process includes the following detail processes (Duncan, 1993):

- Scope verification. These processes to ensure that the project deliverables have been completed according to specifications and the owner project requirements.
- Contract close out. Those processes are the completion and settlement of the contract, including resolution of any unresolved items.
- Project closure. Those processes consist of verifying and gathering project results and information to formalize the project completion.

The project closeout can be divided into a two phase process: the pre-substantial completion phase and the post-substantial completion phase (as shown in figure 2.3). The following paragraphs provide a description of the activities involved (Geren, 2012):

The pre-substantial completion phase: The pre-substantial completion phase is the period of build up to the handover of the project from the contractor to the owner. Individual tasks that must be accomplished during this phase include the following (Geren, 2012):

- Starting, testing and adjusting.
- Demonstration and training.

- Commissioning.
- Cleaning.
- Removing temporary facilities.
- Operation and maintenance date preparation.
- Substantial completion inspection.
- Reporting the recording of documents.

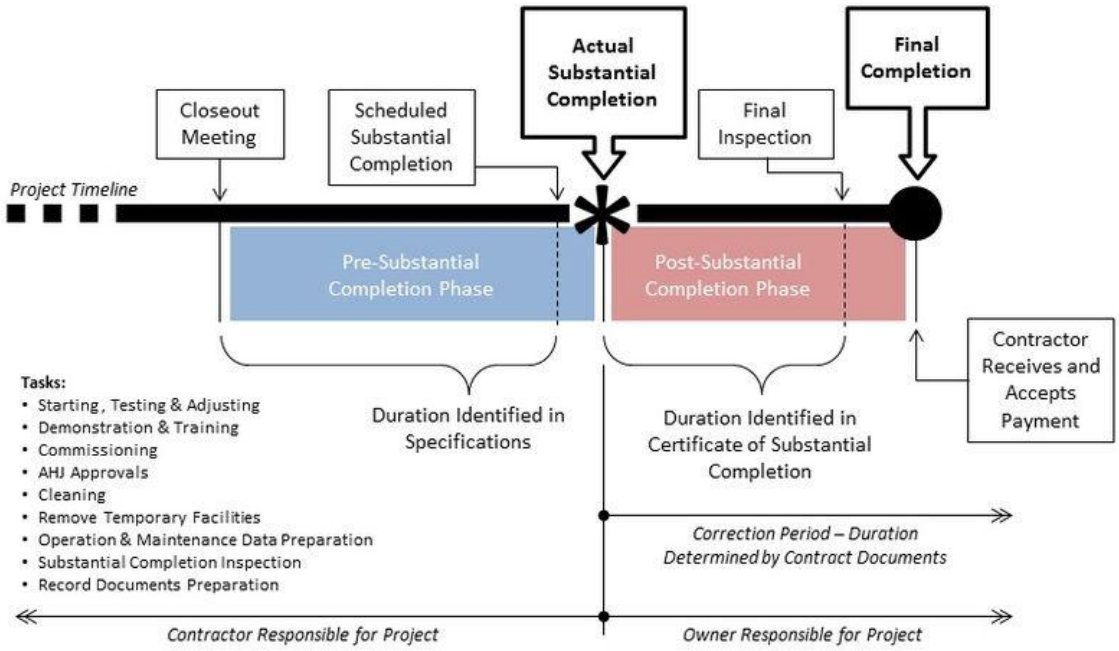

Figure 2.3: the project closeout process (Geren, 2012)

The post-substantial completion phase: at this phase, the owner has taken occupation and most of the closeout activities have been accomplished. Most of the items that must be accomplished during this phase include the following:

- Completing the deficiencies items by the contactor.
- Conducting the final acceptance.

- Conducting the final payment.

2.4 The building commissioning

Commissioning new buildings and retro-commissioning existing construction facilities are becoming a quality assurance measure in the construction industry in USA and many countries (Alzarka, 2009). Before and up to the 1990's, the project team consisted of only six different parties and buildings were not as complex as today (Figure 2.4), mostly because the performance level and energy efficiency were not as high. After 1990's the number of parties increased to ten because of the complexity of the building systems and the owner requirements. An increase in the project team members resulted in poor coordination between them, lost information, costly changes in orders and delays of project schedule as shown in Figure 2.5 (BCA, 2011).

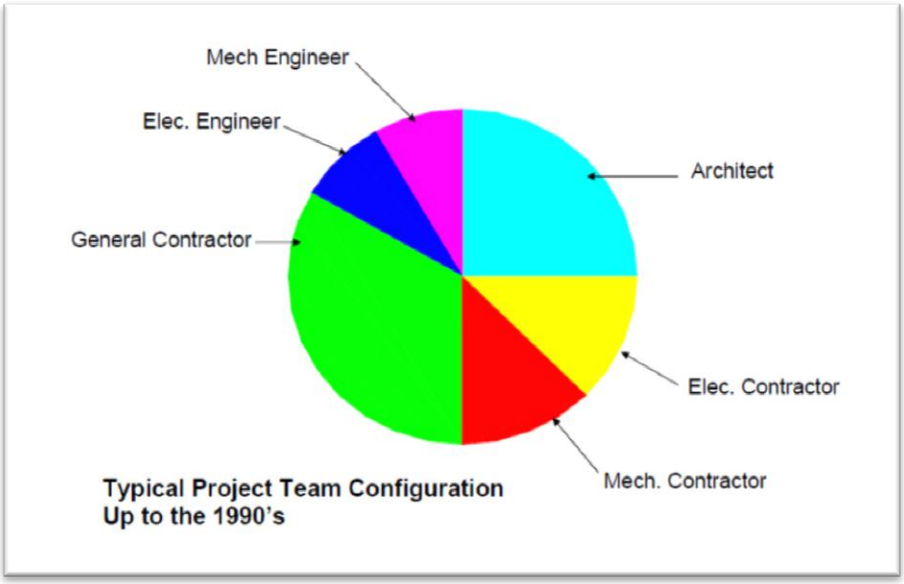

Figure 2.4 shows a typical project team configuration up to the 1990's (BCA, 2011)

One of the reasons to use commissioning in the building industry is that owners have started to realize how building commissioning can bridge the gap between the project

team members by encouraging an increase in communication, documentation and co-operation as shown in Figure 2.6 (BCA, 2011).

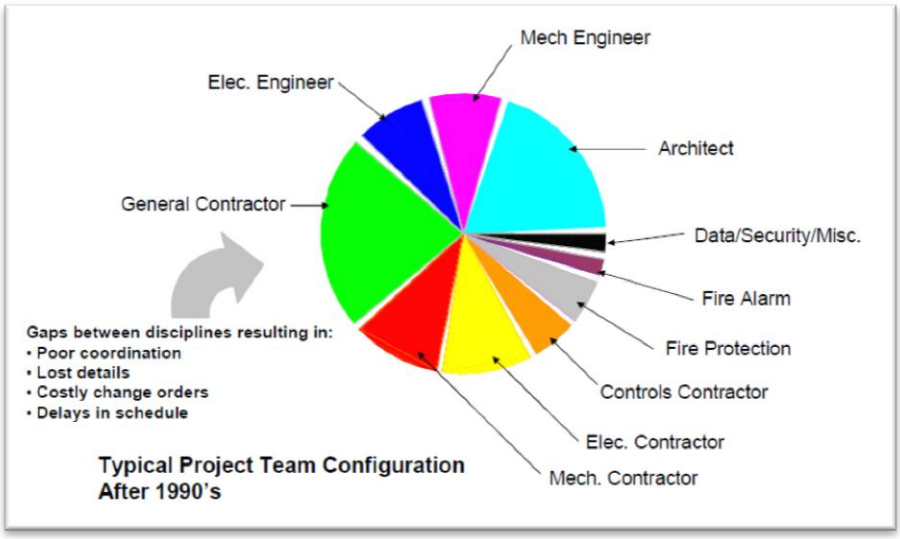

Figure 2.5: shows a typical project team configuration after 1990's (BCA, 2011).

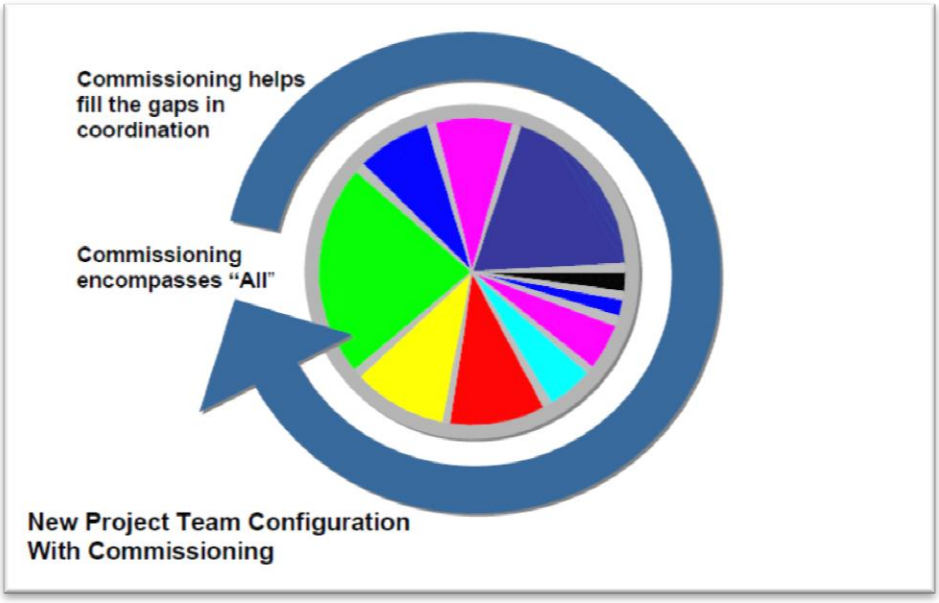

Figure 2.6: shows how commissioning can bridge the gap between project team members (BCA, 2011).

The commissioning process activities should be implemented during the pre-substantial completion phase of the project closeout. Commissioning typically is a quality-assurance process that increases the possibility that a newly constructed building will meet owner requirements (Claridge, 2003). To realize more benefits of the commissioning process it is important to start the commissioning early in the conceptual design phase of a new building and to continue it through the design phase, construction phase, start-up, occupancy, and the first year of operation (Agustsson, 2010). The commissioning process enhances communication among the project team members which helps to identify problems early and prevents issues from developing.

The recent studies about the commissioning services indicated that when the commissioning process is highly successful the numbers of change orders, delays, scheduling problems, quality problems, unexpected equipment repair and maintenance, conflicts, poor indoor air quality, and other problems will be reduced ((Mills, 2011; Agustsson, 2010; Mills, 2009; Elzarka, 2009).

This section of the literature will describe the commissioning process in detail.

2.4.1 Definitions

There are several different definitions of building commissioning:

In the summary report from the 1993 National conference of building commissioning is defined as: “Building commissioning for new construction or renovations is a systematic process that verifies that all building systems perform interactively according to the documented design intent and the owner’s operational needs.” (Agustsson, 2010).

- The ASHRAE Guideline (2005) defined building commissioning as: "A quality focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated and maintained to meet the owner's project requirements."

Most of these definitions refer to the commissioning as a process of building systems performance designed to meet the needs and requirement defined by the owner.

2.4.2 Previous studies

A review of literature in building commissioning processes indicates that there are many international studies which have been completed on various aspects of the commissioning process. Based on the literature, there are a few countries that have issued guidelines, standards, publications and research reports on the subject, namely USA, Canada, China, Hong Kong, and the United Kingdom. ASHRAE, (1989) published the first commissioning guideline on HVEC, and in 2005, published the Guideline 0-2005, the Commissioning Process guideline named "Guideline 0-2005 the Commissioning Process". Besides ASHRAE, there are many educational institutions, organizations, and associations that have published guidelines and standards for types of commissioning, building commissioning process, the commissioning team and their publications are as follows:

- In 2002, The Association of Professional Engineers and Geoscientists of Manitoba (APEGM) - developed and published guidelines named "building commissioning guidelines".

- In 2005, Energy Design Resources developed “the Building Commissioning Guidelines” as a Source Book on Building Systems Performance.
- In 2006, California Commissioning Collaborative (CCC) developed and published set of guidelines named “California Commissioning Guide: New Building”. And another, for existing building named “California Commissioning Guide: Existing Building”.
- In 2011, Building Commissioning Association (BCA) developed and published guidelines named “New Construction Building Commissioning Best Practice.”

The main commissioning process that is included in these publications and guidelines is summarized in Figure 2.7.

Several research papers were published about building commissioning:

PECI (2002); CCCa (2006a); Mills et al. (2004) and Mills (2009) studied the costs associated with the commissioning.

Necholson and Mplenaar (2004); Mills (2009); and Agustsson (2010) studied the benefits and the cost saving with commissioning.

Altwise and Mclntosh (2001) developed a structured methodology to help owners, contractors, and commissioning agents to define the cost saving of commissioning. The study indicated that the commissioning process is the method for identifying problems early and resolving them before they become more costly to fix. This methodology involves three steps, as follows:

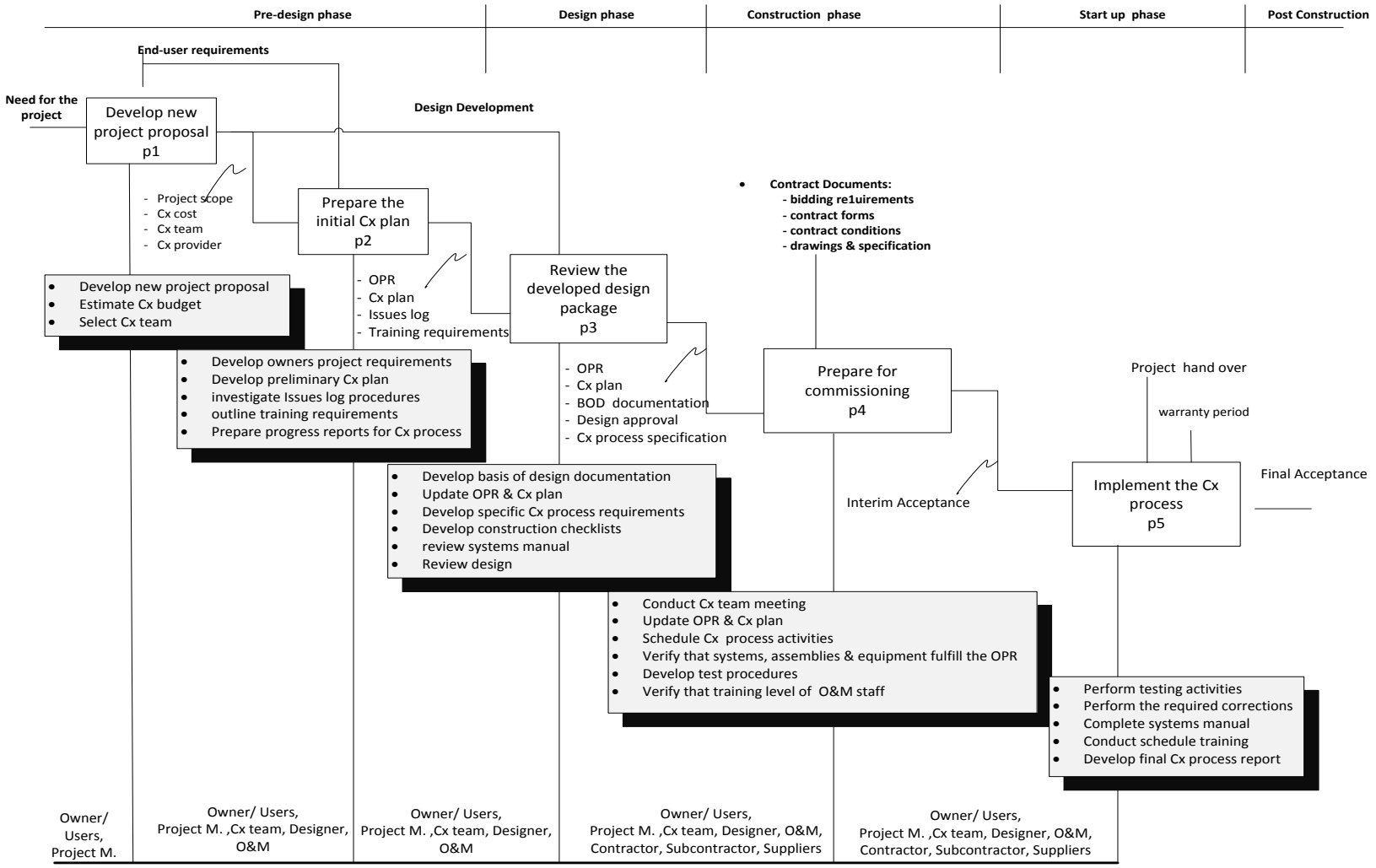

Figure 2.7: the main building commissioning process (APEGM, 2002; ASHRAE, 2005; CCC, 2006; Grondzik, 2009; BCA, 2011)

- Identify and record commissioning issues.
- Calculate the saved costs.
- Evaluate the range of the saved costs.

Yeon Cho (2002) conducted a study to investigate the persistence of savings obtained from continuous commissioning (CC) performed on ten existing buildings on the Texas A&M University campus. The investigation analyzed five years of measured heating, cooling, and other electric consumption data from the buildings to see how savings have changed over time. The results of this study show that hot water, chilled water and electricity savings have all degraded. Aggregate annual cost savings for the ten buildings decreased by 17% from 1998 to 2000 from $1,192,884 to $985,626.

Wei (2003) developed key procedures for commissioning a large campus with many buildings with the aim of reducing the building energy consumption, operation costs, and to improve the comfort of the occupants. The key procedures involve the following steps: information gathering, system survey, identification of problems, development of commissioning plan, implementation of commissioning plan, and documentation.

Agustsson (2010) conducted a comparative study to investigate the advantages of using building commissioning in Denmark. A comparison was made between two buildings where the main difference was that during the building process in only one of the buildings a commissioning process was used. The results of this comparison showed that the commissioned building had less energy consumption while having similar operational and maintenance costs.

APEGM (2002) presented a framework model for managing the building commissioning process. This framework was developed by the Commissioning Branch of the Alberta Public Works Supply and Services Department. The framework is divided into four phases: planning, preparation, implementation, and project evaluation. Within each of these phases are major activities that should be achieved.

Elzarka (2009) conducted a survey of 160 commissioning providers in the United States to investigate the current practice and to identify the best practices for obtaining commissioning services on new construction projects. The key results of this study are presented in Table 2.1.

Table 2.1 The difference between the current practice and best practice (Elzarka, 2009)

Items	Current practice	Best practice
Timing of commissioning agent involvement	Design phase	Pre-design phase
Who should commission	Independent commissioning firm	Independent commissioning firm
Qualifications of commissioning agents	Not Important	Important
Selecting commissioning agent based on:	Cost	Cost, qualifications, and repeat business
Benefits of various commissioning tasks	Functional testing	Functional testing
Number of time to review the design	2	>1

Dorsett (2008) conducted a study to examine how contractors are relating to the commissioning process in the building construction industry in Florida. The study found that many contractors had only a basic understanding of the commissioning process. The

study also went on to show that there was indeed an increase in the amount of buildings that were being commissioned and revealed many other insights into improving and streamlining the commissioning process from a contractor's perspective.

2.5 What Building Commissioning Can and Cannot Do

The best procedure to realize more benefits of the commissioning process is for the commissioning process to start early in the conceptual design phase of a new building and to continue through the design phase, construction phase, start-up, occupancy, and the first year of operation. When the commissioning process is highly successful, the numbers of change orders, delays, scheduling problems, quality problems, unexpected equipment repair and maintenance, conflicts, poor indoor air quality, and other problems will be reduced (Mills, 2009; Grondzik, 2009; California Commissioning Collaborative a, 2006).

The building commissioning cannot cover sertain points if the commissioning process is not introduced early enough in the project. These points include the following, thought the list is not exhaustive (Grondzik, 2009):

- Unrealistic project expectations.
- Unrealistic project budget.
- Correction of problems that occurred early in the building process.
- Operation and maintenance of the building.
- Repair of major problems with systems without high costs.

2.6 Types of Commissioning

There are four types of the commissioning process as shown in Figure 2.8, namely:

- Building commissioning
- Retro-commissioning
- Re-commissioning
- Continuous Commissioning

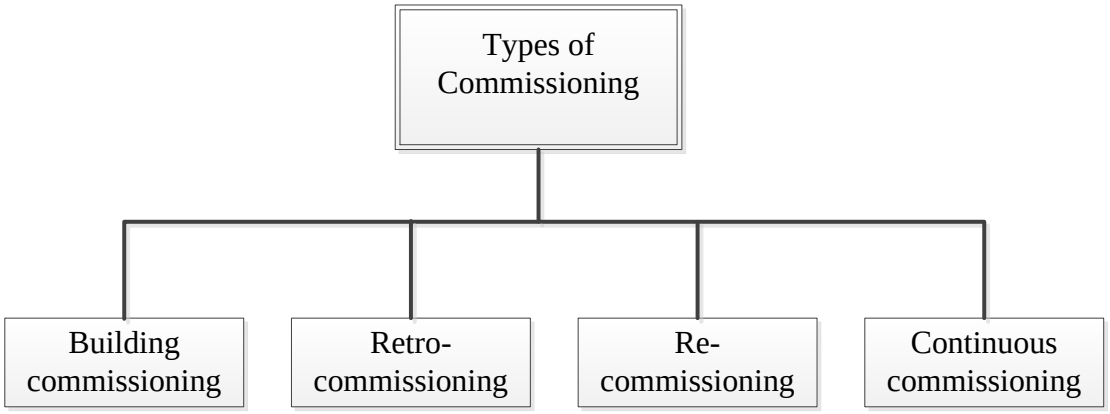

Figure 2.8: types of commissioning (CCC, 2006a)

2.6.1 Building Commissioning

The building commissioning means the commissioning process for new buildings. The term building commissioning has gained great attention worldwide and the commissioning process of the new building begins early in the conceptual design phase of a new building and continues through to the design phase, construction phase, start-up, occupancy, and the operation phase (California Commissioning Collaborative A, 2006).

2.6.2 Retro-commissioning

Retro-commissioning means the commissioning process for existing buildings. California Commissioning Collaborative (2006) defined retro-commissioning as "a systematic method for investigating how and why an existing building's systems are operated and maintained and identifying ways to improve overall building performance". The objectives for applying the retro-commissioning process depend on the owner's requirement, budget, and condition of the equipment.

2.6.3 Re-commissioning

Re-commissioning involved when a building that has already been commissioned undergoes another commissioning process for the purpose of evaluating the building's existing systems and determining how effective of the initial commissioning was. Other reasons for using re-commissioning include modification in the user requirements, the discovery of poor system performance, or the desire to fix errors that were made during the initial commissioning of the building (California Commissioning Collaborative, 2006).

2.6.4 Continuous Commissioning

The Continuous Commissioning (on-going commissioning) process is different from new building commissioning, retro-commissioning, and re-commissioning. This new process was pioneered by the Energy Systems Laboratory at Texas A&M University (Claridge et al, 2000). The goals and objectives of the continuous commissioning process are to minimize the building energy consumption, to optimize the HVAC system operation and control, and to make the building comfortable for the occupants (Wei, 2003). In continuous commissioning, even after the initial commissioning is complete, the team

continues to work together to check and analyze building performance data to monitor if there any problems in the equipment performance.

2.7 The Commissioning Process

According to the ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) The Commissioning Process Guideline 0-2005, there are four phases of the process: pre-design, design, construction, occupancy and operations. Each phase in the four processes has different activities for the commissioning team. See Figure 2.9.

2.7.1 Pre-design phase

The commissioning process begins in the pre-design phase and the major commissioning activities that are to be carried out by the commissioning team during the pre-design phase are the development the owner's project requirements, development of the preliminary commissioning plan, budget and scope, commissioning team and issues log. Figure 2.10 provides a summary of the main activities that are to be carried out during the pre-design phase (ASHRAE, 2005, CCC, 2006, Grondzik, 2009).

2.7.1.1 Identify Commissioning Team

Identifing the commissioning team is the first Step in the pre-design phase. The responsibilities of the commissioning team during the pre-design phase are the following (ASHRAE, 2005):

- Develop owner’s project requirements
- Develop preliminary commissioning scope and budget

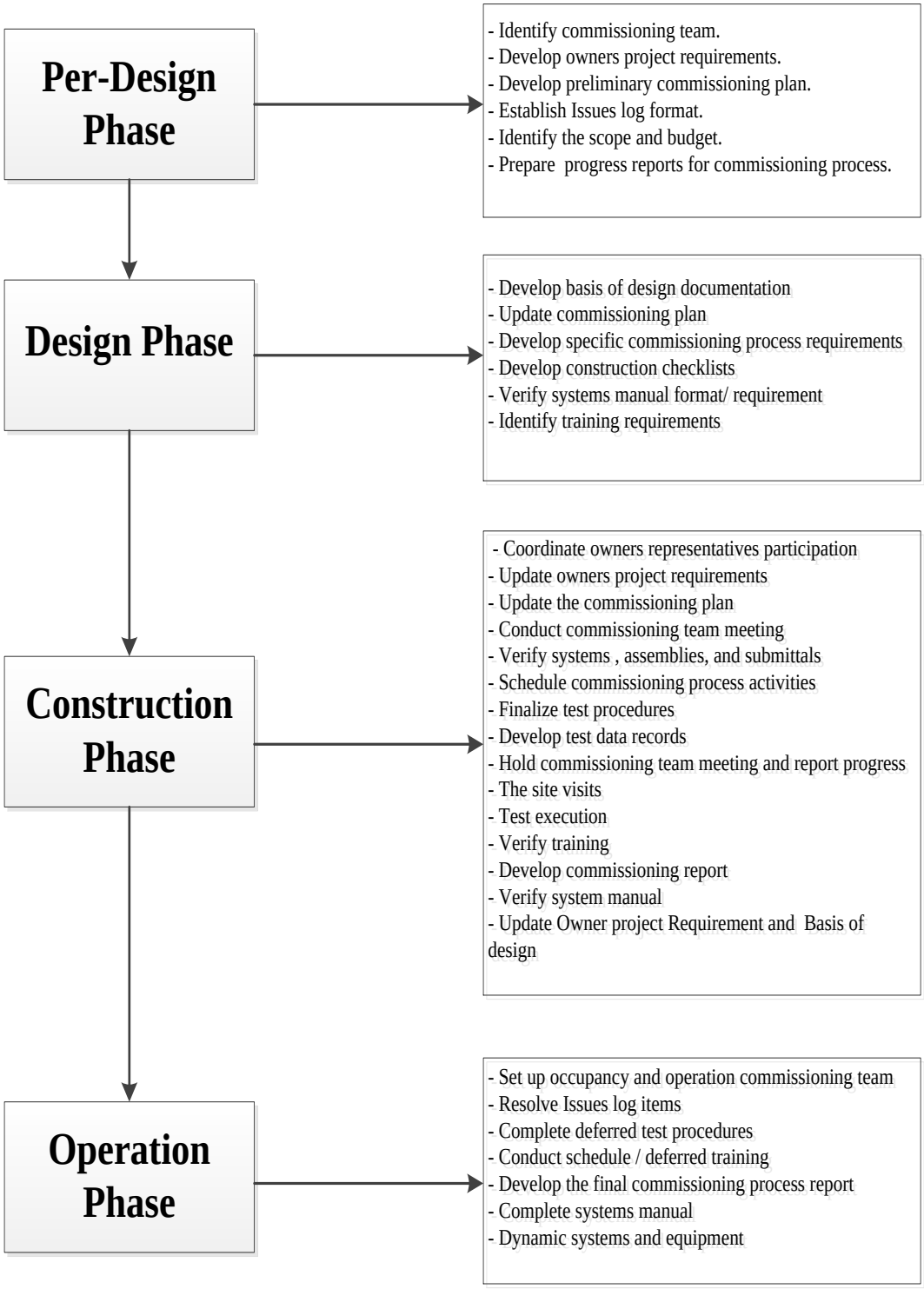

Figure 2.9 A summary of the commissioning activities during the project phases (Grondzik, 2009; ASHRAE, 2005; CCC. 2006)

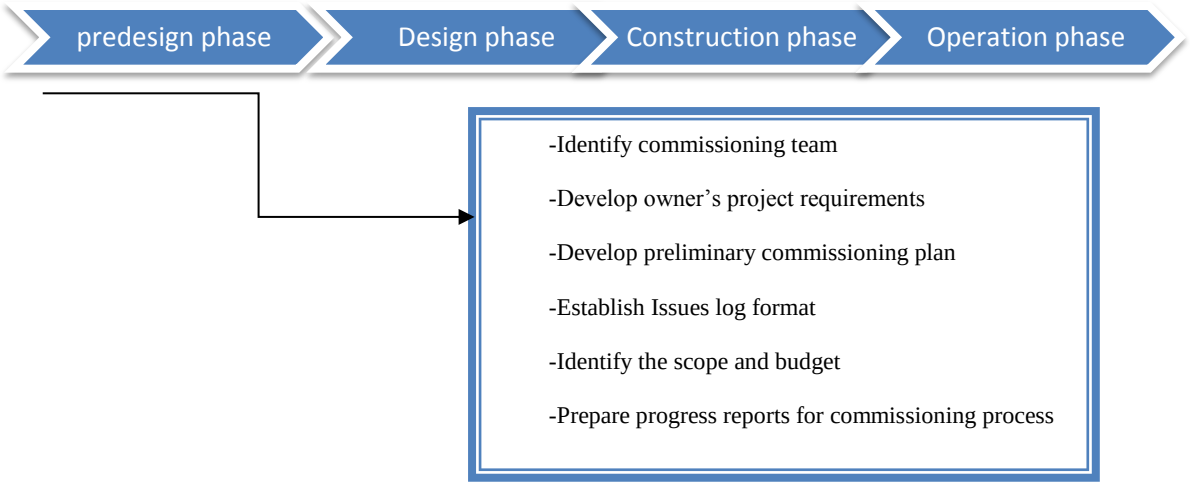

Figure 2.10: A summary of the main activities to be performed by the commissioning team during the pre-design phase (Grondzik, 2009; ASHRAE, 2005; CCC. 2006)

- Develop a preliminary commissioning plan
- Develop the project schedule to integrate the commissioning process activities
- Develop the initial format that is to be used for issue logs.
- Write the commissioning progress report.

