

ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

A GUIDE TO IMPROVE BUILDING COMMISSIONING IN ETHIOPIAN CONSTRUCTION : CASE STUDIES ON SELECTED PUBLIC INSTITUTION PROJECTS IN ADDIS ABABA

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Construction Technology and Management.)

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2018 G.C

Addis Ababa

ADDIS ABABA UNIVERSITY

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ACKNOWLEDGMENTS

I would like to take this opportunity to express my sincere appreciation for Abebe Dinku (Prof. Dr. –Ing.) for his unlimited supervision, guidance and advice during the period I was carrying out this research. Many people, contractors, consultants, public employers, and professionals of the sector have greatly contributed for the successful completion of this research by sacrificing their invaluable time; hence I would like to express my gratitude for their support.

Finally, I would like to give my special thanks to my wife whose patience and love enabled me to complete this work and to all my friends who have been very supportive in this venture. I am deeply grateful to all of them.

ABSTRACT

Commissioning (Cx) new buildings and retro-commissioning existing construction facilities are becoming a quality assurance measure in the construction industry in many countries. The purpose of the commissioning process is to verify the performance of the systems and to provide documentation evidence that all equipment and systems are installed and functioned according to the design intents, standards and requirements of the client. However, building commissioning (BCx) has never been systematically and strategically promoted in the 'program', 'design', 'construction' and 'acceptance' stages. This has not been properly addressed. Very often, Cx is overlooked by owners, architects and engineers, contractors and operators mainly due to mis-conception on Cx as a "less technical and lower level task". As a result, commissioning process is implemented differently from project to project, firm to firm, and sometimes polarized by "personal expertise".

This paper