The list of the responsibilities above is not exhaustive and only the key responsibilities of the commissioning team are mentioned. More details can be seen in ASHRAE guideline 0-2005.

2.7.1.2 Develop Owners Project Requirements (OPR)

"The Owner's Project Requirements (OPR) are a formal document prepared by the owner (or someone designated by the owner) that capture the needs and expectations for a proposed facility" (Grondzik, 2009). OPR includes information and procedure that help to make a successful plan, design, construction operation, and maintenance. OPR will be

developed throughout each project stage and will be updated to reflect the new requirements of the owner (ASHRAE, 2005).

2.7.1.3 Develop Preliminary Commissioning Plan

The commissioning plan is a document that identifies the commissioning process as well as a guideline for the commissioning team members to explain the owner's project requirements and define the scope and budget for the commissioning process. A commissioning plan includes a schedule of commissioning process activities, commissioning team and their responsibilities, commissioning budget and scope.

The commissioning plan is updated during each phase in the project for the purpose of developing any changes in the planning, design, construction, and operations (ASHRAE, 2005; CCC, 2006).

2.7.1.4 Establish an Issues Log format.

The issues log is a document where all the problems of the design, insulation, or performance are documented as well as their solutions. That is means; all the issues that are at a variance with the (OPR) should be documented in the issue log.

The issue log is one of the important documents that is necessary during the commissioning process for the purpose of reducing the risk of problems that can lead to the owners project requirements not being fulfilled (ASHRAE, 2005).

2.7.1.5 Identify the Scope and Budget

The commissioning team is responsible for determining the scope and budget for the commissioning process. The scope of the commissioning process differs from one project

to another and the commissioning team can establish the scope of the commissioning process from the previous experiences (ASHRAE. 2005). The scope of the commissioning process is to identify the systems and the main elements of those systems that are needed to be commissioned. There are a number of systems in the building: HVAC, electrical, security, fire protection, and roofing systems. If any one of those systems is to be commissioned, the commissioning process will cover all the elements in this system. In the pre-design phase the systems have not been designed so it will not be possible to go into specific details about the systems. However, a good overview of the systems that will be commissioned and what to look out for is recommended as a preliminary plan.

The commissioning process budget will be made based on a defined scope of the commissioning process. It is important that the commissioning process budget is realistic, and that it is allocated among the commissioning activities. The absence of a budget at this stage will adversely affect the commissioning process in meeting the owner's project requirement (Grondzik, 2009).

2.7.2 Design phase

During the design phase, the commissioning team is responsible for translating the owner's project requirements into construction documents "which called the basis of design" and for developing the commissioning plan to include the activities of the construction, occupancy, and operation phase (ASHRAE, 2005; Grondzik, 2009) .

The commissioning process activities to be carried out by the commissioning team during the design phase are shown in Figure 2.11.

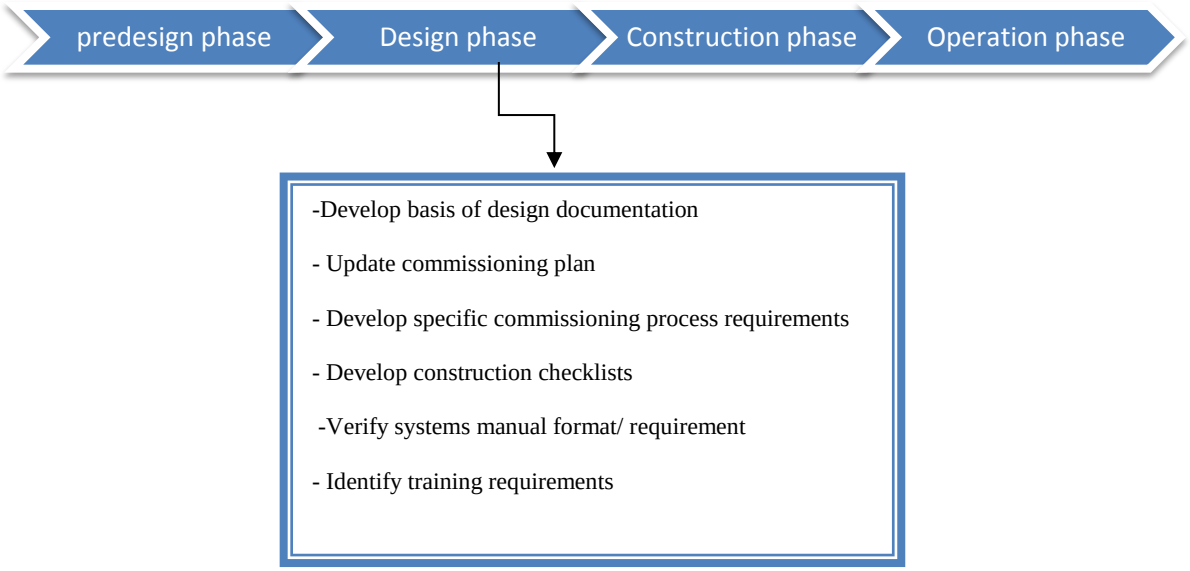

Figure 2.11: A summary of the main activities to be performed by the commissioning team during the design phase (Grondzik, 2009; ASHRAE, 2005; CCC, 2006).

2.7.2.1 Develop the basis of design documentation

The basis of design is a document, developed during the design phase by the design team and reviewed by the commissioning team. The main purpose of the basis of design is to capture the thought about the design that produces the construction documents that are provided to the contractor. The construction documents show what the contractor should do but don't show why it should be done; here the basis of design comes in (Grondzik, 2009).

The basis of design should include specific descriptions about the systems, current regulations, codes, standards, guidelines, and assembly performance assumptions (ASHRAE, 2005).

2.7.2.2 Update the Commissioning Plan

The commissioning plan is developed during the pre-design phase and updated during the

design phase for the purpose of including additional information and to show the activities that will be carried out during the construction phase. Moreover, the activities that will be completed during the occupancy and operations phase will be added to the commissioning plan. The items that will be updated or added to the commissioning plan are the following (ASHRAE, 2005):

- What systems will be commissioned?
- Roles and responsibilities.
- The commissioning process activities, schedule, protocols, and procedure during the construction phase as well as the occupancy and operations phase.

2.7.2.3 Develop Specific Commissioning Process Requirements

The commissioning requirements are included in the contract specifications, and should be specific to allow the contractor to add them in the construction budget and schedule and to help him to understand the design, materials, and requirements. The construction documents should include the schedule of the meeting, scope and responsibilities of all parties, documentation requirements, training requirements, and requirements for testing systems and assemblies, construction checklists, specific equipment, access and coordination issues, and all details of the commissioning process. Specific commissioning process requirements must be clearly spelled out for the contractor. The Commissioning Agent and the A/E are responsible for ensuring that the commissioning requirements are integrated and included in the contract specifications (CCC, 2006; Grondzik, 2009).

2.7.2.4 Develop Construction Checklists

The aim of developing the construction checklists is to provide details on the OPR for equipment and assemblies. The construction checklists include the following (ASHRAE, 2005):

- **Equipment\assembly verification**. This part of the checklist should include the necessary information about the equipment or materials that was submitted and delivered to the site of the project.
- **Pre-installation checks**. This part of the checklist is used to confirm the state of the equipment and materials at the site.
- **Installation checks**. This part of the checklist is used to confirm that the installation of the equipment/materials is according to the OPR and Construction Documentation.

2.7.2.5 Verify Systems Manual Requirements and Format

There are several details about the systems, and assemblies which are not mentioned in the design and construction process. So, a systems manual should be developed to include this information about the operation and maintenance of the systems and assemblies as well as any information gathered during the commissioning process. The system manual format should include the index of the systems manual, owner project requirements (OPR), basis of design (BOD), construction documentation, operating and maintenance manual, and commissioning process report (ASHRAE. 2005).

2.7.3 Construction phase

During the construction phase the commissioning team is responsible to undertake the following:

- Verifying that the systems and assemblies meet the OPR.
- Verifying training of the owners, operation and maintenance members
- Developing systems manual
- Updating the OPR
- Updating the commissioning plan

Figure 2.12: provides a summary of the main activities that are to be carried out during the construction phase (ASHRAE, 2005, CCC, 2006, Grondzik, 2009).

2.7.3.1 Update Owners Project Requirements

The owners project requirements are developed during the pre-design phase, and must be updated during the construction phase for the purpose of reflecting any changes that are made by the owner or in case the design\construction process initiated changes to the construction documents. In those cases, if the owner made the change, the design shall be modified to meet the change. Similarly, if the change is made through the design/construction process, the OPR must be updated as necessary to match the change (ASHRAE, 2005).

2.7.3.2 Systems and Equipment Verification

Systems and equipment verification is one of the most important parts of the commissioning process during the construction phase. Verification activities will vary from system to system due to the importance of the systems equipment. The

comprehensive process of the verification that should be carried out is as follows (Grondzik, 2009):

1. Verify that correct equipment has been delivered to the site.
2. Verify that equipment has been rightly installed.
3. Verify that equipment works within its own context.
4. Verify that equipment operates as intended within the whole system.
5. Verify that equipment is compatible with other systems.

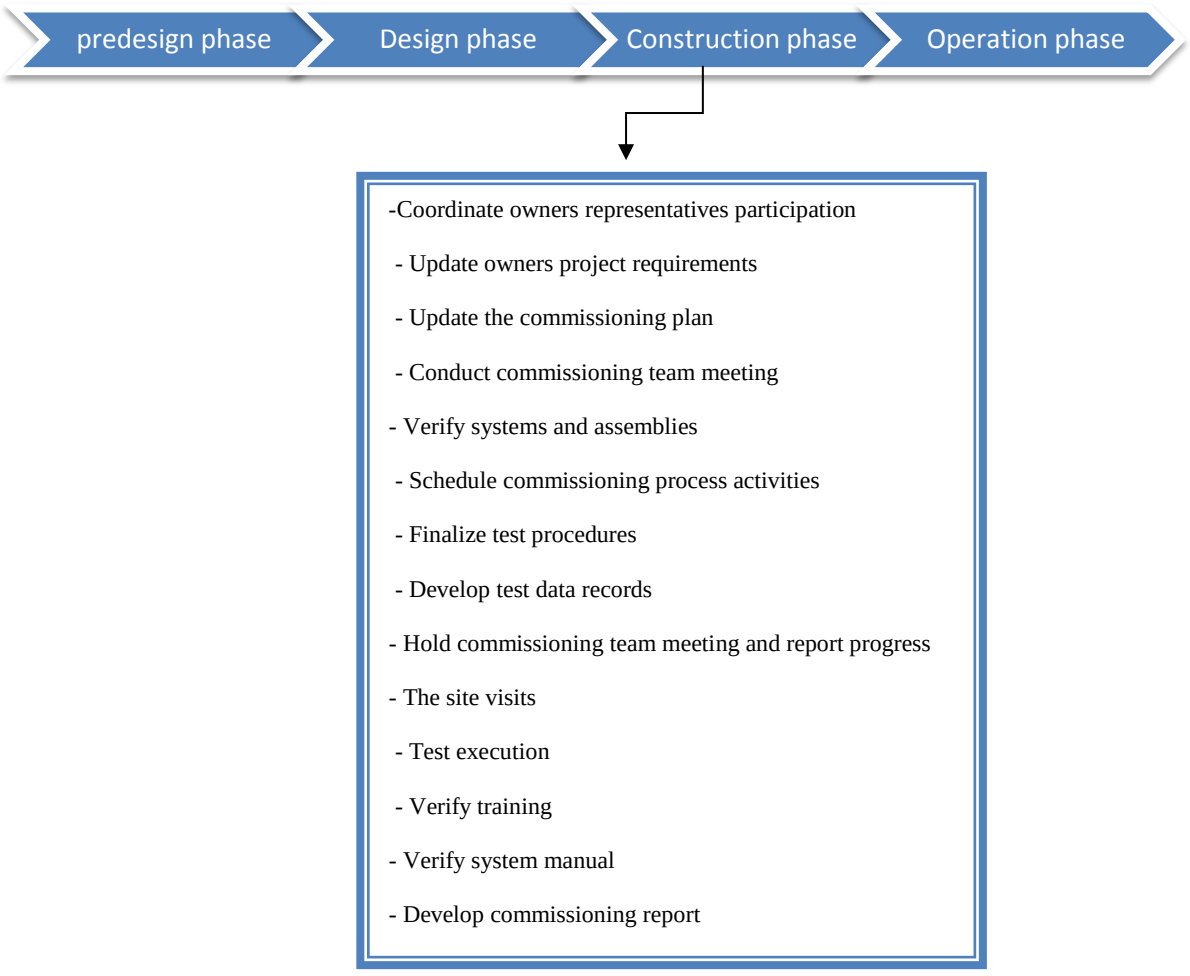

Figure 2.12: summary of the main activities to be performed by the commissioning team during the construction phase (Grondzik, 2009; ASHRAE, 2005; CCC, 2006).

Systems and equipment verification are carried out using checklists developed for a specific system\equipment at a distinct project. The verification process is carried out by the contractor and must be approved by the commissioning authority or any members of the commissioning team.

2.7.3.3 Updating the Commissioning Plan

The commissioning plan is updated during the construction phase to reflect any changes to the project, or to include new details of commissioning activities, change orders, systems testing failure. The commissioning plan will be updated to provide descriptions of the commissioning activities that will develop during the construction phase, for example test procedure, roles and responsibilities of the new commissioning team during the construction phase, and schedule of the commissioning process activities. The commissioning plan is also updated to include more details on commissioning process activities that will take place during the occupancy and operations phase (Grondzik, 2009).

2.7.3.4 Verify Training

Training of the owner's operations and maintenance members is an important item in the commissioning process. It is a critical aspect of construction phase commissioning. The operations and maintenance personnel should understand how to walk through the key steps to resolve the problems and to have the skills required to operate the facility to meet the OPR. During the training program the trainees should provide the necessary information about adjustment instruction, maintenance and inspection procedure, repair procedure, and the emergency instruction for operating the facility during the different conditions (CCC, 2006).

The commissioning authority is responsible for verifying and documenting the requirements and the scope of the training in the construction documents.

2.7.3.5 Verify Systems Manual Update

The systems manual is developed during the design phase to include the information about the operation and maintenance of the systems and assemblies as well as any information gathered during the commissioning process. The systems manual is updated during the construction phase to integrate the materials that are produced during this phase. Those materials are (ASHRAE, 2005):

- Test procedures.
- Test data records.
- Updates of OPR, basis of design (BOD), Commissioning plan, and issues log.
- Training plans and records.
- Commissioning progress reports.

2.7.4 Operation phase

The commissioning process activities during the occupancy and operation phase should continue through to the end of the warranty period of the operation phase. The active involvement of the commissioning team during the beginning of the operation phase is an integral aspect of the commissioning process. The main activities that should be performed by the commissioning team during the operation phase are shown in Figure 2.13 (ASHRAE, 2005; CCC, 2006; Grondzik, 2009).

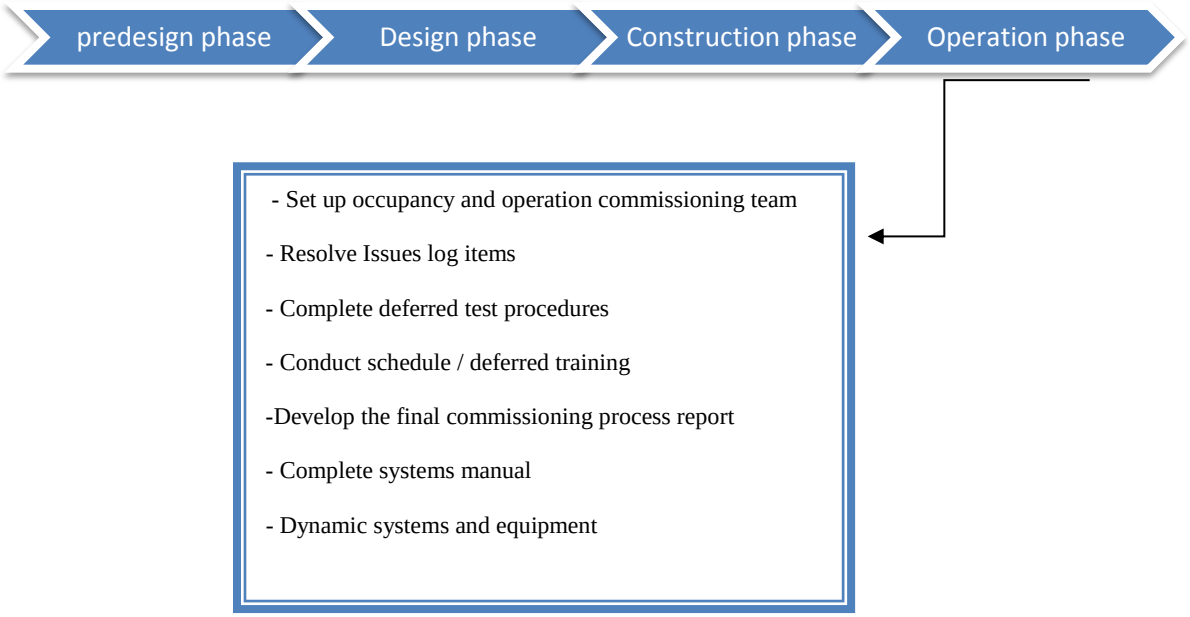

Figure 2.13: A summary of the main activities to be performed by the commissioning team during the Occupancy and Operation phase (Grondzik, 2009; ASHRAE, 2005; CCC, 2006).

2.7.4.1 Occupancy and Operations Phase Commissioning Process Responsibilities

The main responsibilities of the commissioning team during the occupancy and operation phase are as follows (ASHRAE, 2005):

- Coordinate vital contractor callbacks.
- Verify required training for the operation and maintenance personnel.
- Verify that the systems and assemblies operations meet the OPR.
- Verify systems manual updates.
- Verify performance evaluation of facility systems and assemblies.
- Complete the final report for the commissioning process.

The list of the responsibilities above are not exhaustive and only the key responsibilities of the commissioning team during the occupancy and operation phase are listed. More details can be seen in ASHRAE guideline 0-2005.

2.8 The commissioning team

The members of the commissioning team should be working together to identify issues and resolve problems early in the design phase and construction process to prevent expensive schedule delays and excessive change orders as well as to ensure that the final delivered building meets the owner's needs. It is important for the members of the commissioning team to understand the following (CCC, 2006a):

- The roles and responsibility of each member of the commissioning team.
- The commissioning team does not manage the design or construction of the project.
- The purpose of the commissioning team is to facilitate communication, resolve issues, and document performance.
- The commissioning team is concerned with making sure each of the complex building systems is working as efficiently as possible without any problems.
- Good communication between the team members is very important.

2.8.1 Commissioning Team Members and Their Responsibilities

Each building requires a different type of commissioning and therefore has various needs for commissioning personnel. Similarly, each project has different needs and requirements. Together, the commissioning authority and the owner assign roles and responsibilities to members of the commissioning team. The team's structure will be affected by the budgets and the special project characteristics. The commissioning

authority can help the owner form a team that best matches the size and complexity of the project (Energy, 2005). Figure 2.14 shows the commissioning team involvement in building commissioning process (BCA, 2011).

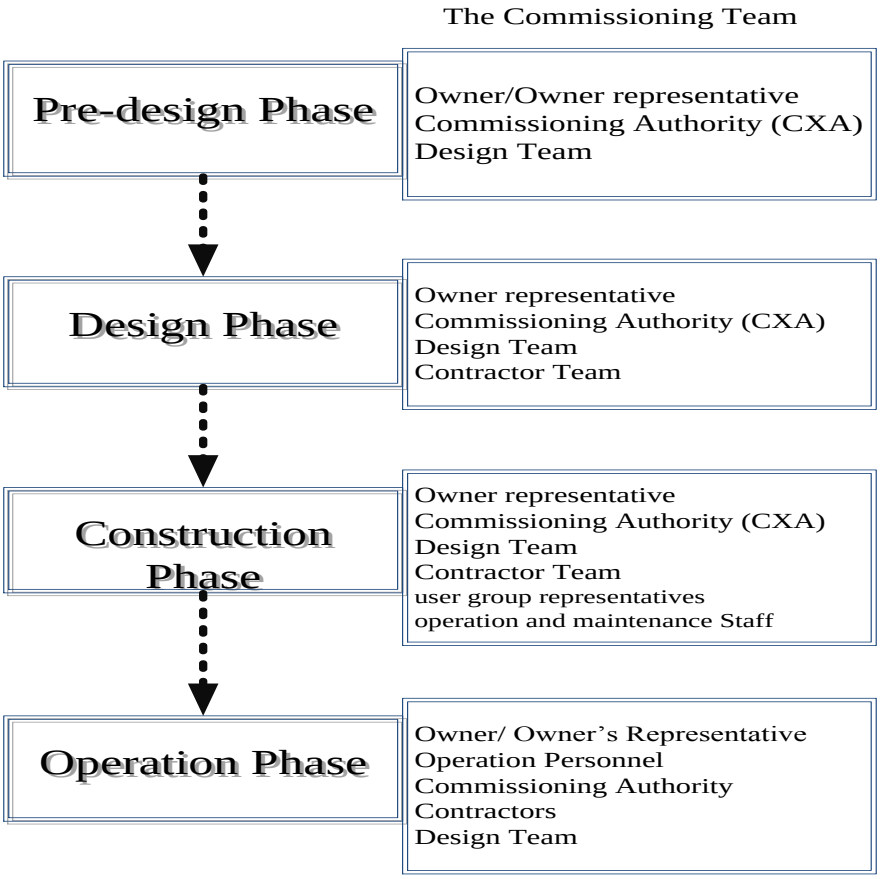

Figure 2.14: the commissioning team involvements in building commissioning process (BCA, 2011)

There are basic roles of most commissioning members. Below is an outline of typical commissioning team members and their responsibilities in the process (Energy, 2005; CCC, 2006):

- Facility owner or owner's representative
- Commissioning authority (CxA).
- Installing contractors and manufacturer representatives.

- Design professionals.
- Facility manager/building operator
- Testing specialists

Facility Owner or Owner's Representative

The building owner or owner's representatives serve basically the same role in the commissioning process. Their most important responsibility is to clearly communicate expectations about the project outcome to the project team. They control the budget and schedule which in turn drives how fast or slowly the project progresses and who gets paid and when. Beyond that, other responsibilities include the following (Energy 2005):

- Determining the goals and direction of the project.
- Attending building training sessions to understand all intricacies of the operations and all aspects of maintenance of the facility.
- Reviewing the qualifications of the commissioning provider if necessary.
- Creating avenues of communication between all the commissioning team members.
- Determining the budget, schedule, and team members needed to successfully complete the project.
- Working with the commissioning provider (if there is one) to work through the details and technical aspects of the commissioning process.
- Approving start-up and functional test completion.

Commissioning Authority (CxA)

Commissioning providers are not all the same. They vary depending on the needs, size, and complexity of the project. The commissioning authority can either be a member of the owner's staff, a designer or contractor, or an independent commission authority (CCC, 2006a). The commissioning provider's main responsibility is to verify that all aspects of the design are according to the design intent and the owner requirements throughout the entire process. They are an advocate for the owner and are paid a fixed fee. This fee is usually broken into two parts. The first part of the fee includes all the commissioning services that are provided in the design phase of the project. An example of this may include ensuring that the owner's objectives are accurately reflected in the design. The second part of the fee includes all services for construction, testing, and post-acceptance paperwork and training. An example of this may include writing an operations and maintenance manual for the staff that are in charge of running a specific facility. Other responsibilities of the commissioning provider include (Energy 2005):

- Seeing that all project documentation is completed and in order.
- Assisting in documenting the commissioning requirements.
- Developing and implementing a commissioning plan.
- Ensuring that all team members are aware of their specified commissioning responsibilities.
- Providing advice regarding commissioning design features and future operation and maintenance of the building.
- Witnessing and verifying that the contractors who perform tests, balancing, and duct pressure testing do so according to the owner's wishes.

- Writing construction, functional, and performance tests to ensure that all systems are functioning properly.
- Submitting regular reports to the building owner or project manager, updating them on everything from potential delays to outcomes of diagnostic tests.
- Conducting all necessary testing of systems.
- Developing and maintaining an issues log.
- Reviewing that training of the staff is acceptable.
- Developing diagnostic and/or test plans for all the systems that will be commissioned.
- Reviewing operation and maintenance manuals documentation for completeness.
- Writing a final commissioning report documenting the final evaluation of the systems' capabilities to meet design intent and owner needs.
- Developing an operations and maintenance manual that details the most important equipment and system O&M parameters.

Installing Contractor and Manufacturer Representatives

The responsibilities of the contractor and manufacturer representatives include (Energy 2005):

- Working with the owner and commissioning provider to develop the commissioning schedule.
- Documenting system start-up, and conducting regular performance tests (with the help of the commissioning agent) of the equipment systems they install.

- Providing operation and maintenance manuals to the owner for any of the equipment they install.
- Training facility managers and the operation and maintenance staff to be familiar with systems they have installed.

Design Professionals

The responsibilities of the design professionals will differ according to the needs of the project and owner and the interests of the designers. The responsibilities of design professionals include (Energy 2005):

- Documenting the design for all systems.
- Answering questions and issues brought up by the commissioning provider during the design phase.
- Writing system descriptions and recording design basis information.
- Making sure that commissioning is included in the bid conditions.
- Assisting in resolving construction and operational problems highlighted by the commissioning process.
- Clarifying design issues associated with the system operation and design intent.
- Reviewing the commissioning plan and the functional performance test plan.

Facility Manager/Building Operator

The tasks of the building operator include (Energy 2005):

- Assisting with (or at least observing) as much of the functional testing as possible. This is to improve the operator understanding of the equipment and control

strategies. It is also to improve the operator's skills to be able to retest systems periodically as part of their ongoing O&M protocol.

- Attending training sessions provided by the contractors or manufacturer's representatives.
- Interfacing the facilities management software, owner's standards, and equipment preferences with the project.

Testing Specialists

Testing specialists may be required to carry out the following tasks (Energy 2005):

- Performing special testing according to the complexity of the project.
- Reviewing documentation relating to the systems they test.
- Training operators on the proper use of testing equipment.

2.8.2 Selecting the Commissioning Authority

The literature research has revealed that currently owners can assign any of the following parties to select and manage the commissioning provider's contract:

- Owner's staff.
- Architect or engineer.
- The contractor.
- An independent third-party provider.

Each of these parties will have their individual strengths and weaknesses. The literature research recommended that using an independent third-party provider is the best choice for the owner to perform the commissioning service (Elzarka, 2009).

Nicholson and Molenaar (2004) indicated that according to the size and complexity of the project, there are different levels of commissioning which can be used, and many choices of how to commission. For small, less complex projects, the subcontractors can perform the commissioning of their systems. For larger, more complex projects, the contractor or the designer can be required to perform the commissioning process of their systems. For total commissioning of the project, an independent commissioning agent can perform the commissioning process from the pre-designed phase to the operation phase of the building. Figure 2.15 shows how to select the commissioning authority based on the size\complexity of the building project.

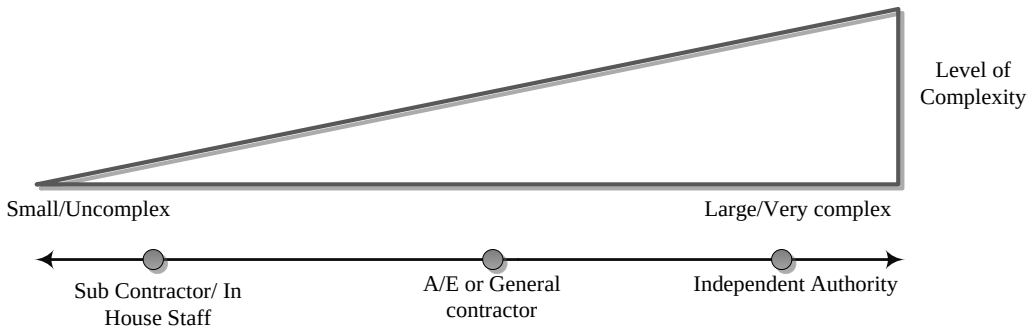

Figure 2.15 Selecting the commissioning authority based on size\complexity (Nicholson and Molenaar, 2004)

When the design professional performs the commissioning service, he is already familiar with the owner project requirements, and can start the commissioning process in the design phase. The disadvantage of this approach is that the design professional may not have the necessary skills and experience, and he is less likely to acknowledge problems (English, 2006).

When the general contractor performs the commissioning service, it is difficult for contractors to objectively test and assess their own work, especially since repairing

deficiencies found through commissioning may increase the costs (Elzarka, 2009). In some cases the owner can use the installing contractor as the commissioning provider. These cases include when the size of the building is less than 20,000 square feet, the commissioning requirements are clearly detailed in the project specifications, and the owner's staff have skills that can help them to review the contractor's commissioning work (Energy, 2005). The advantage of this approach is that, because the contractor is responsible for the final product, he will be interested in making sure that the building's performance is according to the design intent (Nicholson and Molenaar, 2004).

2.8.3 The Commissioning Authority Qualifications

The basic qualification that a commissioning agent should have to be able to perform the commissioning job include the following (Nicholson and Molenaar, 2004):

- Construction process knowledge (experience in design, construction process, and conducting project scope meeting).
- Special systems skills (expertise in commissioning, testing, adjusting, and balancing).
- Commissioning skills (experience in commissioning, start-up, and training facility staff).
- Personal skills (coordination, and communication skills).

2.9 Commissioning Costs

Currently, no standard accounting method exists for calculating the cost of commissioning. The cost of commissioning is dependent upon many factors including the commissioning scope, equipment type, a building's size and complexity, traveling

requirements, and whether the project consists of new construction or building renovation (PECI 2002).

The cost of commissioning is often difficult to estimate and the owner should make sure of fully understanding what costs to expect (California Commissioning Collaborative 2006).

There are many published industry averages that estimate the commissioning cost.

According to PECI in (2002), the average cost of total building commissioning is as follows:

- The commissioning provider fees are from 0.5% to 1.5% of construction cost.
- The costs for the contractor from 10% to 25% of the commissioning provider's costs. These costs include attending meetings, supporting with testing, and documenting the construction checklists.
- The designer's fee may range anywhere from 0.1- 0.3% of the total construction budget.

The average cost of commissioning the systems in the construction phase is:

- Mechanical systems from 2.0% to 3.0% of the mechanical budget (Includes fire, safety, and controls systems).
- Electrical systems from 1.0% to 2.0% of the electrical budget (includes emergency power, lighting controls and limited connection and grounding checks).
- All systems from 0.5% to 1.5% of the construction budget (Includes HVAC, controls and electrical system).

A study in the United State reported the actual commissioning costs of 69 new commissioning projects and the retro-commissioning costs of 106 retro-commissioning projects. The result of the study is shown in Table 2.2 and Table 2.3.

Table 2.2: commissioning costs (Mills et al. 2004)

Item	**Value**
Total Commissioning Cost	$6.56 - $22.17/m2
Commissioning Authority Fee as % of Total Commissioning budget	74 - 86%
Commissioning Authority Fee as % of Total Construction budget	0.3 - 1.1%

Table 2.3: Retro-commissioning costs (Mills et al. 2004)

Item	**Value**
Total Retro-commissioning Cost	$0.13 to $0.45/sqft
Provider Fee as % of Total RCx budget	35 - 71%
Simple Payback Time	0.2 to 2.1 years

Mills (2009) stated that commissioning can have both benefits and costs and sometimes can result in either net delivery costs or net savings. Costs can include the finding and resolution of deficiencies. Benefits can include energy savings and non-energy savings, reductions in other utilities or operations and maintenance costs. Costs and benefits can occur at one point at the same time, for example the commissioning can influence the type and number of change orders and can influence the cost of operation and maintenance, as shown in Figure 2.16.

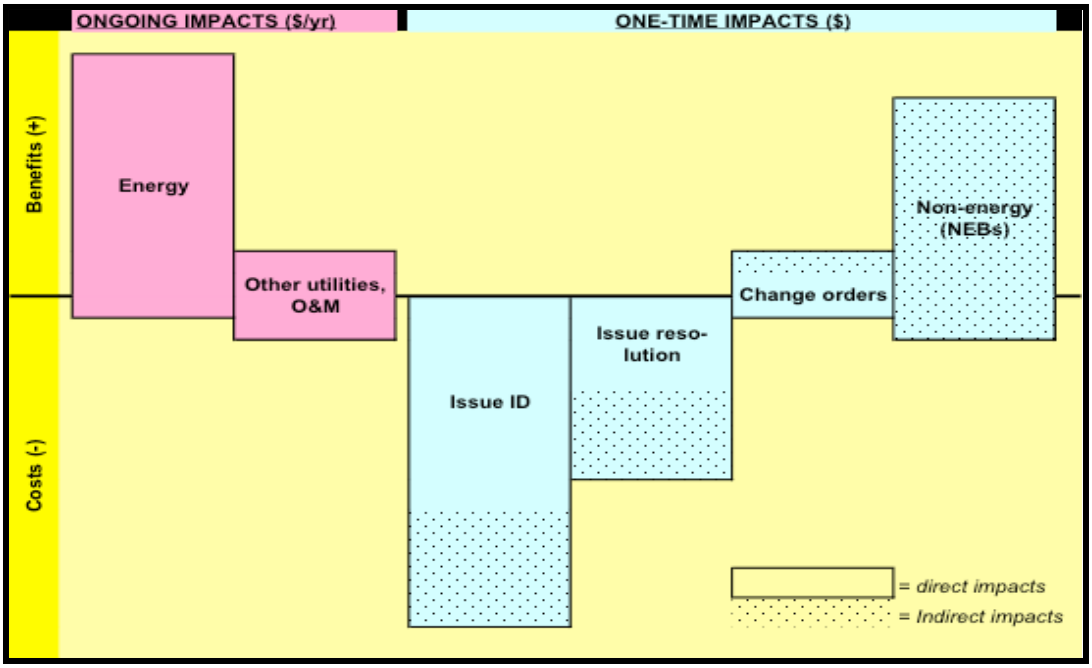

Figure 2.16: A Conceptual map of commissioning costs and benefits (Mills 2009)

2.10 General Benefits of Commissioning

There have been many studies about the benefits of the commissioning process. These studies indicated that everyone benefits from building commissioning: the building's owner, staff, design team, contractor, and occupants. These differ for each type of commissioning project, but some of the usual benefits include (Mills, 2009):

- Energy saving.
- Construction cost saving.
- Improved coordination between design, construction, and occupancy.
- Reduced quantity of change orders.
- Improved indoor air quality.
- Early detection of potential problems.
- Reduced operation and maintenance costs.

- Improved occupant productivity.
- Improved training of operation staff.

The benefits of commissioning can be divided into two categories:

- Energy benefits.
- Non-energy benefits.

2.10.1 Energy benefits

Energy saving is the important issue for many owners, while the majority of the commissioning process focuses on many systems that have a high energy consumption. The most common systems that need to be commissioned are (Nicholson and Mplenaar 2004):

- Cooling systems.
- Lighting systems.
- Ventilation systems.
- Hydraulic systems.

The commissioning process ensures that all these systems are designed and installed correctly to achieve high efficiency and greatest energy saving. The energy savings are real depending on the type of the building, location, and the scope of the commissioning process. The rate of the energy savings, according to a comprehensive study in the Unite Stated is \$0.22 - \$2.58/m^2 (Mills, et al. 2004).

Agustsson (2010) conducted a comparative study between two shopping malls in Denmark to identify the electricity consumption p. m^2 for each one to classify the impact of the commissioning process. The study showed that there is a difference between the two buildings: the building that used commissioning used 40% less electricity than the building that did not use commissioning.

2.10.2 Non-energy benefits

Non-energy benefits are becoming in many situations the most important reason to utilize commissioning (Mills, 2009). Recently, owners have begun to realize other benefits of commissioning, including improved indoor air quality, reduced operation and maintenance costs, reduced equipment replacement cost, improved occupant productivity, reduced risk of system failure, extension of life equipment, and improved training of operation staff (Maure, 2005).

Altwies (2001) conducted a study of six newly constructed buildings to investigate the impact of the commissioning process. He found that due to the commissioning the change orders reduced by 87%, the contractor call-backs by 90%, and the total cost of the construction by an estimated 4% to 9%.

Nicholson and Molenaar (2004) stated that there are several benefits for building commissioning that make it advisable. Benefits for the owner, reduction in design defects, change orders, omission of plans, and increase in the quality of the final product. Benefits for the contractor provide a clear map for the project and provide more incentive not to cut corners. Benefits for the owner's staff, the control of operating systems, easy maintenance, and increase in the reliability of the equipment.

Mills (2009) conducted a study to look into what the non-energy benefits of building commissioning are. The data gathered from a total of 112 construction commissioning projects which included 68 existing buildings and 44 new construction buildings. The results of this study showed that there were about 480 non-energy benefits. For existing projects the following were noted: cost saving, improved indoor air quality, improved equipment life, and improved thermal comfort. For new buildings the following were noted, reduced change orders, improved thermal comfort, improved team function, improved occupant productivity, and improved equipment life. The total result of non-energy benefits can be seen in Figure 2.17. The rate of the non-energy savings according to a comprehensive study in the United State is \$3.12 - \$92.86/m^2 (Mills et al. 2004).

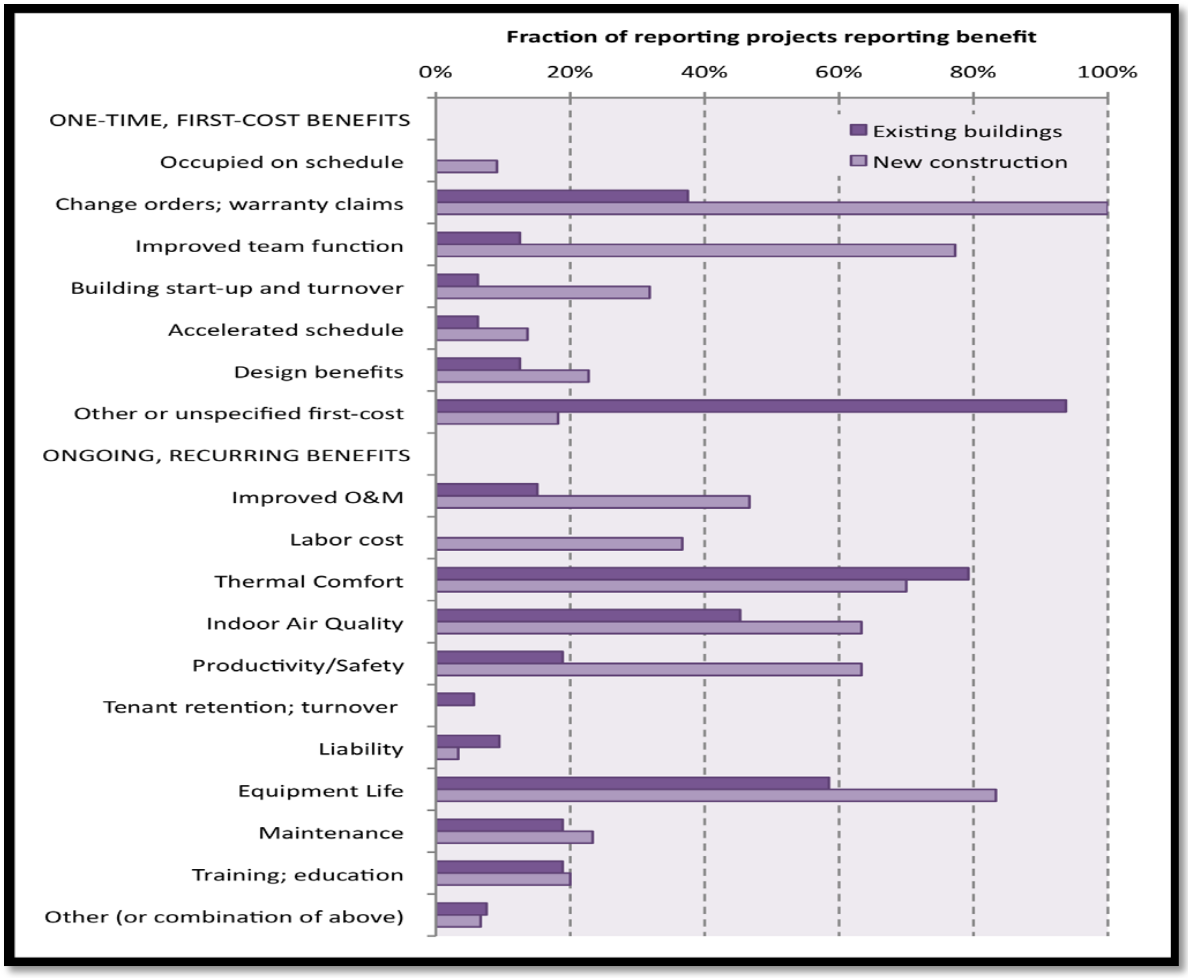

Figure 2.17: The Non-energy benefits observed following commissioning (Mills. 2009)

2.11 Commissioning Documentation

Documentation is a very important part of the commissioning process. Without documentation many things get missed, information is lost, and communication is poor. The major commissioning process documents are as follows: the commissioning plan, basis of design (BOD), systems manual, owner's project requirements (OPR), training plan, issues log, and commissioning report (Grondzk, 2009). Figure 2.18 shows the development of commissioning documents during the project phases.

The main aims of documenting during commissioning are as follows:

- To record the standards of performance for different building systems.
- To coordinate between building systems and those installing them. It helps to provide connection between parties involved in the commissioning process, thus helping to reduce the errors and schedule delays (Dorsett, 2008).
- To be the road map for the O&M staff when the building is finally turned over to the owner.

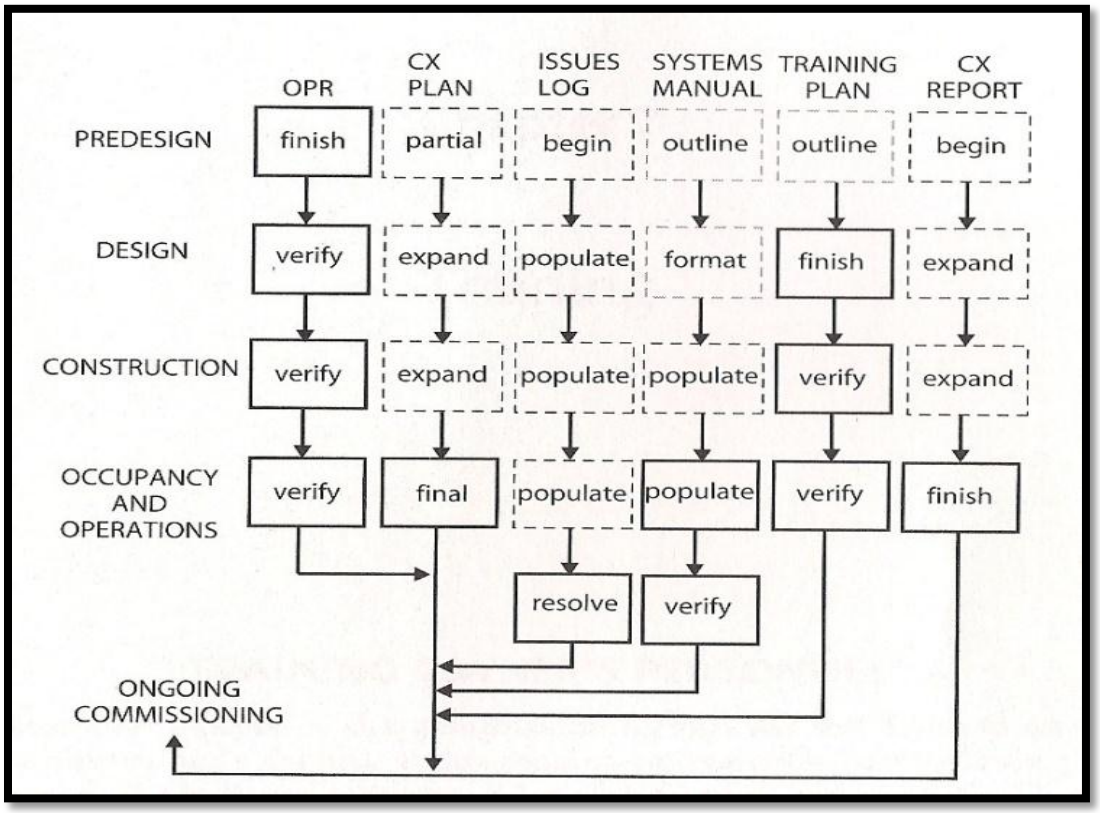

Figure 2.18: The development of commissioning documents during the project phases (Grondzk, 2009).

2.12 Discussion

This chapter presents the literature related to building commissioning, definitions, previous studies, what building commissioning can do and cannot do, types of commissioning, the commissioning team, the commissioning process, commissioning documentation, commissioning costs, and the general benefits of commissioning. The purpose of this is to acquire a comprehensive knowledge of the aspects of the building commissioning process. It has been demonstrated that it is very important for the owner to include the commissioning process early in the programming phase of the project to realize more benefits of the commissioning. Based on the literature, there are only a few countries that have issued guidelines, standards, publications and research reports on the subject, namely USA, Canada, China, Hong Kong, and the United Kingdom. In Saudi Arabia there is a very little information available about this subject. Therefore, direct implementation of international codes and practices may not be suitable for Saudi Arabia. Accordingly, studying the international and the current practice and establishing a recognized building commissioning practice framework will be a strong demand.

CHAPTER 3 Research Methodology

3.1 Research Methodology

The research plan set to achieve the objectives of the thesis consists of six main phases. These phases are illustrated in Figure 3.1, and are described as follows:

3.1.1 Literature Review

This phase implies:

- Searching the literature related to building commissioning in general in order to gain more understanding of the domain area.
- Reviewing international guidelines, books, previous studies, conference proceedings, and internet to prove the basis for the data collection.
- Reviewing some case studies that are relevant to this study.

This phase helps to build the foundation for the research work and to explore potential areas for the commissioning process that are associated with the topic in the Kingdom of Saudi Arabia. This exercise further helps in developing the data collection forms and the questionnaire survey.

3.1.2 Data Collection

To investigate the current practice of building commissioning in Saudi university buildings, personal interviews will be carried out with samples from the principal group involved with the design, construction, and acceptance phases of Saudi University projects. For the interviews, a list of questions is developed for the purpose of

investigating the level of awareness that project team members have about building commissioning as well as the challenges and the limitations of these practices.

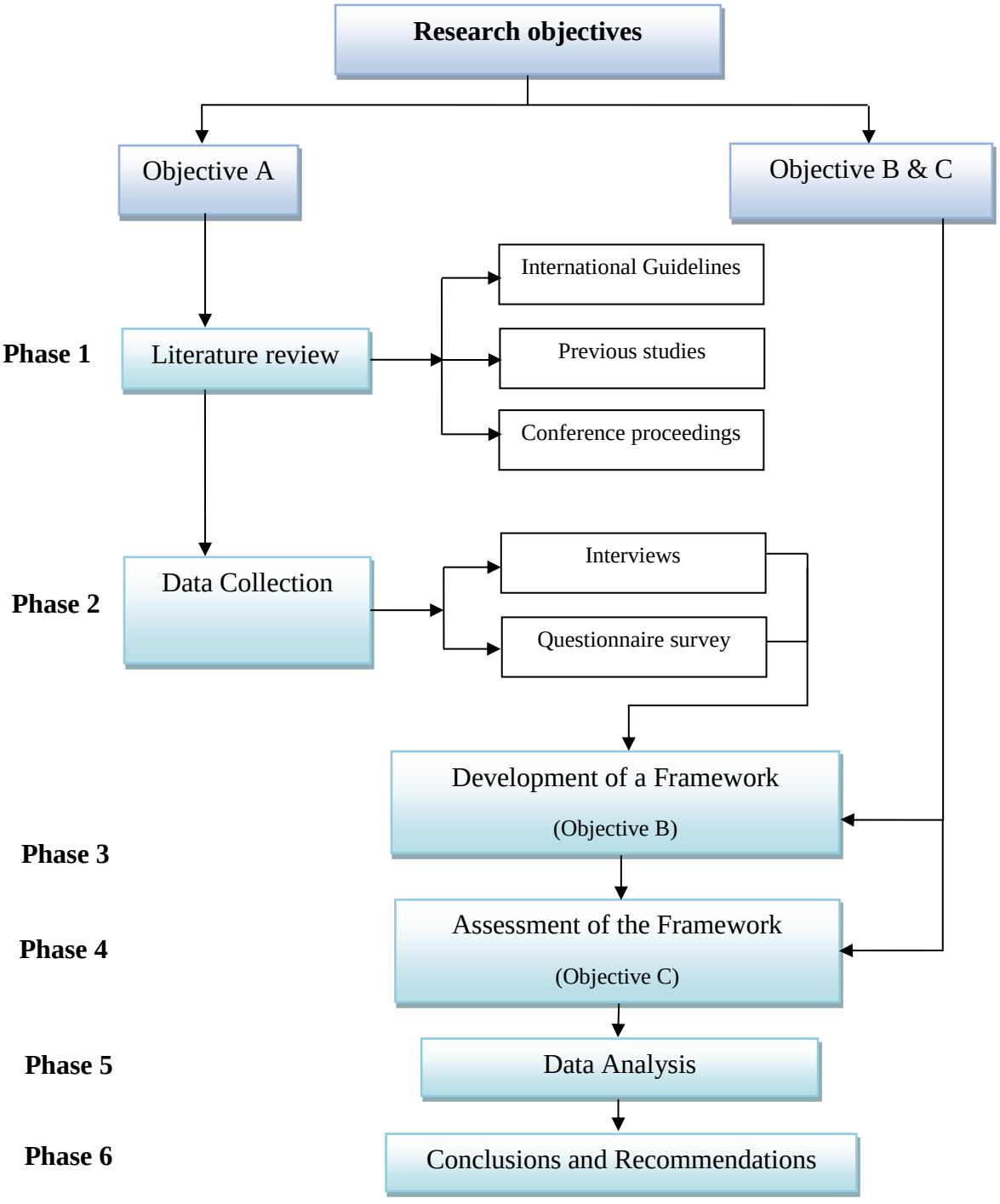

Figure 3.1: Methodology Chart

3.1.3 Development of Potential Framework

During this phase of research the information obtained from the above two phases is used in the developing of a framework for procuring commissioning services for building construction projects in Saudi Arabian universities. A process model displays the interactions between activities in terms of inputs and outputs while showing the controls placed on each activity and the types of resources assigned to each activity. This potential framework will be the primary source of information for developing the final framework model.

3.1.4 Assessment of the Framework

This is one of the important phases of the research methodology. The assessment will eventually lead to the assessment of the applicability of the developed framework in Saudi Arabia and to the modification of the developed potential framework if required. This phase will be carried out through the following steps:

3.1.4.1 Development of questionnaire surveys

An electronic questionnaire survey will be developed and emailed to a representative sample of owners\managers, architects, and engineers in the Eastern Province, Riyadh and Jeddah.

The developed questionnaire survey will consist of three parts, as follows:

Part I. This part contains general questions about the respondent's area of professional practice as well as his experience.

Part II. This part of the questionnaire will focus on the level of awareness that respondents have about building commissioning.

Part III. This part of the questionnaire will focus on the respondent's opinions and advice to assess the applicability of the developed framework, and by selecting (Yes) or (No) to state whether their firm performs the identified functions or not.

The respondents to the questionnaire survey will be asked to mark in their perceived relative degree of importance for each of the identified function through selecting one of five evaluation terms:

"**Extremely Important**" with 4 points.

"**Important**" with 3 points.

"**Moderately Important**" with 2 points.

"**Not Important**" with one point.

"**Extremely Not Important**" with zero points.

3.1.4.2 Pilot-testing of the questionnaire survey

Before the final distribution of the questionnaire survey, pilot-testing will be conducted with a selected sample of project managers in the Eastern Province of Saudi Arabia for the purposes of:

- Testing the adequacy of the questions.
- Pointing out locations of ambiguities.
- Incorporating additional possible functions.

- Reviewing the adequacy of provided spaces for each question.
- Estimating the needed time for filling out the surveys.

3.1.5 Data Analysis

This phase will be carried out to statistically analyze the data received from all categories of respondents to the questionnaire survey. Analyzing the obtained data will statistically identify the importance of each function that included in the building commissioning framework by using a "Likert type scale". Using Ms. Excel, this phase will be carried out through the following step:

Calculation of the importance index

Using Excel program, an important index will be calculated to reflect the level of importance of those functions. This index will be calculated using the following equation (Dominowski 1980):

$$\textbf{Importance index } I = \frac{\sum_{i=0}^{4} aixi}{4 \sum xi} \times 100 \quad \% \qquad \textbf{(1)}$$

Where:

i = Response category index where i= 0, 1, 2, 3, 4

ai = Wight given to i response where i= *0, 1, 2, 3, 4*

xi = variable expressing the frequency of i as illustrated in the following:

$\boldsymbol{x0}$ = frequency of **"Extremely Important"** response corresponding to $a0$ = **4**.

$\boldsymbol{x1}$ = frequency of **"Important"** response corresponding to $a1$ = **3**.

***x*2** = frequency of **"Moderately Important"** response corresponding to *a*2 = **2.**

***x*3**= frequency of **"Not Important"** response corresponding to *a*3 = **1**.

***x*4** = frequency of **"Extremely Not Important"** response corresponding to *a*4 = **0**.

To reflect the scale of the respondents' answers to the questionnaire, the importance index of 0–<12.5% is categorized as ''Extremely Not Important'';

12.5–<37.5% is categorized as ''Not Important''; 37.5–<62.5% is categorized as ''Moderately Important''; 62.5–<87.5% is categorized as ''Important''; 87.5–100% is categorized as ''Extremely Important.''

3.1.6 Conclusion and recommendation

In this phase conclusions, recommendations, and suggestions for any future studies in similar subjects are provided.

CHAPTER 4 THE PRACTICE OF BUILDING COMMISSIONING IN SAUDI UNIVERSITY BUILDINGS

4.1 Introduction

This chapter presents an investigation of the current practice of building commissioning in Saudi University buildings. Interviews were carried out with selected samples of project managers/Engineers at the project departments in some Saudi Arabian Universities. The interviews were carried out for the purpose of understanding the procedure or services that are used to ensure that the building systems are performing efficiently and safely and in accordance with contract specifications, design, bill of quantity, and the owner's requirements.

4.2 Methodology of Interviews

Interviews were carried out with a selected sample of nine project managers/engineers at the project departments in the following Saudi Arabian Universities:

- King Fahd University of Petroleum and Minerals
- King Abdul Aziz University
- King Faisal University
- King Saud University
- Dammam University

The interviews focused on identifying the current practices of how to perform the procedure or services that used to ensure that the building systems are performing safely and in accordance with contract specifications, design, and the owner's requirements, as

well as to identify the problems that face the current practices for procuring commissioning services in the new construction projects in Saudi Universities. The conducted interviews were structurally based on a developed standard set of questions (shown in Appendix 1). Details of these interviewees are included in Appendix 3.

4.3 Discussion of the Current Practice

The number of universities in the Kingdom founded over the past 10 years has increased to 25 universities. They have a diverse set of infrastructural facilities which include educational and administration buildings, student and faculty housing, utilities and service networks. Because the number of universities has increased and there is huge development of construction projects in the university cities, this study focused on the practice of using building commissioning to improve their building performance.

Interviews were carried out at five Saudi Arabian universities. The following sections provide a description of the commissioning process involved in the construction projects:

King Fahd University of Petroleum & Minerals

King Fahd University of Petroleum & Minerals is located in Dhahran, near the headquarters of the Saudi Arabian Oil Company (SAUDI ARAMCO) in the Eastern Province of Saudi Arabia. The campus of the University features a physical plan of exceptional beauty and size. The Academic complex consists of 31 major buildings, which are completed and in use. At the same time, there are a number of projects under implementation.

According to the commissioning process at King Fahd University of Petroleum & Minerals, the interviews indicated the following:

- All the new projects to be carried out by the project department include the implementation stage of the building systems commissioning process during the handover phase of the project. (Figure 4.1: illustrates the main process that applies to all construction projects at KFUPM).
- This service is usually implemented by the general contractor or the sub-contractor and sometimes the contractor needs to hire a third party to perform this service.
- The pricing of this service is considered part of the contractor's work.
- The main challenge faced during the implementation of this service is the owner's staff's lack of skill and expertise in the commissioning process.
- The commissioning process typically applies to selected systems in the building, namely HVAC, building control systems, alarm systems, sprinkler systems, and lighting systems.
- The criteria used to determine which systems require this services include the size of the project, complexity of the systems, cost of the systems, known equipment risks, and increase in building performance.
- The operation and maintenance staffs should be present during the commissioning and testing of the new building systems.
- This service is still under development and there is a lack of awareness about it among many of the project department staff.

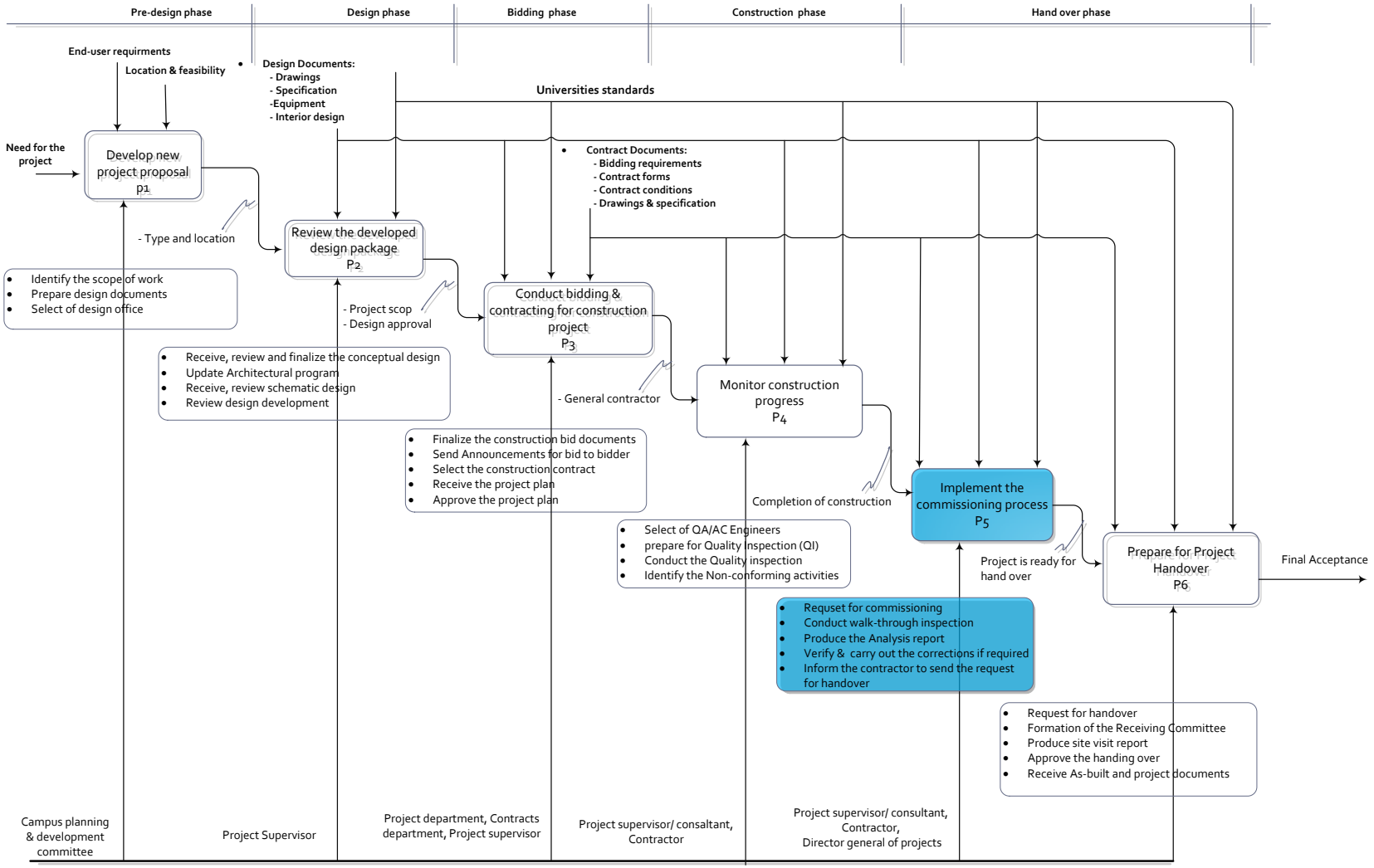

Figure 4.1: illustrates the main process that applies to all construction projects at KFUPM

King Abdul Aziz University

King Abdul Aziz University is located in Jeddah. The campus has a total area of approximately 5,764,000 square meters. The university city of King Abdulaziz university consists of many facilities and large on-going projects. The number of projects under implementation in September 2012 was approximately 128 as show in Table 4.1 (Abdallah, 2012).

Table 4.1: King Abdulaziz University projects under Constructions (Abdallah, 2012)

Total Projects	**128**
Number of projects from the university budget	108
Number of projects from the Ministry of Higher Education budget	20
Total Value SR	**7.298.887.127**
Value of projects from the university budget	5,231,077,897
Value of the projects from the Ministry of Higher Education budget	2,064,809,230

According to the commissioning process at King Abdul Aziz University, the interviews indicated the following:

- The preparation for the commissioning process started during the construction phase by development the commissioning plan.
- This service usually implemented by the general contractor and the pricing of this service considered part of the contractor's work.

- The main challenges faced during the implementation of this service are the lack of the time and the poor expertise of owner's staff.
- The commissioning process supply typically relate to selected systems in the building namely: HVAC, building control systems, alarm systems, and lighting systems.
- The criteria that are used to determine which systems required this service include the size of the project, complexity of the systems, cost of the systems, known equipment risks, and increase in building performance.
- The operation and maintenance staffs should be present during the commissioning and testing of the new building systems.

King Faisal University

King Faisal University is located in Al-Ahsa in the Eastern Province of Saudi Arabia. The campus has a total area of approximately 4,800,000 Sq. m. The University has a number of projects and large facilities from academic buildings and housing for students and teachers, as well as a number of other projects under construction. The total cost to establish a university town is estimated at about 2.16 billion riyals (Al-Arab, 2012).

According to the commissioning process at King Faisal University, the interviews with project managers indicated that:

- All the new projects to be carried out by the project department at King Faisal University include the commissioning and testing service during the construction phase of the project.

- This service is usually performed by the sub-contractor or the company that is responsible for procurement and installation of the building systems.
- The main challenge faced during the implementation of this service is the lack of expertise and skill of the owner's staff.
- The commissioning process typically applied to selected systems in the building, namely HVAC, building control systems, alarm systems, and lighting systems.
- The criteria used to determine which systems required this service include the size of the project, complexity of the systems, cost of the systems, known equipment risks, and increase in building performance.
- The operation and maintenance staffs should be present during the testing of the new building systems.

King Saud University

King Saud University is located in Riyadh. It was founded in 1957. The University has a best potential of both human and material resource. These possibilities are reflected in the huge development of the university's infrastructure.

According to the commissioning process at King Saud University, the interviews indicated that:

- All the new projects to be carried out by the project department at King Saud University include the implementation stage of the building systems commissioning process during the handover phase of the project.

- There is no commissioning plan prepared for this process to define the commissioning requirements, schedule of commissioning process activities, commissioning team and their responsibilities.
- There are no commissioning checklists for use during the commissioning.
- This service is usually performed by the general contractor.
- The main challenge faced during the implementation of this service is the lack of time.
- The commissioning process typically applied to selected systems in the building namely: HVAC, buildings control systems, alarm systems, and lighting systems.
- The criteria used to determine which systems required this service include complexity of the systems, known equipment risks.
- The operation and maintenance staffs should be present during the commissioning and testing of the new building systems.

University of Dammam

The University of Dammam is located in Dammam, in the Eastern Province of Saudi Arabia. It was founded in 2009. The university city comprises about 150 academic and service buildings, located on an area of five square kilometers (El-Sadat, 2012).

According to the commissioning process at the university of Dammam, the interviews indicated that:

- The University of Dammam performs the commissioning service for the total building systems and the pricing of this service is considered part of the contractor's work.

- This service is usually implemented by the general contractor or the sub-contractor and sometimes the contractor has to hire a third party to perform it.
- The main challenge faced during the implementation of this service is the lack of expertise and skill of the owner's staff.
- The commissioning process typically applied to total building systems.
- The criteria used to determine which systems required this services include the size of the project, complexity of the systems, cost of the systems, known equipment risks, and increase in the building performance.
- The main problem during the commissioning phase is that the operation and maintenance staffs are not present during the commissioning and testing to improve their familiarity with the building systems.

4.4 The Results of the Interviews

To gain insight into the practice of the building commissioning process in Saudi Universities, a series of focused interviews were undertaken and the collected data is presented as follows:

- The interviews indicated that the service used to ensure that the building systems are performing safely and according to contract specifications, design, bill of quantity and the owner's requirements is called commissioning and testing. This service is usually performed during the handover phase of the project.
- The interviews indicated that there are different possible levels of commissioning, and many choices of how to commission. For small, less complex systems, the general contractor or the sub-contractors can perform the commissioning of their

systems. For larger, more complex systems, the contractor should hire a third party to perform the commissioning process of their systems.

- The interviews revealed that the commissioning process typically applied to selected systems in the building namely:
  - HVAC
  - Building control systems
  - Alarm systems
  - Sprinkler systems
  - Lighting systems
- The interviews revealed that there are many criteria used to determine which systems should be commissioned. These criteria include the size of the project, complexity of the systems, cost of the systems, known equipment risks, and increase in the building performance.

4.5 Problems Related to the Current Practice

The findings revealed that the service of using the building commissioning process in new construction projects in Saudi universities has been used for many years, but that it is not effective and is still in early development. Several challenges were identified, as follows:

4.5.1 Lack of a clear methodology or guidance on the commissioning process

Interview findings indicated that there exist no frameworks or guidelines for managing the commissioning process and defining the policy and procedure pertaining to the complete commissioning of new projects at Saudi universities' projects. This service was

performed depending on nature of the work at each university as well as the experience of the project managers and engineers. Consequently, several problems may arise such as change orders at later stages; lack of coordination among the project parties, and lack of clear definition of roles, functions and responsibilities of concerned parties in the commissioning process of new projects.

4.5.2 Lack of experience in the building commissioning process

Interviews confirm that one of the major problems in the building industry in Saudi universities is the lack of experience in the building commissioning process among the project parties. From the results of interviews, it was found that some of the owner's staff do not know exactly what is means by building commissioning and its benefits, so they had difficulty in understanding the commissioning process and getting involved in the project process.

4.5.3 The government's requirements

Interviews confirm that the Government's requirements do not allow for more than three procurements or contracts: for design, consultancy, and general contracting. Therefore, a separate contract of commissioning service directly with the owner will be difficult. Consequently, the commissioning service will be automatically part of the general contractor's work.

4.5.4 Lack of Time Allocated for the Commissioning Process

Interviews revealed that one of the major challenges that faced the project manager is that the commissioning service is performed during the last stages of the projects. This caused a time constraint as well as poor preparation and implementation of the commissioning process.

4.6 DISCUSSION

This chapter presents the identification of the current practices of building commissioning in Saudi University projects. It describes the procedure or services used to ensure that the building systems are performing safely and in according with contract specifications, design, bill of quantity, and the owner's requirements. Structured interviews, based on a developed standard set of questions, were conducted with nine project managers and A\E at five universities in Saudi Arabia.

Most of the interviewees believed that their current practices in building commissioning are still in the early development stage. A number of major problems have been identified: lack of a clear methodology or guidelines that manage the commissioning process, lack of experience of the owner's staff to perform the commissioning and testing, change order at a later stage of the project, and lack of time allocated for the commissioning process.

The next chapter will present a development of the framework model for managing the commissioning process of a new project. The framework models will be developed as Integration Definition for Functional Modeling. The proposed framework will be developed based on knowledge gained from the international literature, observed professional practice and the current practice.

CHAPTER 5 DEVELOPMENT OF A FRAMEWORK MODEL FOR MANAGING THE BUILDING COMMISSIONING PROCESS

5.1 Introduction

This chapter presents the development of the framework model for procuring commissioning services on building construction projects in Saudi Arabia. This framework aims to identify the activities, roles, functions and responsibilities of the concerned parties in the commissioning process of new projects and to outline the procedure in carrying out the responsibilities of the various parties involved in the commissioning process.

The proposed framework is developed based on knowledge from the international literature, observed professional practice and the current practice in Saudi Arabia. The framework, presented as a process model, is generic, meaning that the activities involved can be adapted and applied to any project type. The framework model developed herein is presented as an Integration Definition for Functional Modeling process model (Federal, 1993). A process model displays the interaction between activities in terms of their inputs and outputs while showing the controls placed on each activity and the types of resources assigned to each activity.

5.2 Building Commissioning Framework

The framework model consists of five sequential processes. For each of the processes, a number of supporting activities have been defined. As shown in Figure 5.1, the five processes forming the framework model can be described as follows:

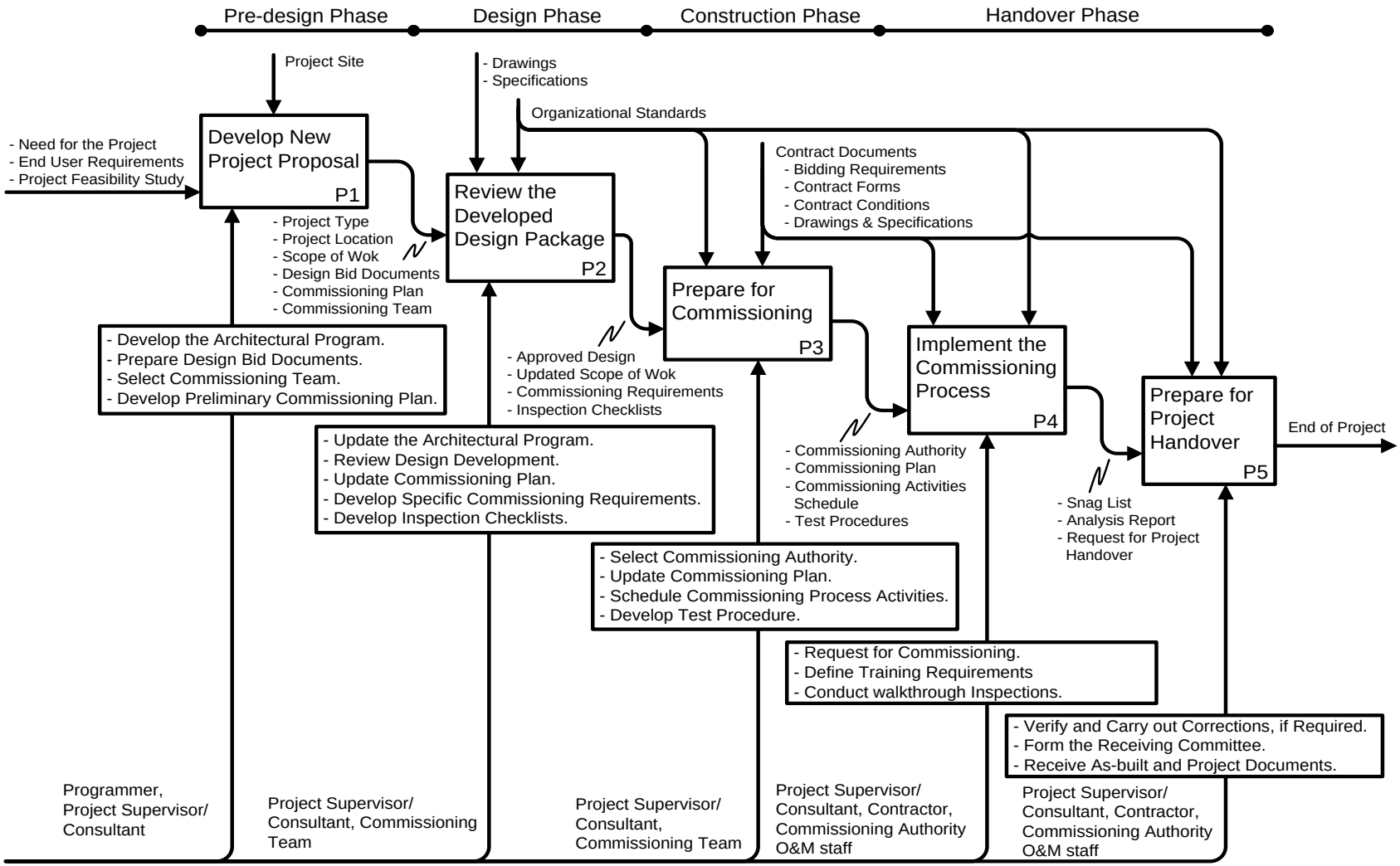

Figure 5.1 general processes involved in the building commissioning framework model

1. Develop new project proposal.
2. Review the developed design package.
3. Prepare for commissioning.
4. Implement the commissioning process.
5. Prepare for project handover.

5.2.1 Develop new project proposal

5.2.1.1 Process Definition

The “Develop new project proposal” process (node “P1” as shown in Figure 5.1) involves investigating the development of the new project proposal and the commissioning process that is carried out in parallel with the project proposal development. The inputs necessary to carry out this process are the need for the project, the end-user requirements, and the project feasibility study. The outputs of this process are a statement of the functional and operational requirements, the architectural program that identifies the scope of work, statements on the project type, design bid documents, the commissioning team, and the initial commissioning plan.

This process is divided into four functions as shown in Figure 5.2. The following paragraphs provide a description of the functions involved.

5.2.1.2 Process Activities

Develop the Architectural program (P1.1): The earliest step in all projects involves developing the architectural program. It is also named as the “scope of work”, “facilities program” or “owner project requirements”.

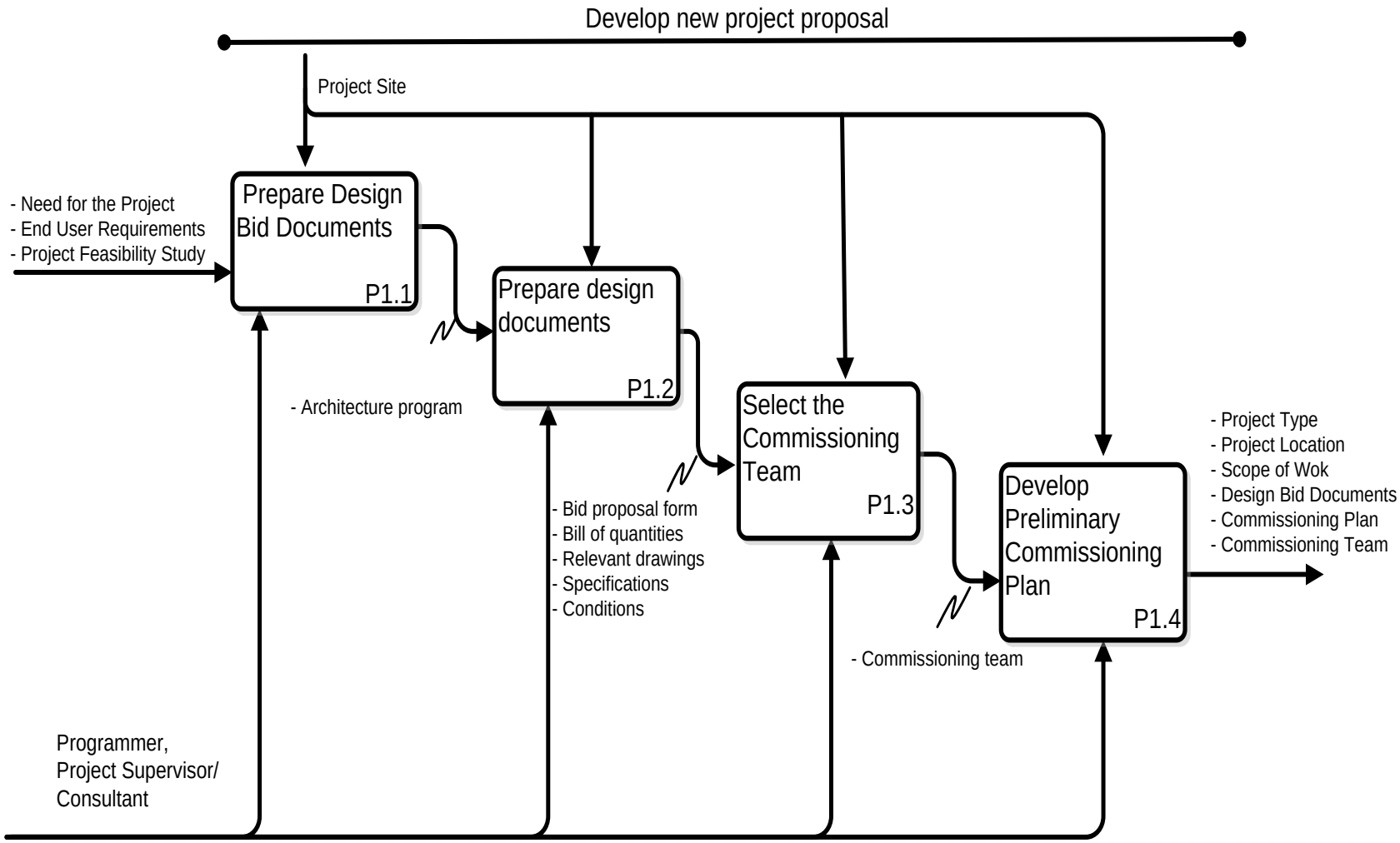

Figure 5.2: Develop new project proposal

The architectural program is a formal document prepared by the owner (or someone designated by the owner) that contains the needs and expectations for a proposed facility (Grondzik, 2009). This document includes information and procedures that provides a successful plan, design, construction operation, and maintenance service (ASHRAE, 2005; Turkaslan-Bulbul, and Akin, O. 2006; Brown, 2007; Elzarka, 2009).

Prepare design bid documents (P1.2): This function serves to prepare the design bid documents that would be submitted in response to an invitation to bid. These include bid proposal form, bill of quantities, relevant drawings, technical specifications, and general and supplementary conditions (Halpin, 2006; Al-Marhoon, 2012). Bidding and contracting for the design project is the next step after preparing the bid design documents.

Select the commissioning team (P 1.3): This function serves to select the commissioning team from the project department (or other departments as required, depending upon the scope of the project). The owner should start the pre-design phase by selecting the commissioning team (Turkaslan-Bulbul, and Akin, O. 2006; Chen, et all, 2011). The most important responsibility of the commissioning team is to clearly communicate the expectations about the project outcome to the project team. Below is an outline of typical commissioning team members and their responsibilities in the process (Energy, 2005; CCC, 2006; BCA, 2011):

- Owner’s representative
- User’s representative
- Design professionals
- System specialists if required
- Commissioning authority (CxA)

The main responsibilities of the commissioning team are:

- Determining the goals and direction of the project.
- Reviewing the project design in coordination with the design office.
- Reviewing the qualifications of the commissioning provider, if necessary.
- Creating avenues of communication between all the commissioning team members.
- Developing and submitting manpower requirements for the project.
- Developing an operational plan for the project including commissioning plan and commissioning process schedule.
- Determining the budget, schedule, and team members needed to successfully complete the project.
- Working with the commissioning provider (if there is one) to work through the details and technical aspects of the commissioning process.
- Approving start-up and functional test completion.

Develop preliminary commissioning plan (P1.4): This function serves to develop the preliminary commissioning plan that identifies the commissioning process as well as to provide a guideline for the commissioning team members to explain the owner's project requirements and define the scope and budget for the commissioning process (ASHRAE, 2005; CCC, 2006). The developed commissioning plan would be updated during each phase in the project for the purpose of keeping up with any modifications in the planning, design, construction, and operations (Brown, 2007).

5.2.2 Review the developed design package

Process definition

The "Review the developed design package" process (node "P2" as shown in Figure 5.1), involves reviewing the design documents that were developed during the design phase by the design office to ensure that the design documents meet the owner's requirements. Elzarka, (2009) indicated that the projects that include the commissioning process in the early stage of the project usually derive more benefits than others.

The inputs to this process are statements on the project type and location, scope of work, initial commissioning plan, commissioning team, and design documents. The outputs from this process are the updated scope of work, approved design, specific commissioning process requirements and the inspection checklists. This process is divided into five functions as shown in Figure 5.3. The following sections provide a description of the functions involved.

Process activities

Update the architectural program (P2.1): This function serves to update the developed architectural program during the predesign phase to include the additional information obtained during the design phase for the purpose of developing the construction documents (BCA, 2011).

Review design development (P2.2): This function serves to have the design development reviewed by the commissioning team from the conceptual phase to the final design development (Turkaslan-Bulbul, and Akin, O. 2006; Toombs, 2007; BCA, 2010; Turner, et all, 2012).

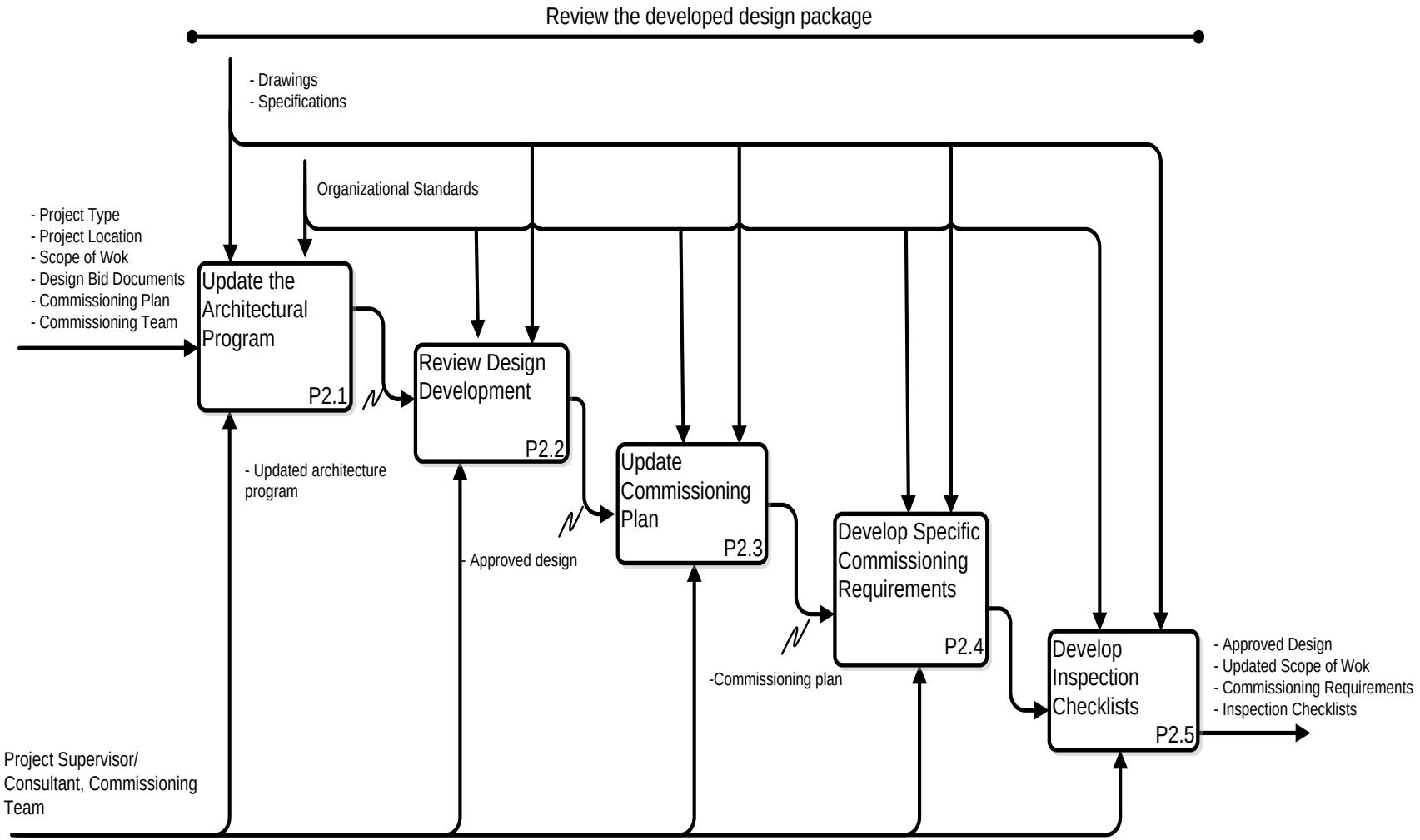

Figure 5.3: Review the developed design package

Elzarka (2009) indicated that project design review by the commissioning team provides for early identification of any potential design problems. Enck, (2010) indicated that most of the projects have three to four reviews, and this number of commissioning design reviews depends on the size and complexity of a facility.

Update the commissioning plan (P2.3): This function serves to update the commissioning plan during the design phase for the purpose of including additional information and to show the activities that will be conducted during the construction and handover phases (Brown, 2007). The items that will be updated or added to the commissioning plan are as follows (ASHRAE, 2005):

- The systems that will be commissioned.
- The roles and responsibilities of the commissioning team.
- The commissioning process activities, schedule, protocols, and commissioning procedure.

Develop specific commissioning requirements (P2.4): This function serves to develop the commissioning process requirements that should be included in the contract documents (Grondzik, 2009; Turner, et all, 2012). The contract documents should include the commissioning process meeting, scope and responsibilities of all parties, documentation requirements, training requirements, and requirements for testing systems and assemblies, construction checklists, specific equipment, access and coordination issues, and all details of the commissioning process and specification of who must carry out the commissioning and testing process (Turkaslan-Bulbul, and Akin, O. 2006; BCA, 2011).

Develop inspection checklists (P2.5): This function serves to develop the inspection checklists that will be used to provide details on the architectural program for systems and equipment. The inspection checklists include the following (ASHRAE, 2005):

- Equipment verification. This part of the checklist includes the necessary information about the equipment or materials that will be submitted and delivered to the project site.
- Pre-installation checks. This part of the checklist is used to confirm the state of the equipment and materials at the site.
- Installation checks. This part of the checklist is used to confirm that the installation of the equipment/materials is according to the project scope and construction documentation.

5.2.3 Prepare for Commissioning

Process definition

The "prepare for commissioning" process (node "P3" as shown in Figure 5.1), involves a number of activities depending on the size and complexity of the project. The inputs necessary to carry out this process are A statement of the updated scope of work, approved design, commissioning requirements, the developed checklists, and the design documents. The outputs generated from this process are the commissioning authority, the updated commissioning plan, commissioning activity schedules, and test procedures.

This process is divided into four functions as shown in Figure 5.4. The following paragraphs provide a description of the functions involved.

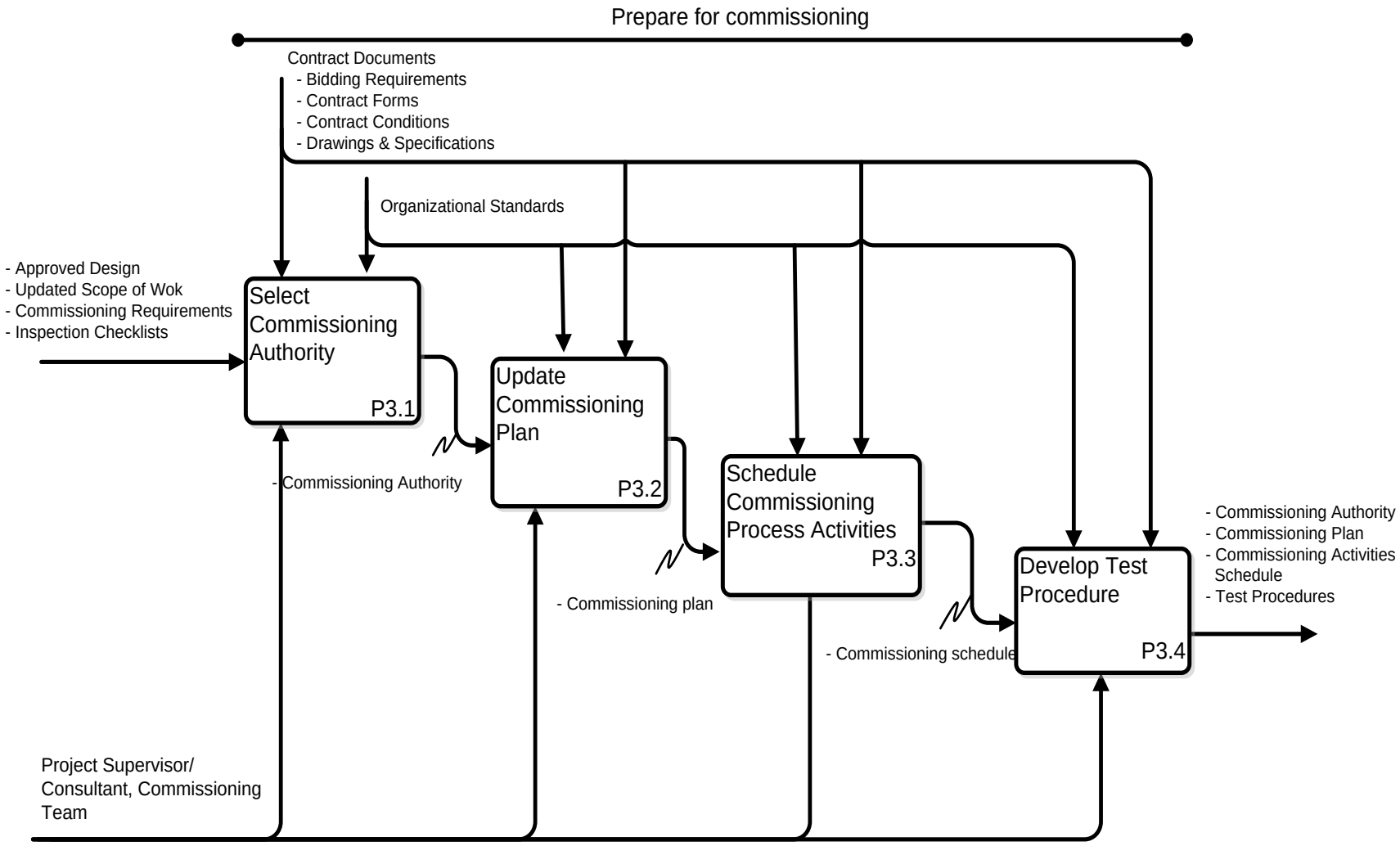

Figure 5.4: Prepare for commissioning

Process activities

Select the commissioning authority (P3.1): This function serves to select the commissioning authority. The commissioning authority can either be a member of the owner's staff, designers or contractor, or an independent commissioning authority (CCC, 2006a; Djuric, and Novakovic, 2009). The literature recommends hiring an independent third-party to provide the required commissioning service as this might be the best choice for the owner (Brown, 2007; Elzarka, 2009). ASHRAE (2005) suggested that "the commissioning authority will be an independent contractor and not an employee or subcontractor of the General Contractor or any other subcontractor on this project, including the design professionals".

Update the commissioning plan (P3.2): This function serves to update the commissioning plan during the construction phase to reflect any changes to the project, or to include new details of the commissioning activities. The updated commissioning plan will provide descriptions of the commissioning activities that will be developed during the construction phase, for example test procedure, roles and responsibilities of the new commissioning team during the construction phase, and the schedule of the commissioning process activities (CCC, 2006a). Grondzik (2009) indicated that the commissioning plan should be updated to include more details on the commissioning process activities that will take place during the occupancy and operation phase.

Schedule the commissioning process activities (P3.3): This function serves to schedule the commissioning process activities to coordinate them with the other construction phase activities (ASHRAE, 2005; Enck, 2010). The commissioning schedule should be

developed by the commissioning authority and should include all the commissioning activities and their durations from the start to end (Wilkinson, 2000).

Develop test procedures (P3.4): This function serves to develop the test procedures that describe the methods to carry out the tests that are required during the construction phase (Turner, et all, 2012). Nicholson and Molenaar (2004) indicated that the testing procedure should be developed before the handover phase and discussed with the contractor to enable him to understand the commissioning process easily and more efficiently.

5.2.4 Implement the commissioning process

Process definition

The "Implement the commissioning process" (node "P4" as shown in Figure 5.1) involves implementing the commissioning and testing process. This process is carried out by the commissioning team to ensure that the compliance of the building systems are ready for handing over as per contract specifications, design, and required conditions. The inputs necessary to carry out this process are the commissioning authority, commissioning plan, commissioning schedule activities, and the test procedures. The outputs generated from this process are the completion of commissioning and testing activities, snag list, analysis report, and the start of the handover phase. The snag list is defined as a list of quality defects at the end of the building process (Heinz, and Casanlt, 2004).

This process is divided into three functions as shown in Figure 5.5. The following paragraphs provide a description of the functions involved.

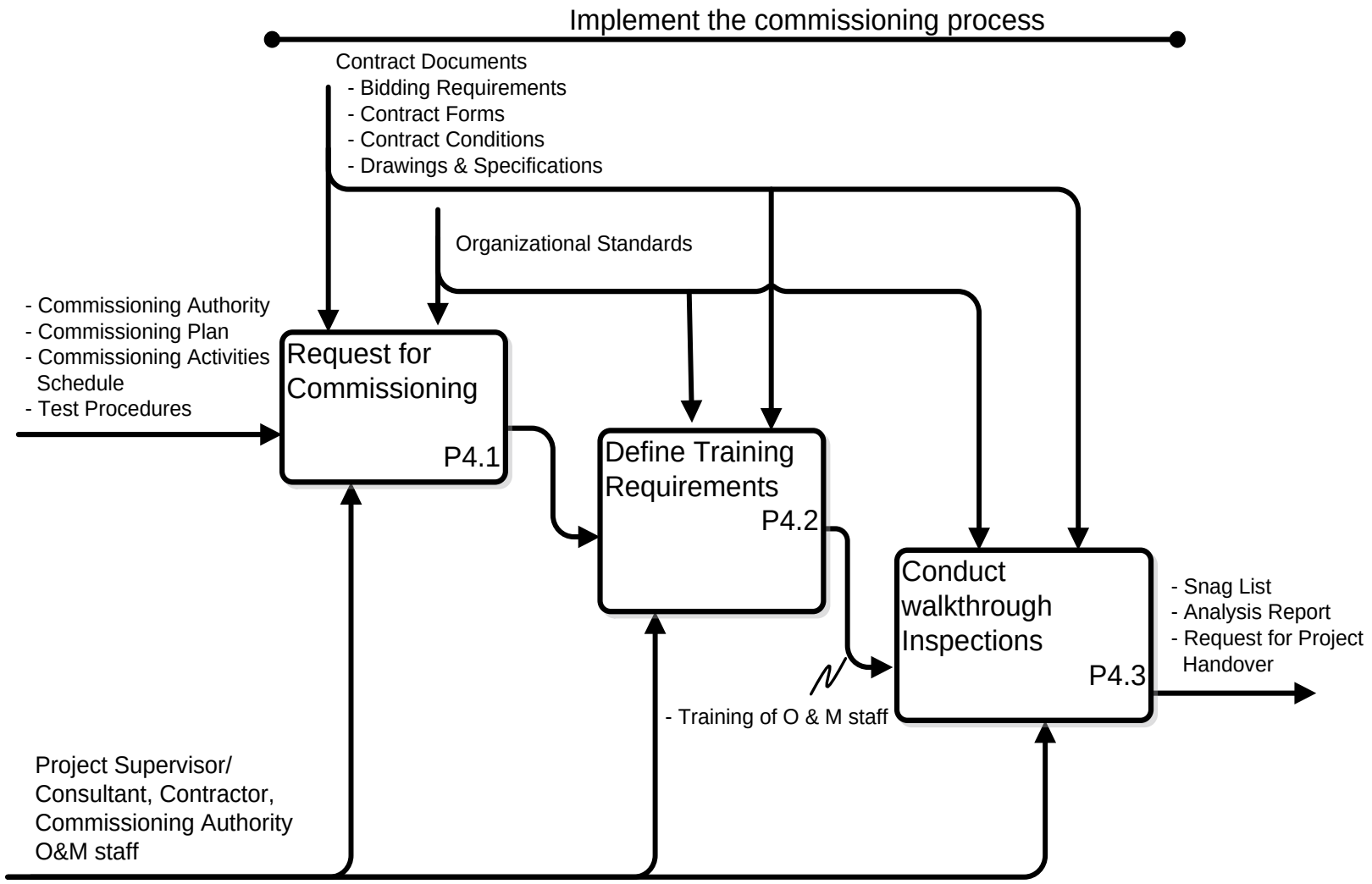

Figure 5.5: Implement the commissioning process

Process activities

Request for commissioning (P4.1): This function serves to identify the contractor is request for commissioning. This request is filed by the contractor to inform the owner that the project is ready for handing over.

Define the training requirements (P4.2): This function serves to define the training requirements for the operation and maintenance staff that should be implemented by the project contractors and documented and verified by the commissioning authority (Enck, 2010; Chen, et all, 2011). The training program should provide the necessary information about adjustment instruction, maintenance and inspection procedure, repair procedure, and the emergency instruction for operating the facility during the different conditions (CCC, 2006). Turkaslan-Bulbul, and Akin, O. (2006) indicated that training program needs to be carried out before testing because the operation and maintenance staff who attend testing need to be familiar with the new systems.

Conduct walk-through inspections (P4.3): This function serves to identify building components that do not comply with the owner's project requirements. The commissioning authority will visit the site and conduct the performance tests to verify that all systems meet the specifications defined in the design, and will fill in the project commissioning checklist (Meuro, 2005; Elzarka, 2009). Based on the findings, the commissioning authority will prepare an analysis and snag list reports. These reports are forwarded for corrective actions.

5.2.5 Prepare for project handover

Process definition

The "Prepare for project handover" process (node "P5" as shown in Figure 5.1), involves preparing for the stage in the construction where the building is ready for handover to the owner, usually at the stage of practical completion.

The inputs necessary to carry out this process are the analysis report and request for project handover from the contractor. The output generated from this process is the end of the project. This process is divided into three functions as shown in Figure 5.6. The following paragraphs provide a description of the functions involved.

Process activities

Carry out corrective actions if required (P5.1): This function serves to perform the required corrections by the contractor. The functions of verifying and carrying out corrections will continue until the commissioning team is satisfied (Elzarka, 2009). If the project commissioning team is satisfied with the completion of the project, they will inform the contractor to send the request for handover.

Form a receiving committee (P5.2): This function serves to form the receiving committee for the final acceptance of the project. The receiving committee will conduct a walk-through inspection to verify that corrective actions have been implemented based on the analysis and snag list reports (Al-Marhoon, 2012). Based on the findings, the receiving committee can either approve the project, or disapprove the project. If the committee disapproves the handing over, a snag list report shall be dispatched to the contractor along

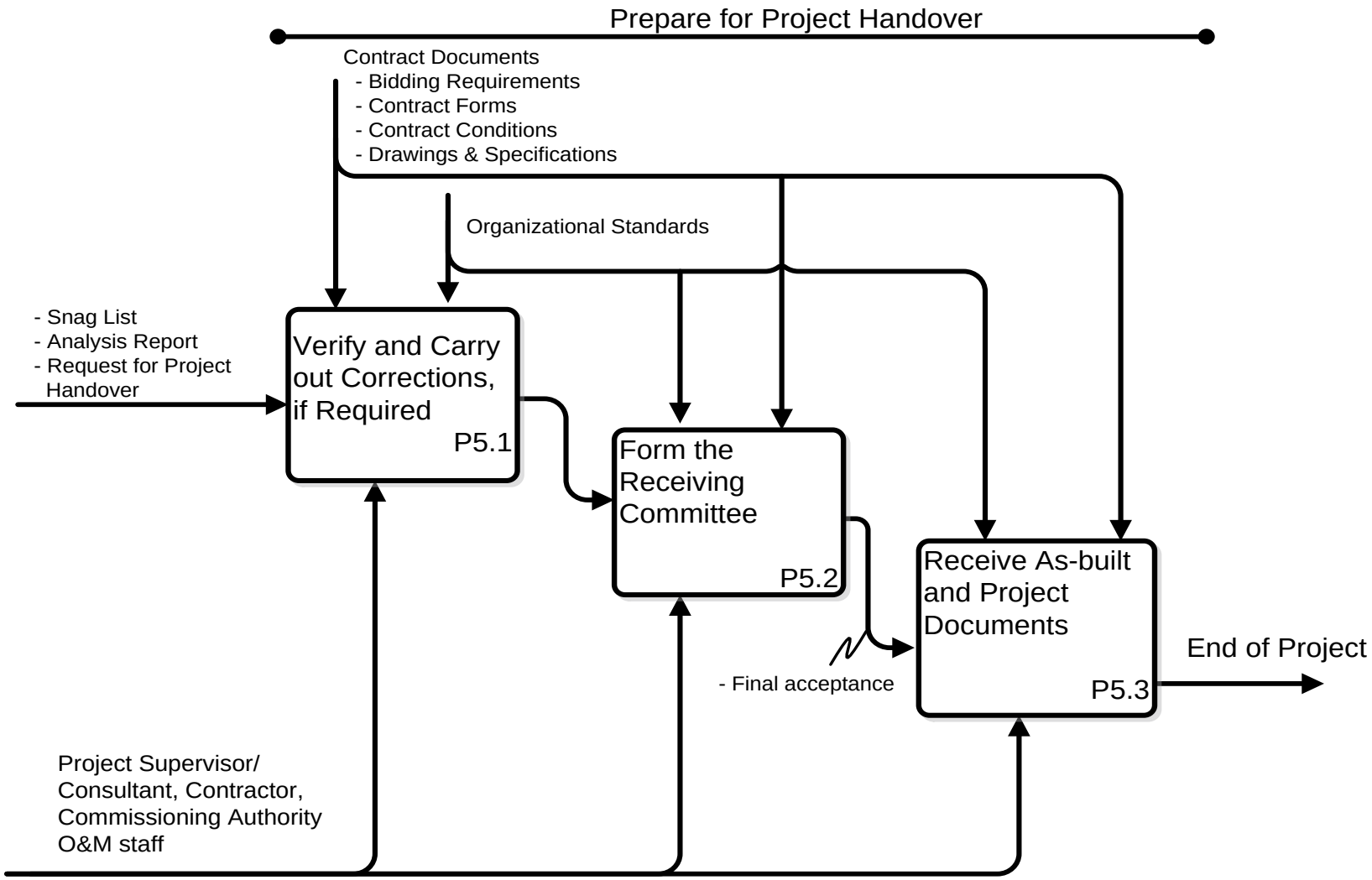

Figure 5.6: Prepare for project handover

with points for remedial actions. On the other hand, if they approve the handing over of the project, it will be considered to have been received officially.

Receive as-build and project documents (P5.3): This function serves to receive the record drawing that have been developed by the contractor to demonstrate the actual dimensions, maintenance manual and locations of installations after the construction work has been completed (Brown, 2007).

5.3 Discussion

The term building commissioning has gained great attention worldwide. To realize more benefits of the commissioning process it is important to start the commissioning early in the conceptual design phase of a new building and continues through the design phase, construction phase, and the handover phase of the project (Grondzik, 2009). The commissioning process enhances communication among the project team members that help to identify problems early and prevent issues from developing (BCA, 2011).

Interview findings indicated that there exist no frame workings or guides that used to manage the commissioning process and define the policy and procedure pertaining to the complete commissioning of the new projects at Saudi Universities' projects. This service performed depending on nature of the work at each University as well as the experience of the project managers and engineers. Consequently, several problems may arise such as change orders at later stages; lack of coordination among the project parties, and absence of the clear roles, functions and responsibilities of concerned parties in the commissioning process of new projects. The findings revealed that current practices of building commissioning are not really effectively.

The framework model developed herein is presented as Integration Definition for Functional Modeling process models (Federal, 1993). A process model displays the interaction between activities in terms of their inputs and outputs while showing the controls placed on each activity and the types of resources assigned to each activity.

Usefulness of the developed framework as follows:

- Providing owners/project managers a clear idea about all the building commissioning process that should be carry out from the predesign phase until the handover phase of the project.
- Describing the commissioning process that should be implemented for each phase and illustrate the parties who perform this process.
- Including the commissioning team during the early stages of the project to manage all the commissioning process.
- Dividing the commissioning process into three stages: planning, preparing during the design and construction phases, and implementing during the handover phase of the project.
- Providing flexible process where all the activities involved can be updated and applied to any project type.

CHAPTER 6 DATA ANALYSIS

6.1 Introduction

The proposed framework was developed based on knowledge gained from the international literature, observed professional practice and the current practice in Saudi Arabia. The proposed framework was assessed to investigate the applicability of the developed framework in Saudi Arabia.

The proposed framework was assessed through developing, testing and administering of the questionnaire survey as described in the following:

6.2 Development of Questionnaire Survey

An electronic questionnaire survey was developed online and distributed to a representative sample of owners\managers, architects, and engineers in the Eastern Province, Riyadh and Jeddah.

The developed questionnaire survey was consisted of three parts as follows:

Part I: This part of the questionnaire contains general questions about the respondent's area of professional practice as well as his experience.

Part II: This part of the questionnaire focused on the level of awareness that respondents have about building commissioning.

Part III: This part of the questionnaire focused on the assessment of the applicability of the developed framework.

6.3 Pilot-testing of the questionnaire survey

Before the final distribution of the questionnaire survey, pilot-testing was conducted with a selected sample of project managers in the Eastern Province of Saudi Arabia for the purposes of:

- Testing the adequacy of the questions.
- Pointing out areas of ambiguity.
- Incorporating additional possible functions.
- Reviewing the adequacy of provided spaces for answers to each question.
- Estimating the time needed for filling out the surveys.

6.4 Distribution of the Tested Questionnaire Survey

At this step, an electronic questionnaire survey was developed online to increase the efficiency of completing the survey and analyzing the results. The survey was e-mailed to **200** owners\managers, architects, and engineers in the Eastern province, Riyadh, and Jeddah. The respondents to the questionnaire survey were asked to mark their perceived relative degree of importance for each of the identified the functions of through selection one of five evaluation terms; "**Extremely Important**", "**Important**", "**Moderately Important**", "**Not Important**" and "**Extremely not Important**". The respondents to the questionnaire survey were also asked to explain whether their firm performs identified functions by selecting (Yes) or (No).

Due to that there were many respondents who were not helpful. There were 120 responses to the questionnaire survey, and the response rate was 60% from the Eastern Province, Riyadh and Jeddah.

6.5 Data Analysis

The area of this section was grouped under the following headings:

- Part one. General information.
- Part two. Awareness and perceptions of building commissioning.
- Part three. Assessment of functions pertaining to the commissioning processes during the different project phases.

6.5.1 General Information

This part aims to collect basic factual data about the respondents who answered the survey. It started by asking them about their organization, years of experience they have and their position in their organization. The data received was analyzed using statistical techniques, including percentages and simple graphs.

Respondents' Positions in Their Organizations

The respondents were asked to specify their role in their organizations by choosing one of the three main categories: “engineer/architect”, “manager”, “owner”, or any other position they are holding. As illustrated in Figure 6.1, the results indicated that the majority of respondents 44 % are practicing either as architects or engineers. It was also noticed that 47% are practicing as project managers, and 9 % of respondents are owners.

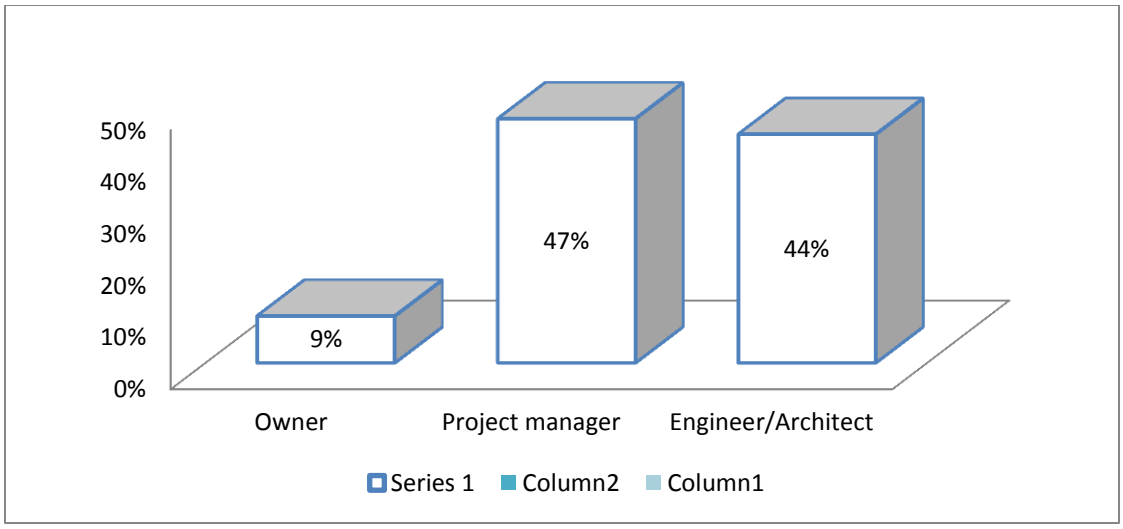

Figure 6.1: Respondent's Positions in Their Organizations

Respondents' Years of Experience

The study considers the respondents' years of experience. The years of experience were classified into four main categories: “Less than 5 years”, “5-10 years”, “10-20 years” and “Over 20 years”. The results showed that 3% of the respondents had been practicing for more than 20 years, 58% have experience ranging between 10-20 years, 29 % have experience ranging between 5 -10 years, while 11% have at least 5 years or less as shown in Figure 6.2.

6.5.2 Awareness of Building Commissioning

The main aim of the second part of the survey is to gain insight into the level of awareness that respondents have about building commissioning. The respondents were firstly asked whether they had heard of “building commissioning” before today. Table 6.1 indicates that 51 % of the respondents had heard of building commissioning, 14 % of the

respondents had heard of and were currently working in building commissioning, and 35 % of the respondents had never heard about building commissioning.

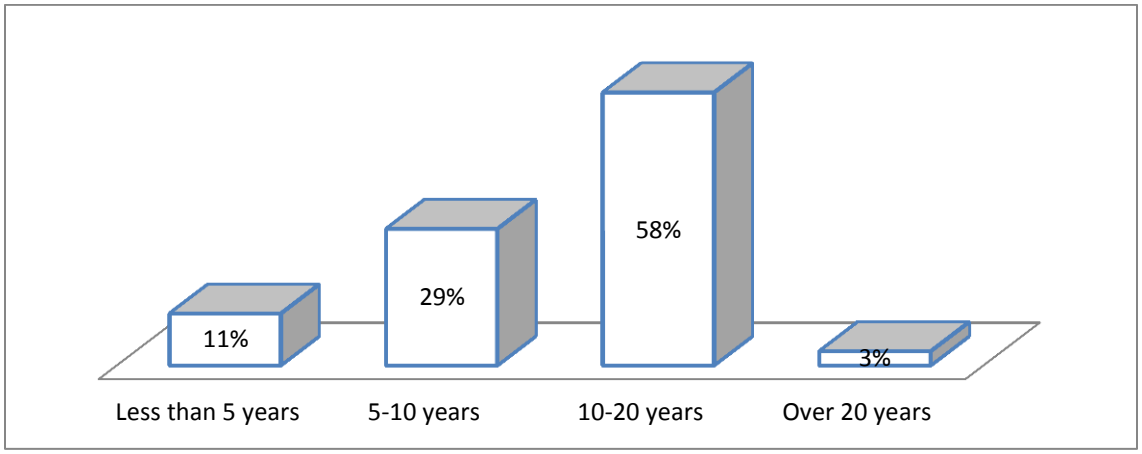

Figure 6.2: Respondents Years of Experience

Table 6.1: Had you heard of "building commissioning" before today?

Main categories	Number of Respondents	Percentage %
Yes	61	51%
Yes, currently I am working in building commissioning.	17	14%
No, I have never heard about building commissioning	42	35%

To explore the awareness of respondents who had heard of building commissioning, they were asked to indicate their level of awareness of building commissioning by choosing one of the following levels of awareness: extremely aware, moderately aware, slightly aware and not at all aware. The results suggest that 8 % of the respondents (6 out of a

total of 78) were extremely aware of the building commissioning process, 36% were moderately aware (28 out of a total of 78), 56 % were slightly aware (44 out of a total of 78) and those was nobody who was not all at aware as shown in Table 6.2.

Table 6.2: The level of awareness of the building commissioning process

Extremely aware	Moderately aware	Slightly aware	Not at all aware
Percentage %	Percentage %	Percentage %	Percentage %
8	36	56	0

In the next open-ended question, respondents were asked how they typically refer to the procedures or services that are used to ensure that building systems are designed, installed, and tested to perform according to the design intent and the building owner's operational needs. Table 6.3 suggests that a wide variety of terms are used to describe these services, 64% of the respondents (50 out of a total of 78) used the term "Commissioning", 14% of the respondents (11 out of a total of 78) used the term "Final inspection", 9% of the respondents (7 out of a total of 78) used the term "Project handover", 6% of the respondents (5 out of a total of 78) used the term "Quality assurance",4% of the respondents (3 out of a total of 78) used the term "Project close out", and 1% of the respondents (1 out of a total of 78) used the term "testing".

6.5.3 Assessment of Functions Pertaining to the Commissioning Processes

The purpose of the third part of the questionnaire survey was to explore the respondents' opinion about the relative importance of all functions pertaining to the commissioning processes. To clarify the meaning of these functions to the respondents, a brief definition of each function was written. The respondents were asked to choose the most appropriate

answer that describes the relative importance of functions pertaining to the commissioning processes and also asked whether their firms perform these functions or not.

Table 6.3: the procedures or services that are used to ensure that building systems are designed, installed, and tested to perform according to the design intent and the building owner's operational needs.

The term of services	Percentage %
Basic services	0
Commissioning	64
Quality assurance	6
Check list	0
Supervising	0
Final inspection/inspection	14
Project close out	4
Project handover	9
Testing	1

Calculation of the Importance Index

As illustrated in Chapter 3, the importance index and mean value have been calculated using Excel Software based on the following equation:

$$\text{Importance index (II)} = \frac{4(n1)+ 3(n2)+ 2(n3)+ 1(n4)+ 0(n5)}{4(n1+n2+n3+n4)} \times\%$$

The importance index was classified as follows to reflect the respondents' answers:

0–<12.5% is categorized as ‘‘Extremely Not Important’’;

12.5–<37.5% is categorized as ‘‘Not Important’’;

37.5–<62.5% is categorized as ‘‘Moderately Important’’;

62.5–<87.5% is categorized as ‘‘Important’’;

87.5–100% is categorized as ‘‘Extremely Important.’’

The above ranges are used to measure each variable using a range from 1 to 100. A summary of the assessed function's mean values and importance indexes is shown in Table 6.4.

Table 6.4: Mean Values and Importance Indexes of the Assessed building commissioning process

	Building Commissioning Process	Mean Value	Importance Index(II) %	Ordinal Scale	Does your firm perform this function?	
					Yes	No
Pre-Design phase						
1	Development of the architecture program based on the requirements of end-user.	3.91	97.75	Extremely Important	100%	0%
2	Selection of the commissioning team (owner group member).	2.98	74.67	Important	38%	62%
3	The responsibility of the commissioning team is to clearly communicate their expectations about the project outcome to the project team.	2.89	72.43	Important	12%	88%
4	Development of the preliminary commissioning plan that identifies the commissioning process.	2.88	72.11	Important	31%	69%
5	The developed commissioning plan should provide a guideline for the commissioning team members to explain the owner's project requirements.	2.83	70.83	Important	14%	86%

Design phase						
6	Update of the developed architectural program during the predesign phase to include the additional information obtained during the design phase	3.70	92.62	Extremely Important	99%	1%
7	Review of the design development by the commissioning team from the conceptual phase to the final design development.	3.17	79.48	Important	58%	42%
8	Update of the commissioning plan during the design phase to include any additional information.	2.76	69.23	Important	19%	81%
9	Development of the specific commissioning requirements including all the requirements for testing systems and assemblies, specific equipment, access and coordination issues, and all details of the commissioning process.	3.37	84.29	Important	53%	47%
10	Specification of who must carry out the commissioning and testing process.	3.60	90.06	Extremely Important	82%	18%
11	Development of inspection checklists that aid the installers by providing specific information on the owner's project requirements for systems and equipment.	3.12	78.20	Important	75%	25%

Construction phase						
12	Selection of the commissioning authority (The commissioning authority can either be a member of the owner's staff, designer, contractor, or an independent third party).	2.89	72.43	Important	15%	85%
13	Update of the commissioning plan during the construction phase to reflect any changes to the project, or to include new details of the commissioning activities.	2.87	71.79	Important	21%	79%
14	Schedule of the commissioning process activities to coordinate them with the other construction process activities.	3.51	87.82	Extremely Important	69%	31%
15	Development of the test procedures that describe the methods to carry out the tests required during the Construction Phase	3.56	89.10	Extremely Important	70%	30%

Hand over phase						
16	Request for commissioning (This request is filed by the contractor to inform the owner that the project is ready for handing over).	3.14	78.52	Important	90%	10%
17	Identify the training requirements for the operations and maintenance staff.	3.37	84.29	Important	51%	49%
18	Conduct a walk-through inspection to identify the building component that does not comply with the owner's project requirements.	3.14	78.52	Important	95%	5%
19	Perform corrective actions, if required (This function serves to perform the required corrections by the contractor).	3.03	75.96	Important	95%	5%
20	Forming of the Receiving Committee (The receiving committee will conduct a walk-through inspection to verify that corrective actions have been implemented based on the analysis and snag list reports).	3.43	85.89	Important	94%	6%
21	Development of As-built drawing and project documents by the contractor to demonstrate the actual dimensions and locations of installations after the construction work has been completed.	3.30	82.69	Important	95%	5%

6.6 Discussion of Results

The responses from the owner, project manager, and A\E respondents are analyzed to assess the applicability of each building commissioning process during each phase of the project. Discussion of assessments results and variances with brief descriptions for each building commissioning process is illustrated in the following sections.

Pre-Design phase

- Considering the previous experiences, figure 6.5 shows how the respondents scored the development of the architecture program based on the requirements of end-user. The result is 91% of the respondents selected it as “Extremely important”, 6% as “important”, and 3% as ‘Moderately Important”, while none of the respondents consider it as “Not Important” or “Extremely not important”. When asked if their firm performs the development of the architecture program based on the requirements of end-user, 100% of the respondents selected ‘Yes”, and 0% selected “No” as shown in figure 6.4. It can be quite easily interpreted from the given figures that respondents perceive the development of the architecture program based on the requirements of end-user as an extremely important process.

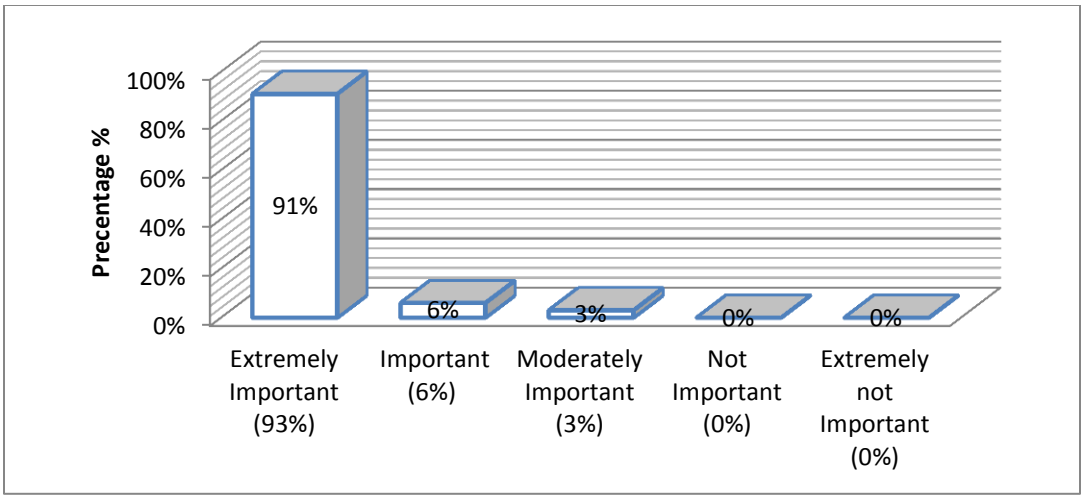

Figure 6.3: Development of the architecture program based on the requirements of end-user

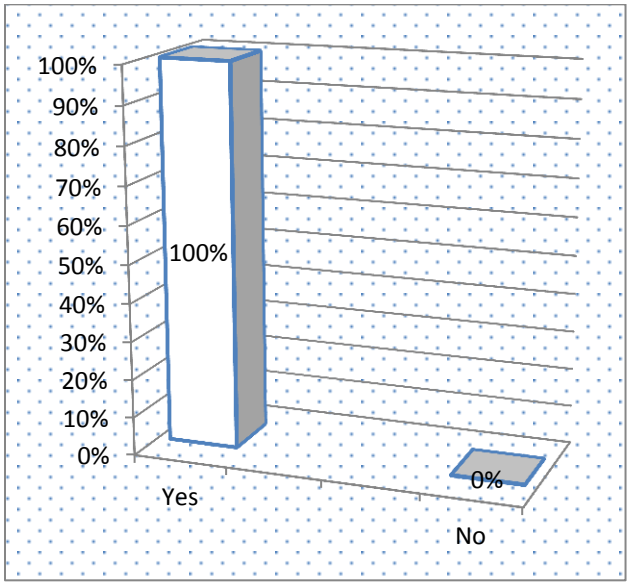

Figure 6.4: Does your firm perform this process?

- Selection of the commissioning team (owner group member) is evaluated according to the responses received from the respondents. Figure 6.5 shows that 1% of the respondents consider it as “Extremely not Important”, and 1% as “Not Important”, whereas 8% of the respondents marked it as ‘Moderately Important”, 77% of respondents selected it as “Important”, and 13% as “Extremely important”. When asked if their firm selected the

commissioning team during the predesign phase, 38% of the respondents selected 'Yes", and 62% selected "No" as shown in figure 6.6. It can be quite easily interpreted from the given figures that respondents perceive selection of the commissioning team as an important process. On the other hand, only 38% of the respondents perform this process.

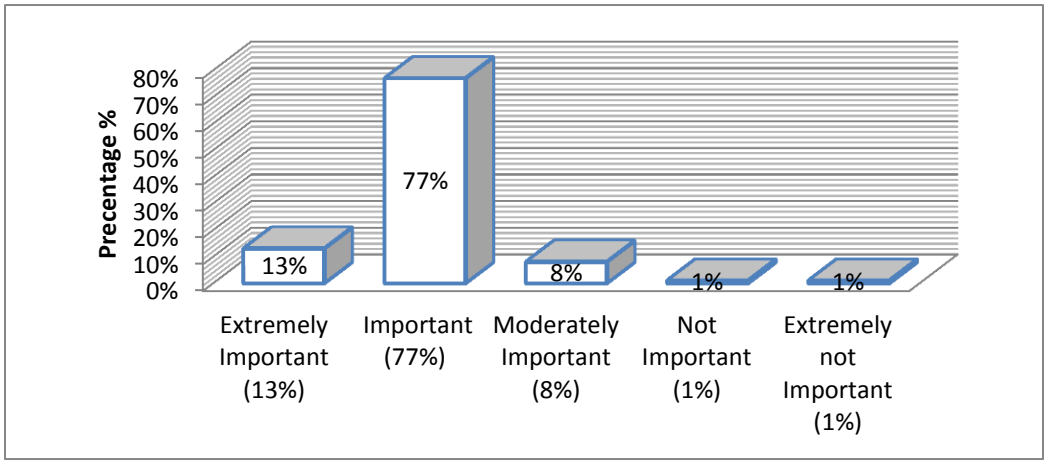

Figure 6.5: Selection of the commissioning team (owner group member

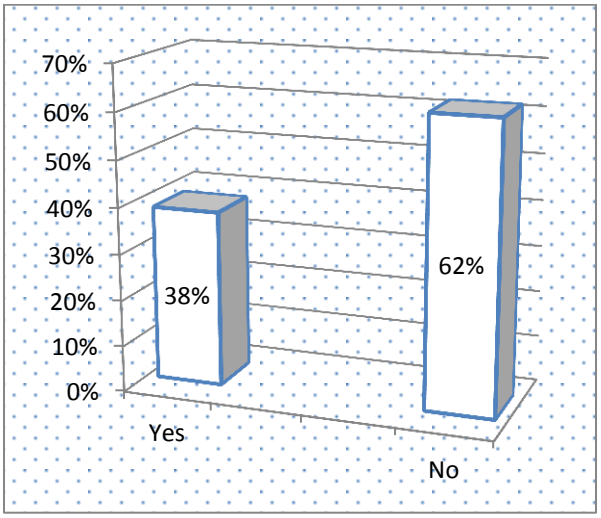

Figure 6.6: Does your firm perform the selection of the commissioning team during the pre-design phase?

- Figure 6.7 shows the respondents responses, in the light of their previous experiences; to the statement (The responsibility of the commissioning team is to clearly communicate

their expectations about the project outcome to the project team). This is considered by 81% of the respondents as “important”, 7% of the respondents scored it as “Extremely Important”, 10% of the respondents as ‘Moderately Important”, 1% as “Extremely not Important”, and 1% as “Not Important”. When asked if their firm performs this service, 12% of the respondents selected ‘Yes”, and 88% selected “No” as shown in Figure 6.8. It can be quite easily interpreted from the given figures that respondents perceive the responsibility of the commissioning team as an important process, yet only 12% of the respondents perform this process in their work.

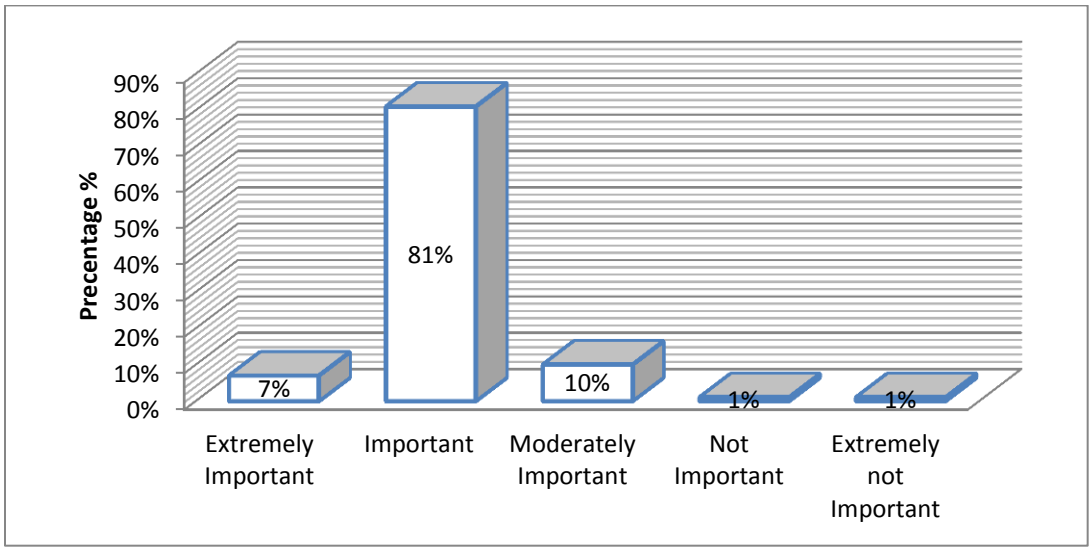

Figure 6.7: The responsibility of the commissioning team

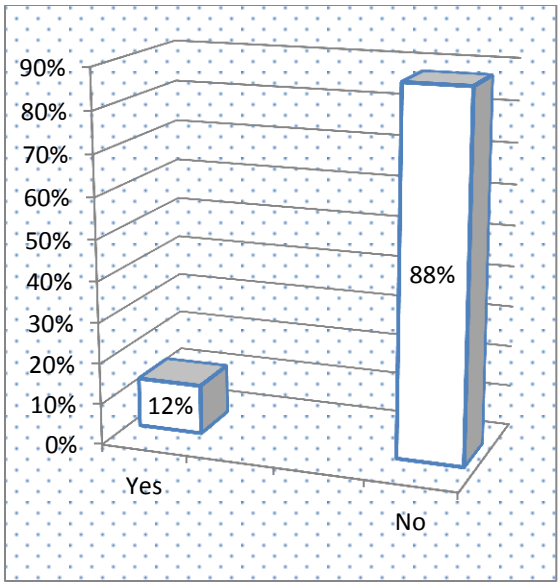

Figure 6.8: The responsibility of the commissioning team is to clearly communicate their expectations about the project outcome to the project team?

- Considering the pervious experiences, figure 6.9 shows how the respondents scored the development of the preliminary commissioning plan that identifies the commissioning process. The result is that 12% of the respondents selected it as “Extremely important”, 72% as “important”, and 14% as ‘Moderately Important”, 1% as “Not Important”, and 1% as “Extremely not important”. When asked if their firm develops the preliminary commissioning plan during the pre-design phase, 31% of the respondents selected ‘Yes”, and 69% selected “No”, as shown in Figure 6.10. It can be quite easily interpreted from the given figures that respondents perceive the development of the preliminary commissioning plan that identifies the commissioning process as an important process, but there are only 31% of them who implement it in practice.

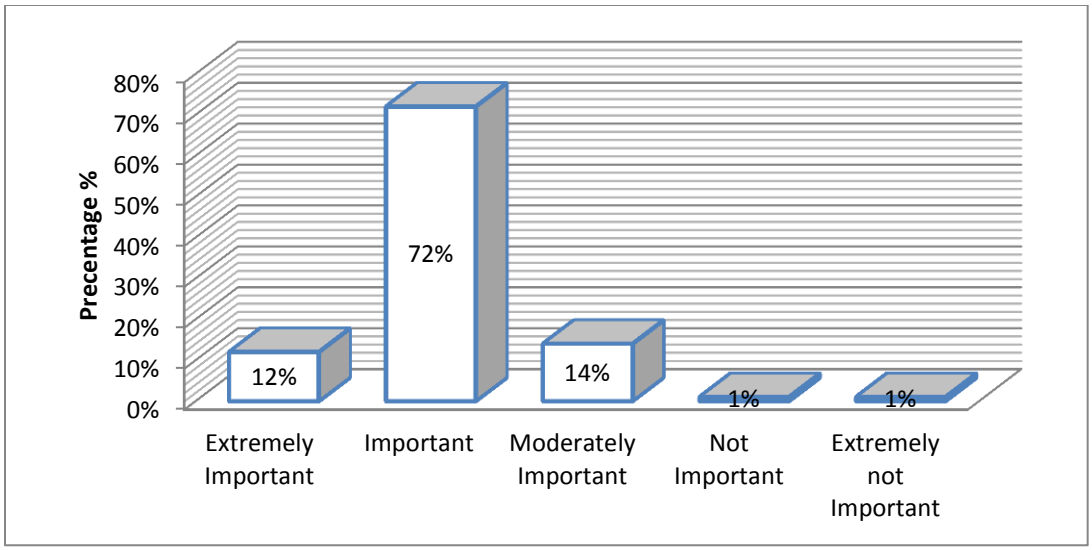

Figure 6.9: Development of the preliminary commissioning plan that identifies the commissioning process

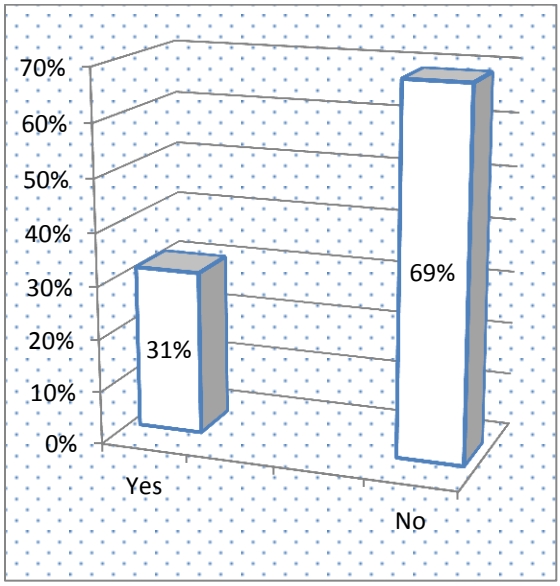

Figure 6.10: Does your firm develop the preliminary commissioning plan that identifies the commissioning process?

- Figure 6.11 shows the respondents' responses, in the light of their previous experiences; to the statement (The developed commissioning plan should provide a guideline for the commissioning team members), is considered by 76% of the respondents as "Important", by 6% as "Extremely Important", 14% of the respondents considered it as 'Moderately Important", by 3% considers it as "Not Important", and by 1% as "Extremely not

Important. When asked if their firm performs this function, 14% of the respondents selected ‘Yes”, and 86% selected “No” as shown in Figure 6.12. Considering the responses, the respondents consider that the developed commissioning plan should provide a guideline for the commissioning team members as an important step in the building commissioning process, but there are only 14% of them who implement it in practice.

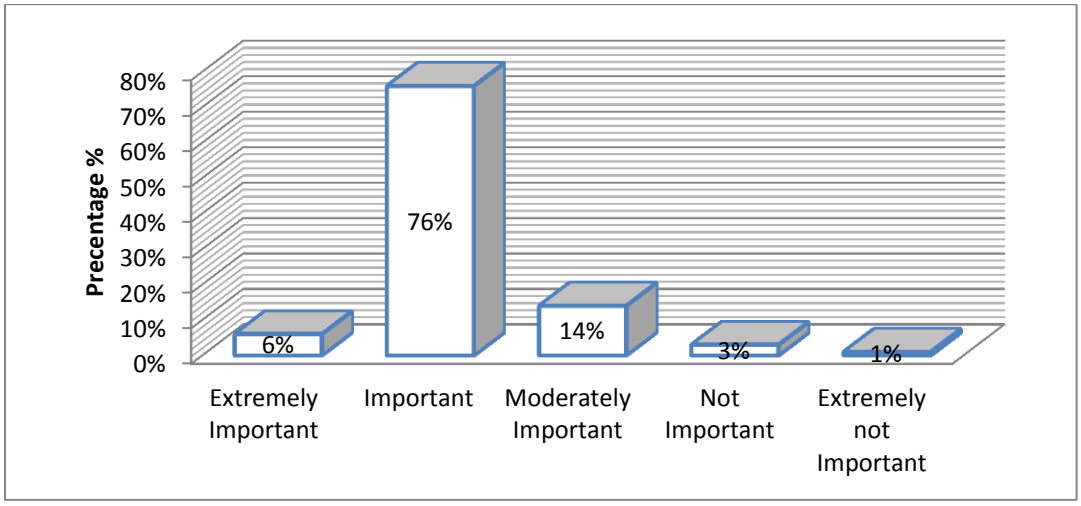

Figure 6.11: the developed commissioning plan should provide a guideline for the commissioning team

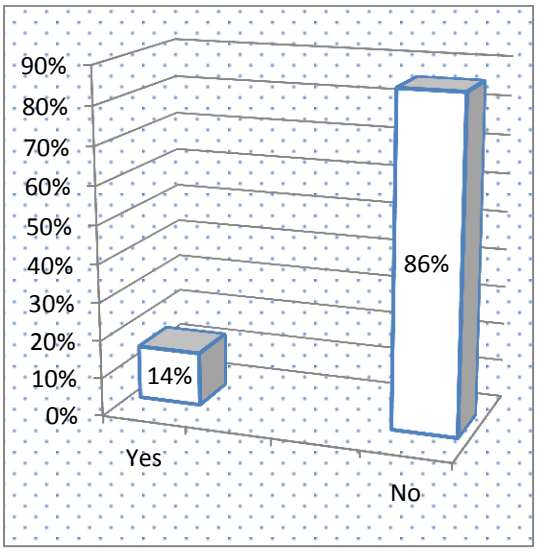

Figure 6.12: Does your firm develop the commissioning plan as a guideline for the commissioning team?

Design phase

- Update of the developed architectural program is evaluated according to the responses received from the respondents. Figure 6.13 shows that none of the respondents have selected it as "Extremely not Important", 1% considers it as "Not Important", whereas 2% as 'Moderately Important", 21% as "important", and 76% as "Extremely important". When asked if their firm Updated the developed architectural program during the design phase, 99% of the respondents selected 'Yes", and 1% selected "No" as shown in Figure 6.14. It can be quite easily interpreted from the given figures that respondents perceive Update of the developed architectural program as an extremely important function, and 99% of the respondents implement it in practice.

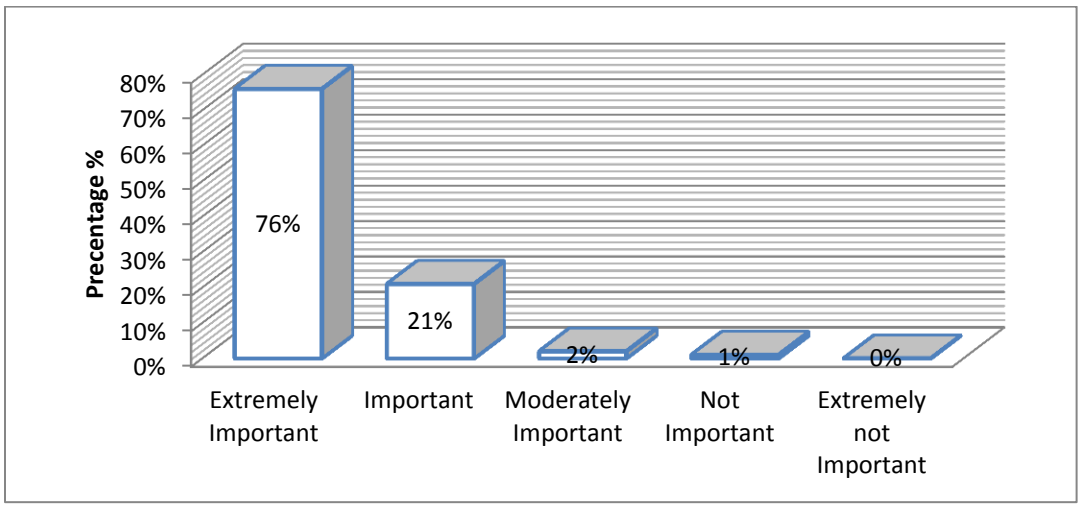

Figure 6.13: Update of the developed architectural program

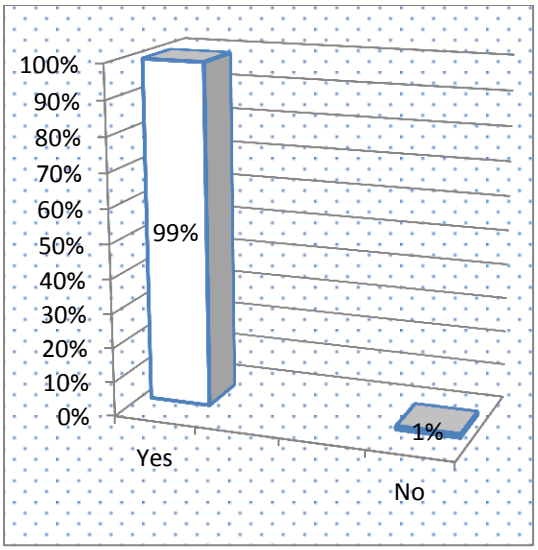

Figure 6.14: Does your firm update of the developed architectural program during the predesign phase?

- Figure 6.15 shows the respondents' responses, in the light of their previous experiences; to the statement (Review of the design development by the commissioning team from the conceptual phase to the final design development), is considered by 26% of the respondents as "Extremely important", 68% as "important", 5% as 'Moderately Important", and 1% as 'Not Important", none of the respondents selected it as "Extremely not Important". When asked if their firm reviews of the design development by the commissioning team from the conceptual phase to the final design development, 58% of the respondents selected 'Yes", and 42% selected "No" as shown in Figure 6.16. It can be quite easily interpreted from the given figures that respondents perceive the review of the design development by the commissioning team as an important process, but there are 58% of them who implement it in practice.

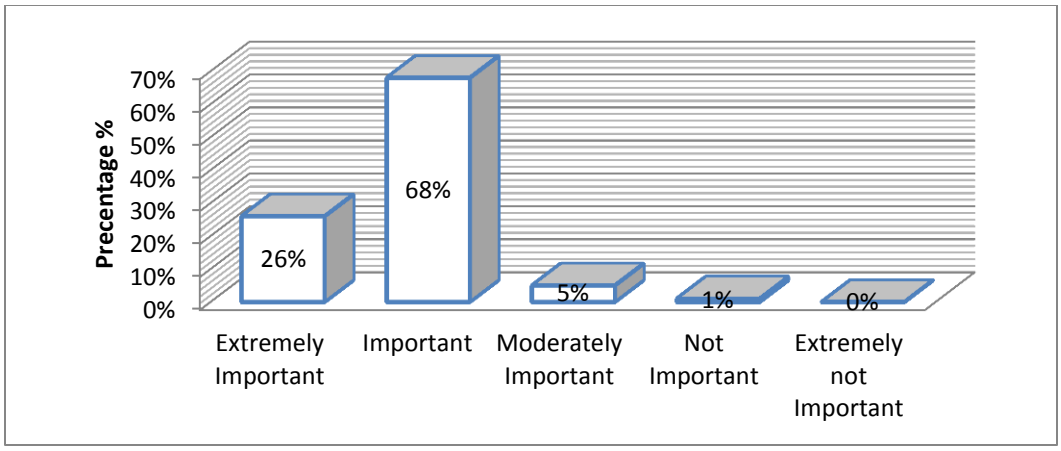

Figure 6.15: Review of the design development by the commissioning team

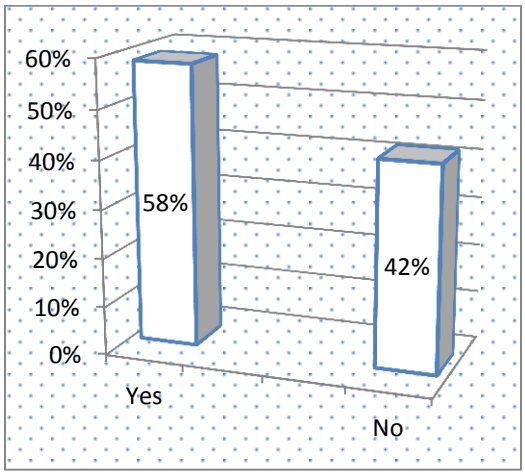

Figure 6.16: Does your firm perform the function (Review of the design development by the commissioning team?

- Figure 6.17 shows the respondents' responses, in the light of their previous experiences; to the statement (Update of the commissioning plan during the design phase to include any additional information), is considered by 78% of the respondents as an "important", 3% as "Extremely Important", 17% as 'Moderately Important", 2% as "Not Important", and none of the respondents selected it as "Extremely not Important". When asked if their firm performs this function, 19% of the respondents selected 'Yes", and 81% selected "No" as shown in Figure 6.18. Considering the responses, the respondents consider that the updated of the commissioning plan during the design phase to include any additional

information as an important step in the building commissioning process, but there are only 19% of them who implement it in practice.

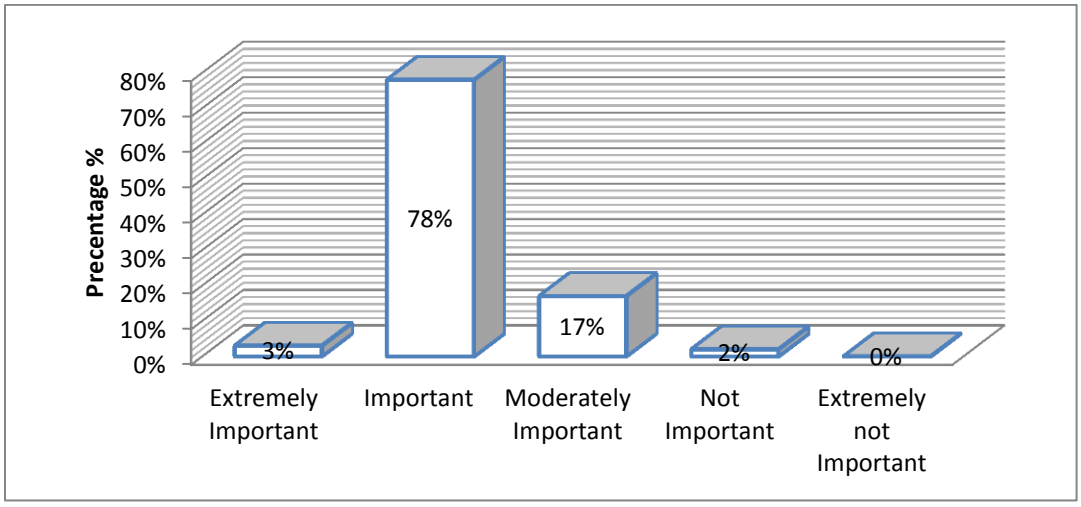

Figure 6.17: Update of the commissioning plan during the design phase

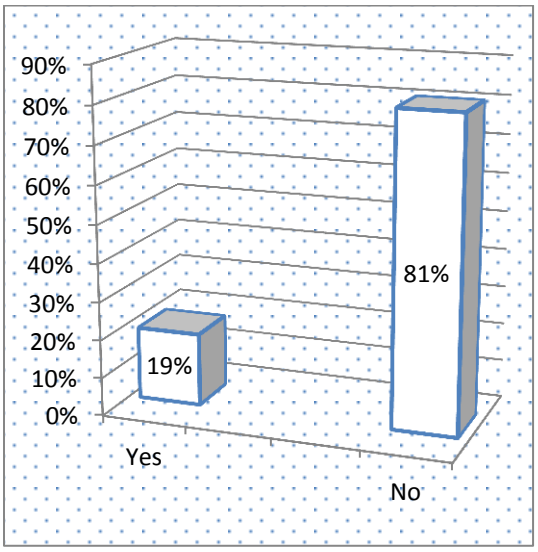

Figure 6.18: Does your firm perform the function (Update of the commissioning plan during the design phase?

- Development of the specific commissioning requirements is evaluated according to the responses received from the respondents as shown in Figure 6.19. None of the respondents have considered it as "Extremely not Important", 1% considers it as "Not

Important", whereas 8% as 'Moderately Important", 44% as "important", and 47% as "Extremely important". When asked if their firm performs this process, 53% of the respondents selected 'Yes", and 47% selected "No" as shown in Figure 6.20. It can be quite easily interpreted from the given figures that respondents perceive development of the specific commissioning requirements during the design phases as an important process and 53% of them implement it in practice.

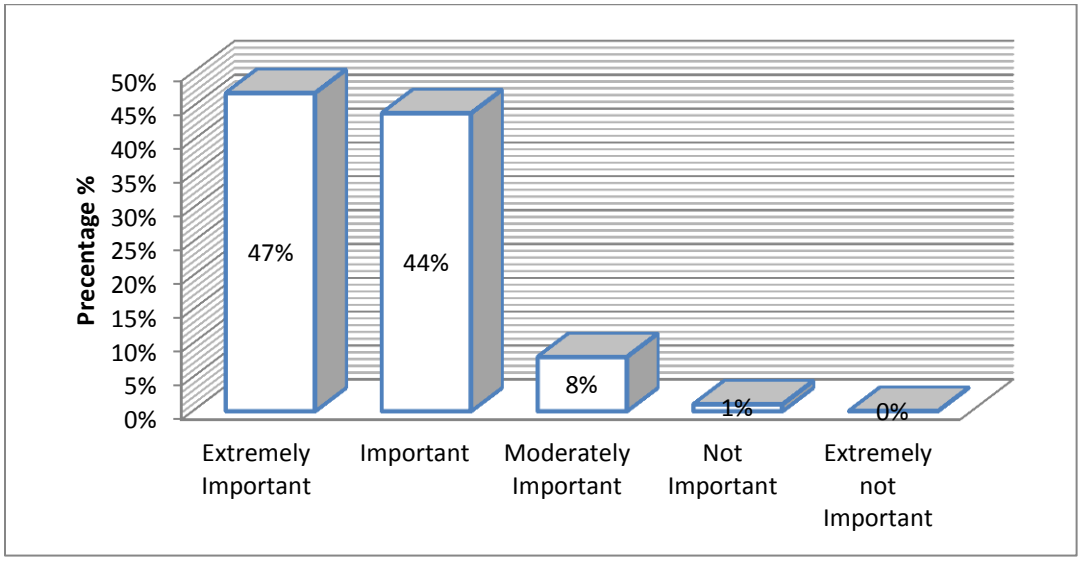

Figure 6.19: Development of the specific commissioning requirements

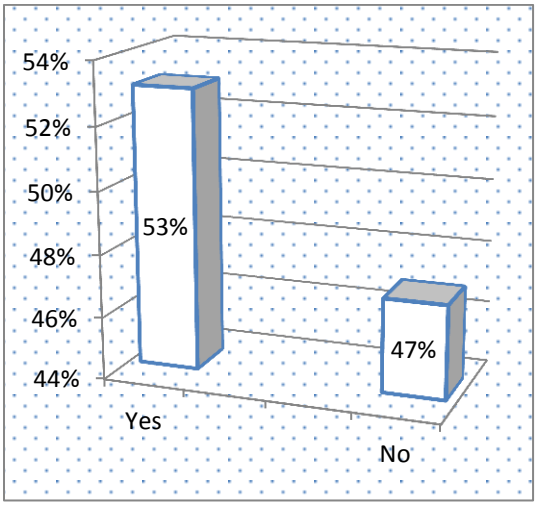

Figure 6.20: Does your firm perform the function (Development of the specific commissioning requirements)?

- Figure 6.21 shows the respondents' responses, in the light of their previous experiences; to the statement (Specification of who must carry out the commissioning process) is considered by73% of the respondents as "Extremely important", 15% as "important", 10% as 'Moderately Important", 2% as 'Not Important", and none of the respondents selected it as "Extremely not Important". When asked if their firm performs this function, 82% of the respondents selected 'Yes", and 18% selected "No" as shown in Figure 6.22. It can be quite easily interpreted from the given figures that respondents perceive the specification of who must carry out the commissioning process as an extremely important process and there are 82% of the respondents implement it in practice.

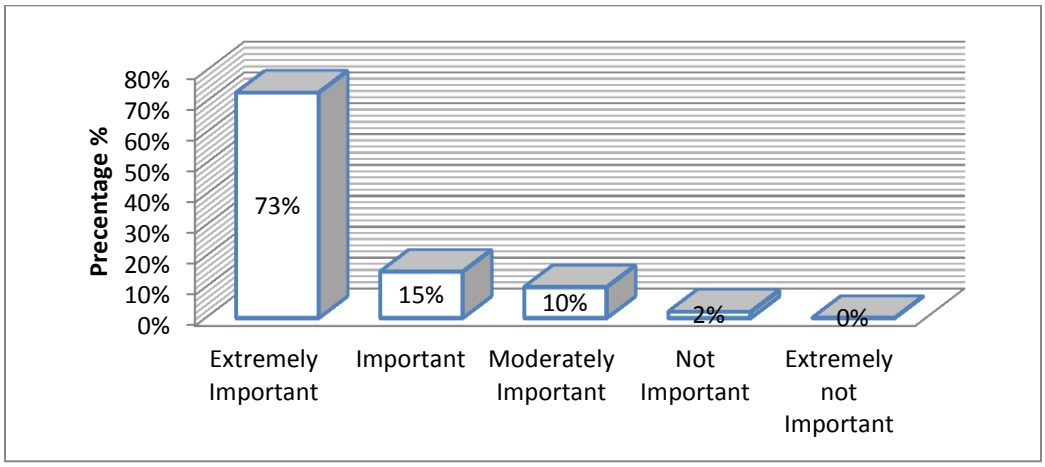

Figure 6.21: Specification of who must carry out the commissioning process

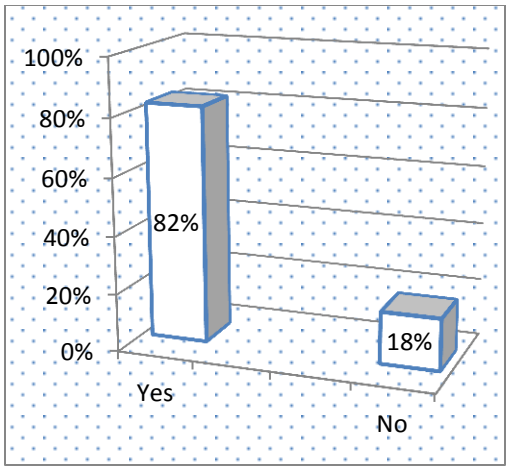

Figure 6.22: Does your firm perform the function (Specification of who must carry out the commissioning process)?

- Figure 6.23 shows the respondents' responses, in the light of their previous experiences; to the statement (Development of the inspection checklists) is considered by 69% of the respondents as an "important", 25% as "Extremely Important", 5% as 'Moderately Important", 1% t as "Not Important", and none of the respondents have selected it as "Extremely not Important". When asked if their firm performs this function, 75% of the respondents selected 'Yes", and 25% selected "No" as shown in Figure 6.24. Considering the responses, the respondents consider that the developed of the inspection checklist as an important step in the building commissioning process and there are 75% of them who implement it in practice.

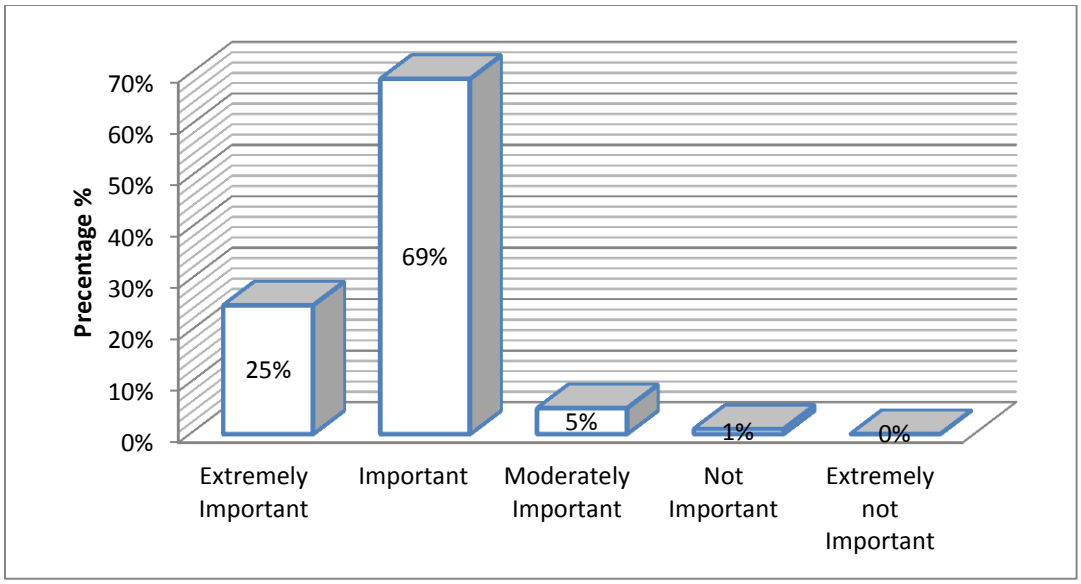

Figure 6.23: Development of the inspection checklists

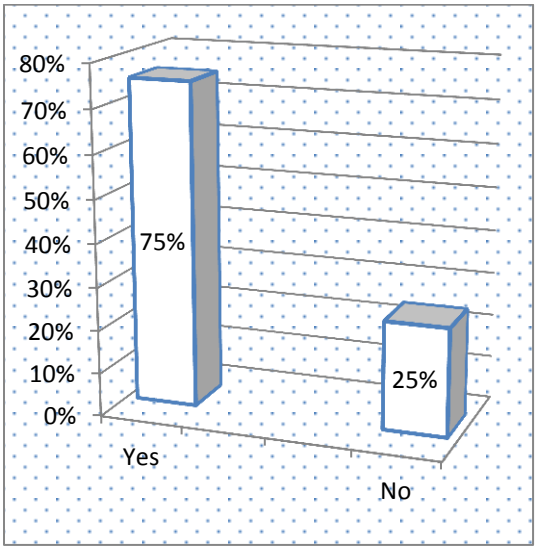

Figure 6.24: Does your firm perform the function (Development of the inspection checklists)?

Construction phase

- Figure 6.25 shows the respondents' responses, in the light of their previous experiences; to the statement (Selection of the commissioning authority) is considered by 8% of the respondents as "Extremely important", 76% as "important", 15% as 'Moderately Important", 1% as 'Not Important", and none of the respondents selected it as "Extremely not Important". When asked if their firm performs this function, 15% of the respondents selected 'Yes", and 85% selected "No" as shown in Figure 6.26. It can be quite easily interpreted from the given figures that respondents perceive the selection of the commissioning authority as an extremely important process, but there are only 15% of the respondents who implement it in practice.

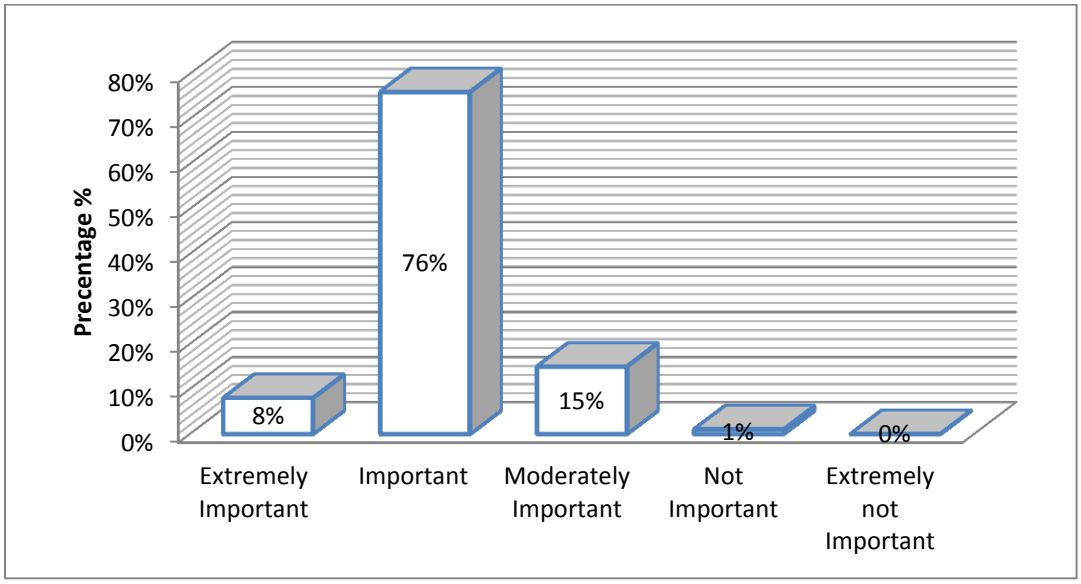

Figure 6.25: Selection of the commissioning authority

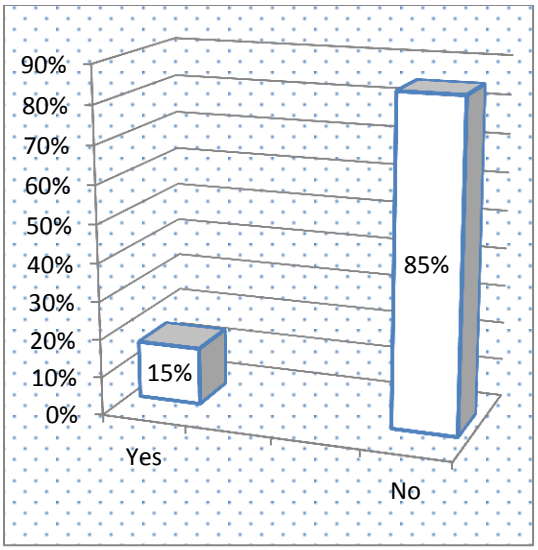

Figure 6.26: Does your firm perform the function (Selection of the commissioning authority)?

- Update of the commissioning plan during the construction phase is evaluated according to the responses received from the respondents as shown in Figure 6.27, none of the respondents have considered it as “Extremely not Important”, 1% as “Not Important”, whereas 17% as ‘Moderately Important”, 76% as “important”, and 6% as “Extremely important”. When asked if their firm performs this process, 21% of the respondents selected ‘Yes”, and 79% selected “No” as shown in Figure 6.28. It can be quite easily interpreted from the given figures that respondents perceive the updated of the commissioning plan during the construction phase as an important process, but there are only 21% of the respondents who implement it in practice.

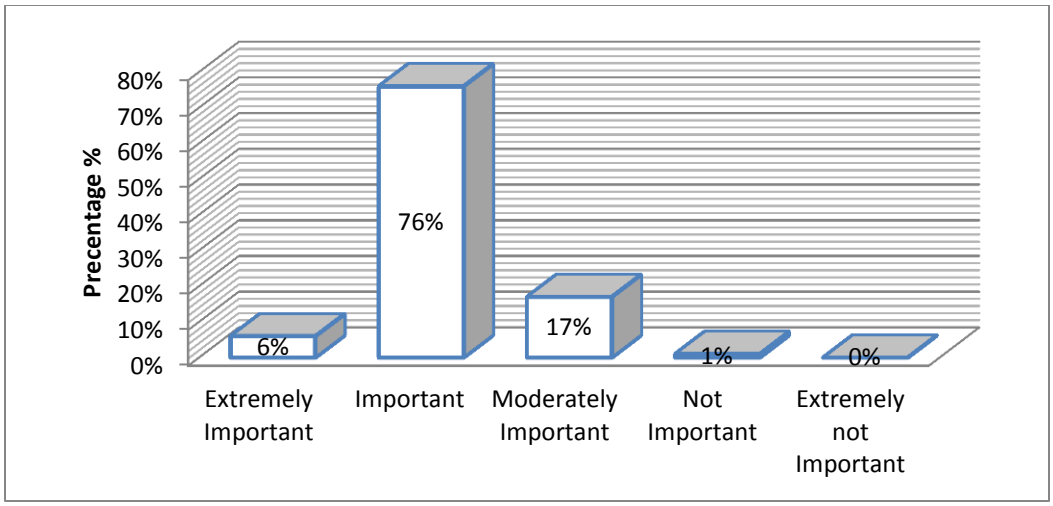

Figure 6.27: Update of the commissioning plan during the construction phase

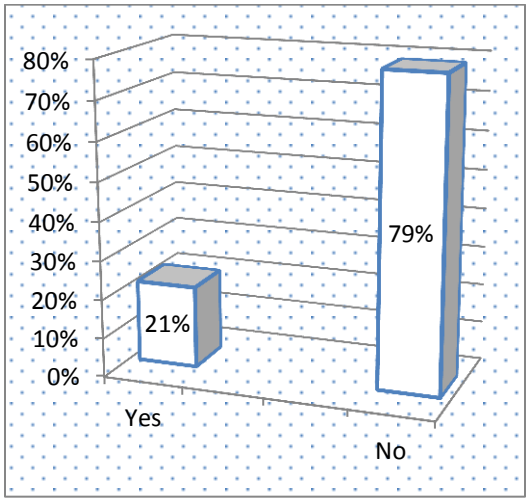

Figure 6.28: Does your firm perform the function (Update of the commissioning plan during the construction phase)?

- Figure 6.29 shows the respondents' responses, in the light of their previous experiences; to the statement (Schedule of the commissioning process activities) is considered by 22% of the respondents as an "important", 65% as "Extremely Important", 12% as 'Moderately Important", 1% as "Not Important", and none of the respondents selected it as "Extremely not Important". When asked if their firm performs this function, 69% of the respondents selected 'Yes", and 31% selected "No" as shown in Figure 6.30.

Considering the responses, the respondents consider that the Schedule of the commissioning process activities to coordinate them with the other construction process activities as an extremely important function in the building commissioning process and there are 69% of the respondents implement it during their work.

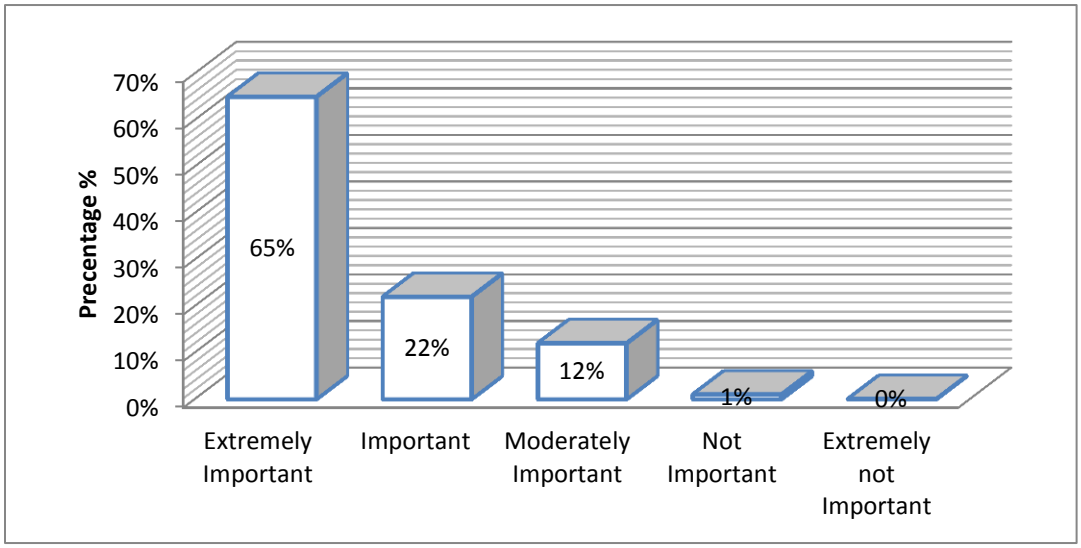

Figure 6.29: Schedule of the commissioning process activities

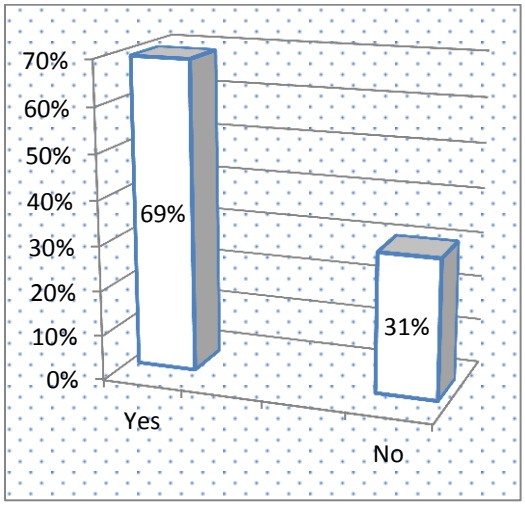

Figure 6.30: Does your firm perform the function (Schedule of the commissioning process activities)?

- Development of the test procedures during the construction phase is evaluated according to the responses received from the respondents as shown in Figure 6.31, none of the

respondents have considered it as “Extremely not Important”, 1% as “Not Important”, whereas 7% as ‘Moderately Important”, 27% as “important”, and 65% as “Extremely important”. When asked if their firm performs this process, 70% of the respondents selected ‘Yes”, and 30% selected “No” as shown in Figure 6.32. It can be quite easily interpreted from the given figures that respondents perceive the development of the test procedures that describe the methods to carry out the tests required during the construction Phase as an extremely important process, and there are 70% of the respondents perform this process.

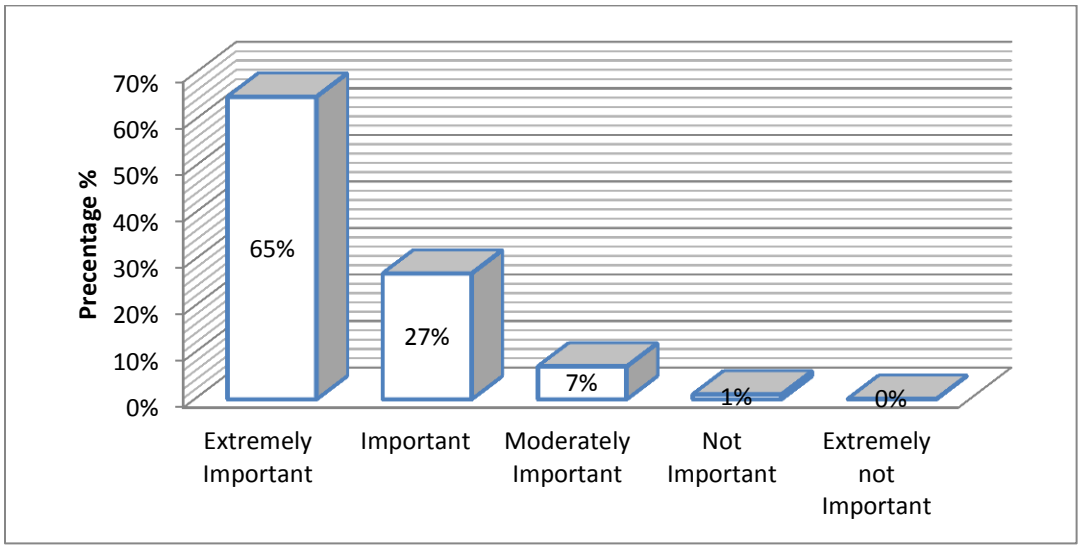

Figure 6.31: Development of the test procedures during the construction phase

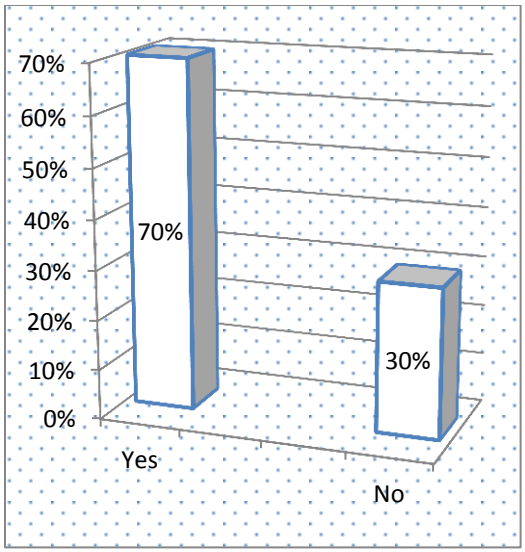

Figure 6.32: Does your firm perform the function (Development of the test procedures)?

Hand over phase

- Figure 6.33 shows the respondents' responses, in the light of their previous experiences; to the statement (Request for commissioning) is considered by 52% of the respondents as an "important", 35% as "Extremely Important", 1% as 'Moderately Important", 1% as "Not Important", and 1% as "Extremely not Important". When asked if their firm performs this function, 90% of the respondents selected 'Yes", and 10% selected "No" as shown in Figure 6.34. Considering the responses, the respondents consider that the request for commissioning (This request is filed by the contractor to inform the owner that the project is ready for handing over) as an important function in the building commissioning process and there are 90% of the respondents implement it during their work.

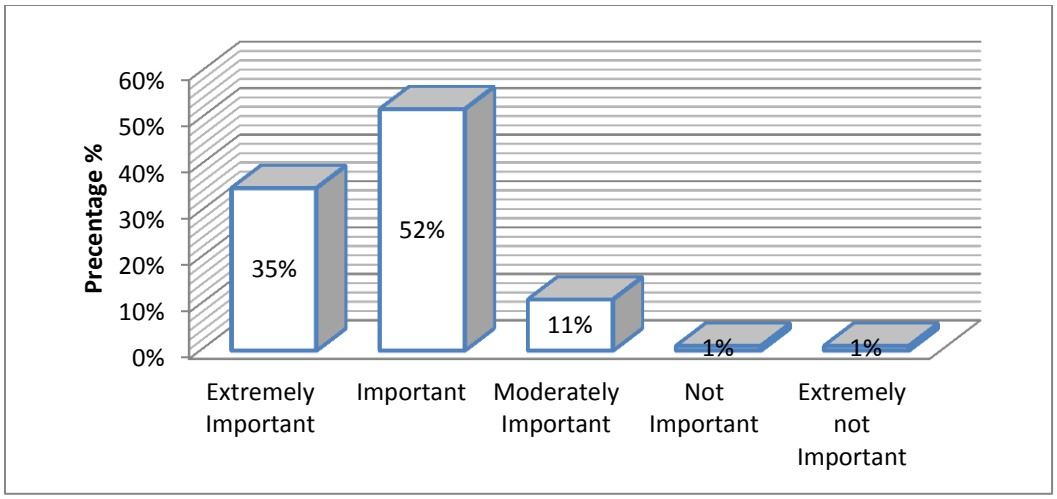

Figure 6.33: Request for commissioning

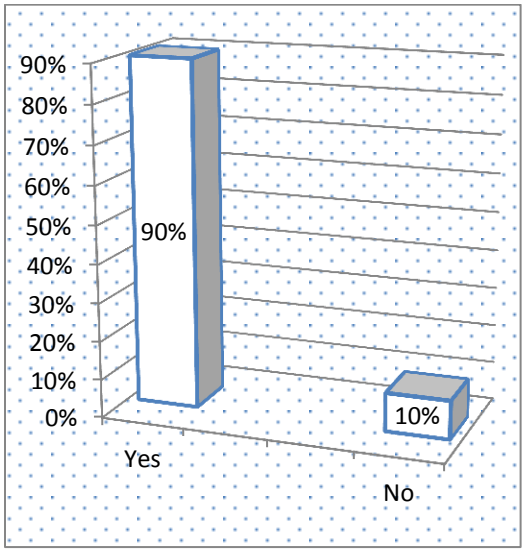

Figure 6.34: Does your firm perform the function (Request for commissioning)?

- Conduct a walk-through inspection is evaluated according to the responses received from the respondents as shown in Figure 6.35, 1% of the respondents considered it as "Extremely not Important", 1% as "Not Important", whereas 3% as 'Moderately Important", 68% as "important", and 27% as "Extremely important". When asked if their firm performs this process, 95% of the respondents selected 'Yes", and 5% selected "No" as shown in Figure 6.36. It can be quite easily interpreted from the given figures that

respondents perceive the walk-through inspection during the handover phase as an important process, and there are 95% of the respondents implement it in practice.

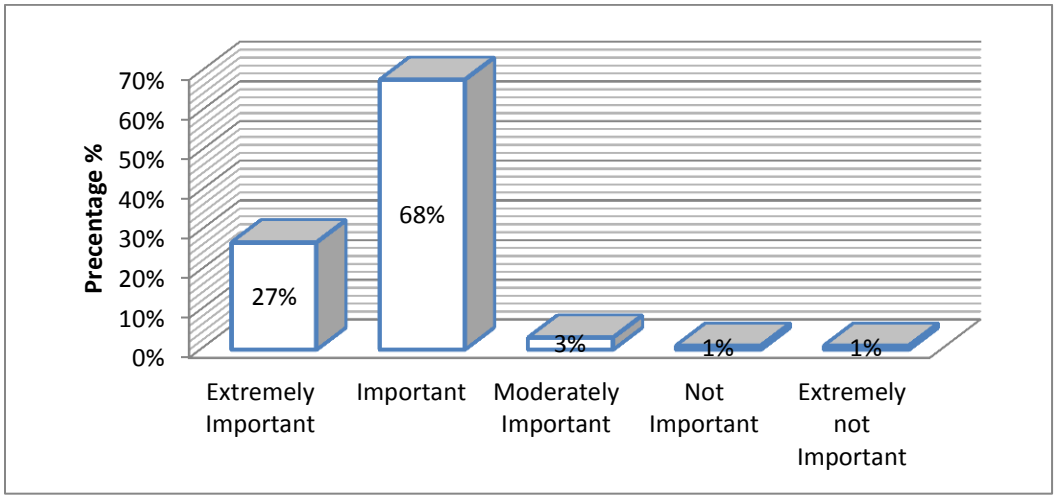

Figure 6.35: Conduct a walk-through inspection

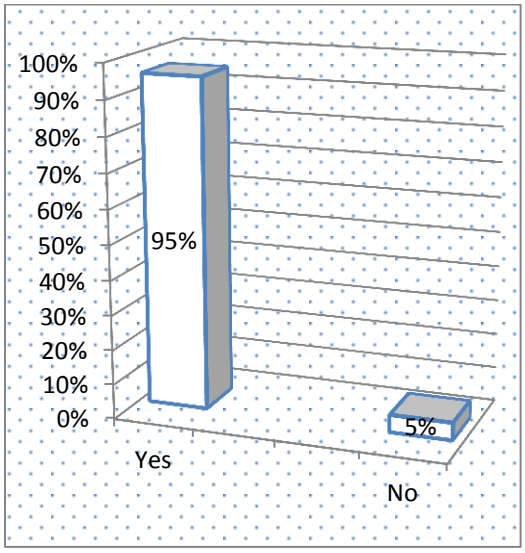

Figure 6.36: Does your firm perform the function (Conduct a walk-through inspection)?

- Figure 6.37 shows the respondents' responses, in the light of their previous experiences; to the statement (Perform corrective actions, if required) is considered by 21% of the respondents as "Extremely important", 67% as "important", 10% as 'Moderately Important", 1% as 'Not Important", and 1% as "Extremely not Important". When asked if

their firm performs this function, 95% of the respondents selected 'Yes", and 5% selected "No" as shown in Figure 6.38. It can be quite easily interpreted from the given figures that respondents perceive the corrective actions as an important process, and there are 95% of the respondents implement it.

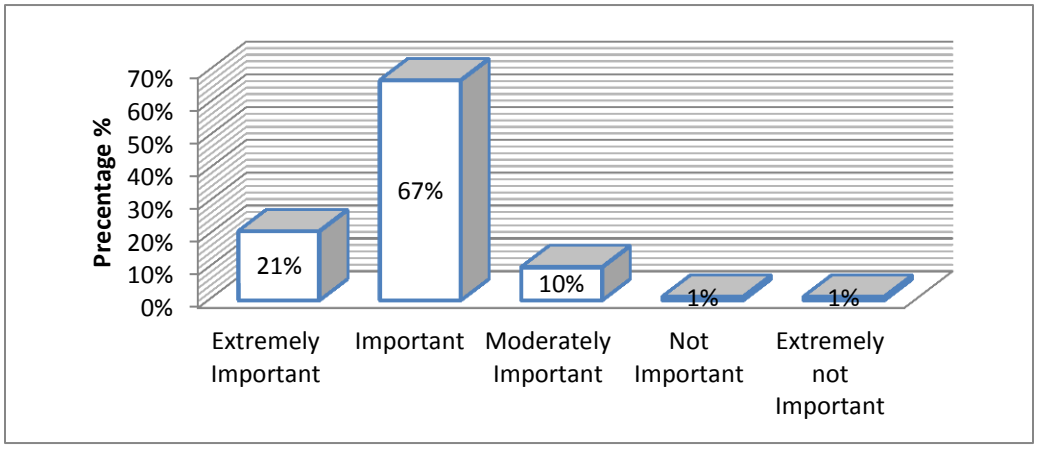

Figure 6.37: Perform corrective actions, if required

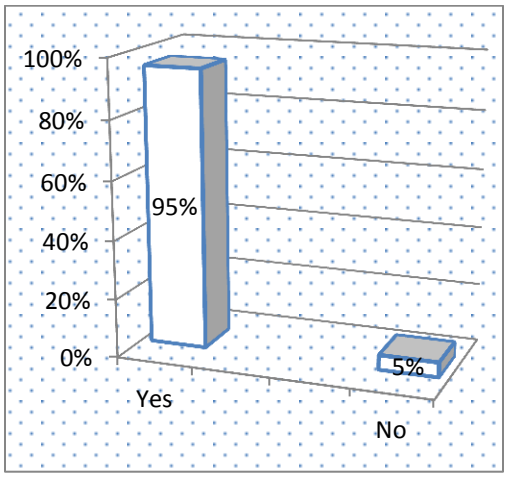

Figure 6.38: Does your firm perform the function (Perform corrective actions, if required)?

- Figure 6.39 shows the respondents' responses, in the light of their previous experiences; to the statement (Forming of the Receiving Committee) is considered by 29% of the respondents as an "important", 58% as "Extremely Important", 12% as 'Moderately Important", 1% as "Not Important", and none of the respondents have selected it as

"Extremely not Important". When asked if their firm performs this function, 94% of the respondents selected 'Yes", and 6% selected "No" as shown in Figure 6.40. Considering the responses, the respondents consider that the forming of the receiving committee as an important function in the building commissioning process and there are 94% of the respondents implement it during their work.

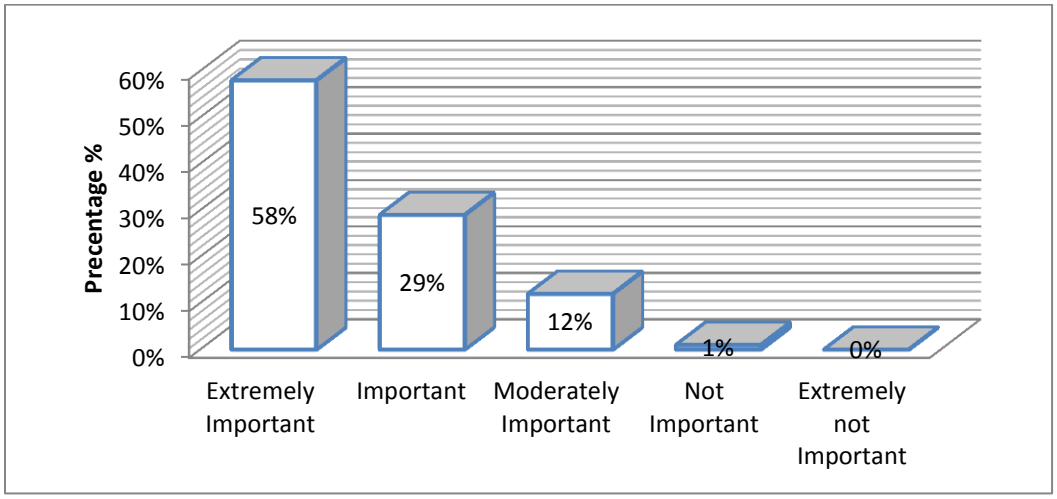

Figure 6.39: Forming of the Receiving Committee

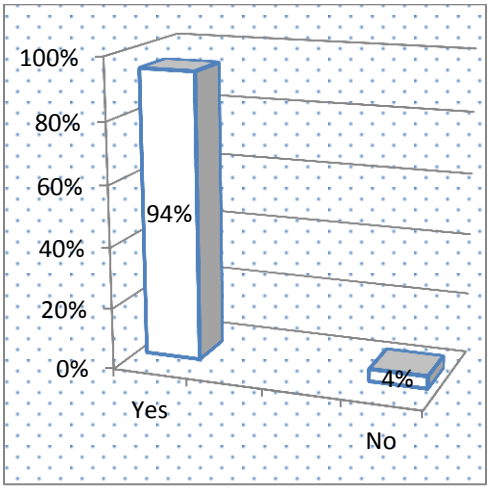

Figure 6.40: Does your firm perform the function (Forming of the receiving committee)?

- Identify the training requirements for the operations and maintenance staff is evaluated according to the responses received from the respondents as shown in Figure 6.41, none

of the respondents have considered it as “Extremely not Important”, 3% as “Not Important”, whereas 13% as ‘Moderately Important”, 29% as “important”, and 55% as “Extremely important”. When asked if their firm performs this process, 51% of the respondents selected ‘Yes”, and 49% selected “No” as shown in Figure 6.42. It can be quite easily interpreted from the given figures that respondents perceive the training for the operations and maintenance staff during the handover phase as an important process, and there are only half of the respondents implement it in practice.

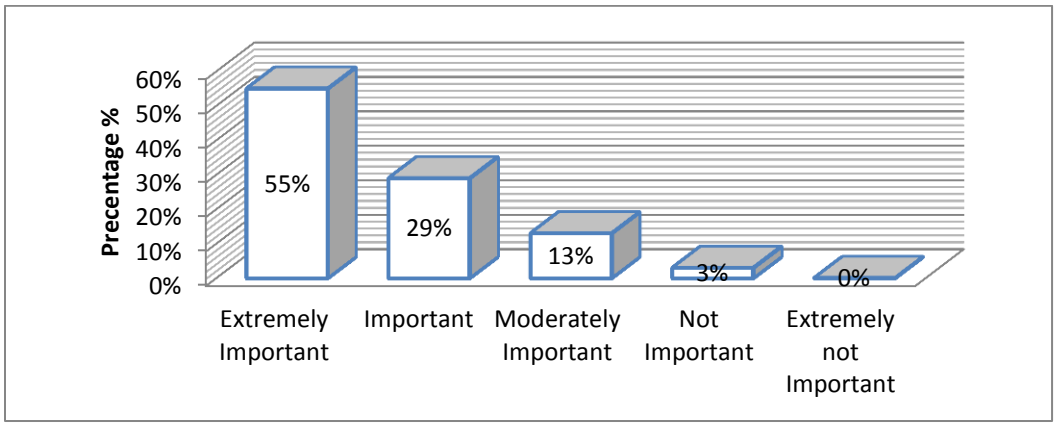

Figure 6.41: Identify the training requirements

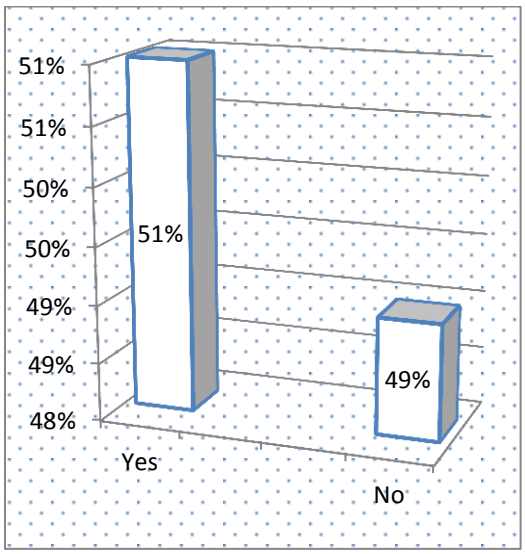

Figure 6.42: Does your firm perform the function (Identify the training requirements)?

- Figure 6.43 shows the respondents' responses, in the light of their previous experiences; to the statement (Development of As-built drawing and project documents by the contractor to demonstrate the actual dimensions and locations of installations after the construction work has been completed) is considered by 46% of the respondents as "Extremely important", 40% as "important", 13% as 'Moderately Important", 1% as 'Not Important", and none of the respondents have selected it as "Extremely not Important". When asked if their firm performs this function, 95% of the respondents selected 'Yes", and 5% selected "No" as shown in Figure 6.44. It can be quite easily interpreted from the given figures that respondents perceive the development of As-built drawing as an important process, and there are 95% of the respondents implement it.

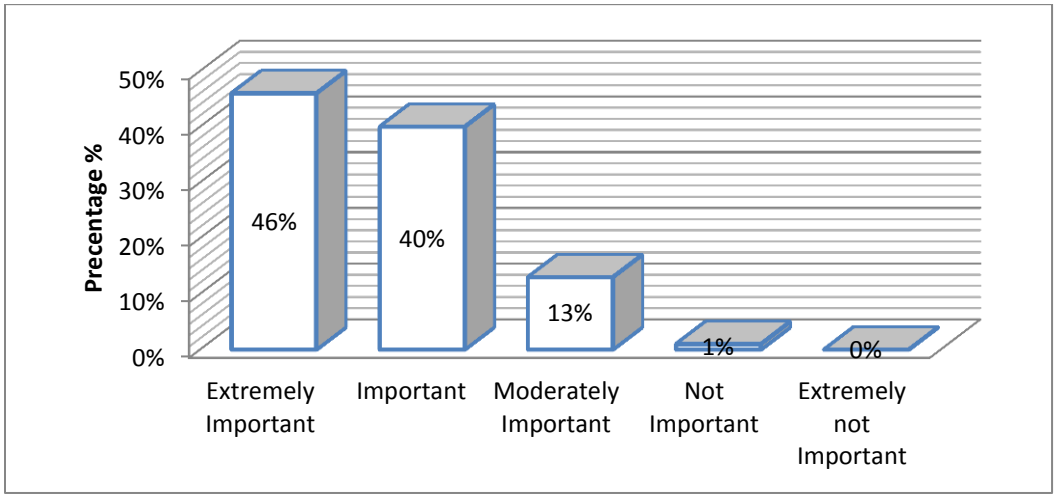

Figure 6.43: Development of As-built drawing

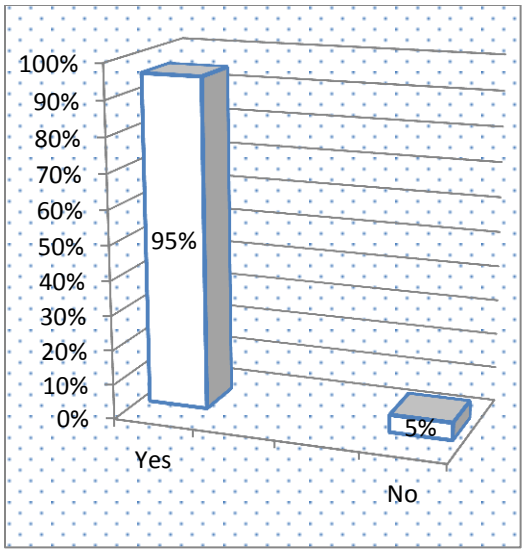

Figure 6.44: Does your firm perform the function (Development of As-built drawing)?

6.7 Discussion

The survey was e-mailed to 200 owners\managers, architect, and engineers in the Eastern province, Riyadh, and Jeddah. 120 respondents completed the survey. The total rate of the response was 60%. The first part of the questionnaire is conclusion the respondent's position as well as the years of experience. The second part of the questionnaire conclusion that there is likely a lack of awareness and understanding of the commissioning process by respondents, where 35 % of the respondents had never heard about building commissioning. The survey answers pointed to the idea that many individuals, even those who had been in construction for several years, had only a basic understanding of the commissioning process.

The conclusion partially drawn from the answers from the Likert type scale questions is that results confirm the importance of the identified building commissioning process where all processes were assessed either important or extremely important.

The last major point that can be drawn from the survey results is that there are a number of processes that has less than 50% applied during the different phases of the project. These

processes include selection of the commissioning team, development of the preliminary commissioning plan, update the commissioning plan during the project phases, and selection of the commissioning authority. These points performed depending on nature of the work at each project as well as the experience of the project managers and engineers. Owners should be aware of these processes and should implement them to maximize the benefits of commissioning. Without an increase in the number of adequate commissioning awareness and training programs for owner's staff and contractors, there will still continue to be a knowledge gap between project team members who are actively involved in the commissioning process.

CHAPTER 7 SUMMARY, CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This chapter contains a summary of the study. It contains the findings obtained from the literature review, and the investigations of the current practice of building commissioning in Saudi university projects, as well as the assessment of the proposed framework for the management of the building commissioning process. A summary of the research will be discussed followed by conclusions and recommendations. The conclusion provides links between the research and the derived findings. The recommendations provide proposals for future elaboration in the field of the study.

7.2 Summary of the Study

The main objectives of this research were to investigate the current practice of building commissioning, and to develop a potential framework for procuring commissioning services on building construction projects, and to assess the applicability of the developed framework which implements the commissioning process on building construction projects in Saudi Arabia.

The methodology consists of six phases:

First, the research focused on identifying international practices of building commissioning. The research focused on acquiring the knowledge through an extensive literature review to identify the international practices of building commissioning.

Second, the current practice of building commissioning in Saudi university buildings was investigated. Interviews were carried out with nine project managers/engineers at the project departments in some Saudi Arabian universities. The interviews resulted in identifying the local current practices of building commissioning and in understanding the procedure or services that are used to ensure that the building systems are performing well.

Third, the framework that aims to manage the building commissioning process was developed. The proposed framework is developed based on knowledge from the literature, observed professional practice and the current practice.

Fourth, the proposed framework was assessed to investigate the applicability of the developed framework in Saudi Arabia. The framework was assessed through an electronic questionnaire survey. The questionnaire survey was developed, tested, and distributed online to a representative sample of owners\managers, architects, and engineers in the Eastern Province, Riyadh and Jeddah.

Fifth, the data received from all categories of respondents to the electronic questionnaire survey was analyzed to identify the importance of each function included in the building commissioning framework.

Finally, a set of conclusions and recommendations was developed. Areas of future research are also highlighted.

7.3 Conclusions

The following conclusion was drawn from summarizing the study:

1. Surveying the literature review in the field of building commissioning process revealed that it is very important for the owner to include the commissioning process early in the programming phase of the project to realize more benefits from the commissioning.

2. Interviews were carried out at five Saudi Arabian Universities; interviewees believed that their current practices in building commissioning are still in the early development stage.

3. The findings revealed that current practices of building commissioning are not really effective. Because of this, a number of major problems have been identified which are lack of a clear methodology or guidelines that manage the commissioning process, lack of experience of the owner's staff to perform the commissioning and testing, change orders at later stages of the project, and lack of time allocated for the commissioning process.

4. The findings revealed that there is a need to develop a framework model for managing the building commissioning process in Saudi Arabia.

5. The proposed framework was developed based on knowledge from the international literature, observed professional practice and the current practice in Saudi Arabia. The framework, presented as a process model, is generic, meaning that the activities involved can be adapted and applied to any project type.

6. The framework model consists of five sequential processes namely develop a new project proposal, review the developed design package, prepare for commissioning, implement the

commissioning process, and prepare for project handover. For each of the main processes, a number of supporting functions have been defined.

7. The questionnaire survey was developed online and emailed to 200 owners\managers, architects, and engineers in the Eastern Province, Riyadh and Jeddah. The responses to the questionnaire survey were 120, and the rate of the response was 60%.

8. The purpose of the questionnaire was to assess the applicability of the developed framework in Saudi Arabia.

9. The assessment results illustrate that all functions were assessed as either important or extremely important. It confirmed that the developed framework can be applied locally in Saudi Arabia. It is flexible for modification and updating according to the type and size of the project.

Descriptions of the specific aspects in the framework are summarized as follows:

- Develop new project proposal. Investigating the development of the new project proposal and the commissioning process that is carried out in parallel with the project proposal development.
- Review the developed design package. Reviewing the design documents that were developed during the design phase by the design office to ensure that the design documents meet the owner's requirements.
- Prepare for commissioning. Involves a number of activities depending on the size and complexity of the project.
- Implement the commissioning process. Implementing the commissioning and testing process. This process is carried out by the commissioning team to ensure that the compliance of the building systems is ready for handing over.

- Prepare for project handover. Preparing for the stage in the construction where the building is ready for handover to the owner, usually at the stage of practical completion.

7.4 Recommendations

The recommendation of this research can be summarized as follows:

- It is recommended that the owners pay more attention to the importance of using building commissioning to improve building performance.
- The development of the building commissioning framework model provides useful information to the owner about the main commissioning process that should be carried out during the project phases.
- Using the proposed framework is necessary and can be updated according to the size, type, and the complexity of the project.

7.5 Directions for Future Research

The building commissioning process has recently become an important focus for international research and guidance. It is observed that there is no research related to this area in Saudi Arabia. There is a need to conduct more research for improving the practice of building commissioning in Saudi Arabia.

Future research in the area of the study may consider the following:

- The scope of this research was limited to the building commissioning process of new projects. Further studies might include all the commissioning types (retro-commissioning, re-commissioning, and continuous commissioning) in the Kingdom of Saudi Arabia.

- The research only considered the opinions of owners and their representatives. Future studies may also take into consideration opinions of contractors to investigate the level of awareness that contractors have about building commissioning.
- Future studies may investigate the effectiveness of a third-party commissioning agent on the project team.
- Future studies may be carried out to investigate the benefits of building commissioning in the Saudi Arabia construction industry.

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APPENDIX 1

Questionnaire survey 1

Investigation of the current practice of using building commissioning

Through Interviews and Questionnaire survey

The Objective of this phase of the study is: To investigate the current practice of building commissioning in Saudi Universities buildings.

QUESTIONNAIRE

This questionnaire consists of two parts. First part is the respondent's general information. The second part is the general questions about the procedure or services that used to ensure that the building systems are performing safely and as specified per contract specifications, design, B.O.Q. and the owner requirements.

Respondent's General Information

1) Respondent Information

University Name	
Telephone No	
Facsimile	
E-Mail Address	
University Address	

2) How many years of experience you have in your work:

- ☐ Less than 5 years
- ☐ 5-10 years
- ☐ 10-20 years
- ☐ Over 20 years.

3) Respondent position:

- ☐ Owner/Project Manager
- ☐ Architect/ Engineer
- ☐ General contractor
- ☐ Operation & Maintenance staff
- ☐ Others …….

Current practices

1) From your daily practice, what is the procedure or services that used to ensure that the building systems are designed, installed, functionally tested, handing over, and operated based on the owner requirements?

- ☐ Commissioning
- ☐ Quality Assurance
- ☐ Examine drawings
- ☐ Experience
- ☐ Others, specify……..……

2) **From your daily practice, who of the following entity usually performs this service?**

- ☐ Owner staff
- ☐ General contractor
- ☐ Subcontractor
- ☐ A third party
- ☐ Others, specify……..……

3) **From your daily practice, at what stage of the construction process is this service first performed?**

- ☐ Programming
- ☐ Design development
- ☐ Construction phase
- ☐ Acceptance phase
- ☐ Others, specify……..……

4**) From your daily practice, what are the main challenges faced during the implementation of this service?**

- ☐ Lack of time
- ☐ Cost
- ☐ Lack of expertise and skill of staff
- ☐ Others, specify……..……

5) From your daily practice, do the procedure supply typically relate to the total building systems or only to selected systems in the building?

- ☐ Total building systems
- ☐ Selected systems

6) What selected systems does your firm most often address to be ensure that systems are designed, installed, functionally tested, handing over, and operated based on the owner requirements ?(Select multiple options if applicable).

- ☐ HVAC
- ☐ Building control systems
- ☐ Alarm system
- ☐ Sprinkler system
- ☐ Lighting and control
- ☐ Thermal envelop system
- ☐ Others, specify……..……

7) What are the criteria that used to determine which systems require these services?

- ☐ Size of the project
- ☐ Complexity of the equipment
- ☐ Cost of the equipment
- ☐ Known risks with equipment/past experience
- ☐ Increase the performance
- ☐ All of the above
- ☐ Others, specify……..……

8) From your daily practice, the pricing of this service considered as:

- ☐ Already Part of the contractor work
- ☐ An overhead cost for the owner
- ☐ Priced separately as line-item cost for commissioning services
- ☐ Priced separately as a competitive bidding
- ☐ Others, specify……..……

9) Based in your experience, please answer the following questions about the current Practices for Procuring Commissioning Services in the <u>new building construction projects</u> in Saudi Universities by selecting (Yes) or (No):

Questions	Yes	No
A) Are there any framework or guideline that used to manage the commissioning process in building construction project in Saudi Universities?		
B) Does the University have a separate commissioning department?		
C) Does your firm perform the planning stage of the building systems commissioning process? (Ex: commissioning budget and commissioning plan)		
D) Does your firm perform the preparation stage of the building systems		

commissioning process? (Prepare the operations and maintenance manual)		
E) Does your firm perform the implementation stage of the building systems commissioning process?		
F) Is there any commissioning plan prepared for each new project? (The commissioning plan should be prepared to define the commissioning requirements, schedule of commissioning process activities, commissioning team and their responsibilities, commissioning budget and scope?		
G) Are the qualifications required to ensure that the engineers who execute the commissioning activities are qualified?		
H) Do you feel the team who performed the commissioning service has the knowledge, expertise, skills and training necessary to execute the commissioning process?		
I) Does the contractor gives training to the Operation and Maintenance staff to be familiar with the new systems?		
J) Are the operation & maintenance staffs present during the testing to increase their familiarity with building systems?		
K) Did you see commissioning process as giving the new building a competitive advantage in any way?		
L) Are there any demands for building commissioning services on building construction projects in Saudi Universities?		

10) From your point of view, what are the Opportunities and Challenges that toward the building commissioning practice in Saudi Arabian Universities?

……..

……..

……..

Name (Optional):

APPENDIX 2

QUESTIONNAIRE 2

Assessment of the Proposed Building Commissioning Framework

The Objective of this phase of the study:

To assess the applicability of the proposed framework for managing the building commissioning process in Saudi Arabia

This questionnaire consists of three parts:

- Part one: Respondent's general information
- Part two: Awareness and perceptions of building commissioning
- Part three: Assessment of functions pertaining to the commissioning & testing processes during the different project phases

Part one: Respondent's General Information

1) Respondent Information

Office or Company Name	
Telephone No.	
Fax	
E-Mail Address	
Office or Company Address	

2) How many years of experience do you have?

☐ Less than 5 years

☐ 5-10 years

☐ 10-20 years

☐ Over 20 years.

3) Position:

☐ Owner

☐ Project Manager

☐ Engineer/Architect

☐ Others …….

Part two: Awareness and Perceptions of Building Commissioning

Definition of Building Commissioning:

Building commissioning for new construction or renovations is a systematic process that verifies that all building systems are designed, installed, and tested to perform according to the documented design intent and the owner's operational needs (The National conference of building commissioning, 1993).

4) **Had you heard of "building commissioning" before today?** (If yes, please continue answering the questions).

☐ Yes

☐ Yes, currently I am working in building commissioning

☐ No, I have never heard about building commissioning

5) Please indicate your level of awareness of the building commissioning process:

☐ Extremely aware

☐ Moderately aware

☐ Slightly aware

☐ Not at all aware

6) When discussing with clients or other contractors, what do you typically refer to the procedures or services that are used to ensure that building systems are designed, installed, and tested to perform according to the design intent and the building owner's operational needs?

☐ Basic services

☐ Commissioning

☐ Quality assurance

☐ Check list

☐ Supervising

☐ Final inspection/inspection

☐ Project close out

☐ Project handover

☐ Testing

☐ Others, specify……..……

Part three: Assessment of Functions pertaining to the commissioning & testing processes during the different project phases

Please rate the degree of importance of each of the following functions by selecting one of the following evaluation scales:

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Best Practices									
In your opinion, how important are the following functions that should be implemented during the following project phases: a) Pre-Design phase b) Design phase c) Construction phase d) Handover phase		Extremely Important	Important	Moderately Important	Not Important	Extremely Not Important	Does your firm perform this function?	
							Yes	No
	a) Pre-Design phase							
1	Development of the architecture program based on the requirements of end-user.							
2	Selection of the commissioning team (owner group member).							
3	The responsibility of the commissioning team is to clearly communicate their expectations about the project outcome to the project team.							
4	Development of the preliminary commissioning plan that identifies the commissioning process.							
5	The developed commissioning plan should provide a guideline for the commissioning team members to explain the owner's project requirements.							

Best Practices

In your opinion, how important are the following functions that should be implemented during the design phase:

	b) Design phase	Extremely Important	Important	Moderately Important	Not Important	Extremely Not Important	Does your firm perform this function? Yes	No
6	Update of the developed architectural program during the predesign phase to include the additional information obtained during the design phase							
7	Review of the design development by the commissioning team from the conceptual phase to the final design development.							
8	Update of the commissioning plan during the design phase to include any additional information.							
9	Development of the specific commissioning requirements including all the requirements for testing systems and assemblies, specific equipment, access and coordination issues, and all details of the commissioning process.							
10	Specification of who must carry out the commissioning and testing process.							
11	Development of inspection checklists that aid the installers by providing specific information on the owner's project requirements for systems and equipment.							

Best Practices

In your opinion, how important are the following functions that should be implemented during the construction phase:

		Select one of the following evaluation scales					Does your firm perform this function?	
		Extremely Important	Important	Moderately Important	Not Important	Extremely Not Important	Yes	No
c) Construction phase								
12	Selection of the commissioning authority (The commissioning authority can either be a member of the owner's staff, designer, contractor, or an independent third party).							
13	Update of the commissioning plan during the construction phase to reflect any changes to the project, or to include new details of the commissioning activities.							
14	Schedule of the commissioning process activities to coordinate them with the other construction process activities.							
15	Development of the test procedures that describe the methods to carry out the tests required during the Construction Phase							

Best Practices

In your opinion, how important are the following functions that should be implemented during the handover phase:

		Select one of the following evaluation scales					Does your firm perform this function?	
		Extremely Important	Important	Moderately Important	No Important	Extremely Not Important	Yes	No
b) Hand over phase								
16	Request for commissioning (This request is filed by the contractor to inform the owner that the project is ready for handing over).							
17	Conduct a walk-through inspection to identify the building component that does not comply with the owner's project requirements.							
18	Perform corrective actions, if required (This function serves to perform the required corrections by the contractor).							
19	Forming of the Receiving Committee (The receiving committee will conduct a walk-through inspection to verify that corrective actions have been implemented based on the analysis and snag list reports).							
20	Identify the training requirements for the operations and maintenance staff.							
21	Development of As-built drawing and project documents by the contractor to demonstrate the actual dimensions and locations of installations after the construction work has been completed.							

APPENDIX 3

Interviewed project manager/engineers

NO	Name of the interview person	University	Region	Date of interview	Method of interview
1	**Abdulraouf Al-marhoon** Project manager	KFUPM	Dhahran	17/6/2012	Face to face
2	**Hamzah Al Titi** Electrical Eng.	KFUPM	Dhahran	18/6/2012	Face to face
3	**Osama Yaseen** Mechanical Eng.	King Faisal	AL-Hassa	19/6/2012	Face to face
4	**Dr. Ahmad O. fallaha** Project manager	King Faisal	AL-Hassa	19/6/2012	Face to face
5	**Dr. Bahaa uldin Al arab** Project manager	King Faisal	AL-Hassa	19/6/2012	Face to face
6	**Rafiq M. AL- Muqeed** Project manager	King Saud	Riyadh	1/9/2012	Face to face
7	**Faiz A. AL-Shalwi** Project manager	King Saud	Riyadh	1/9/2012	Face to face
8	**Sami Ali Abdallah** Project manager	King Abdulaziz	Jeddah	4/9/2012	Face to face
9	**Adel EL-sadat Mosaad** Project manager	Dammam	Dammam	8/9/2012	Face to face

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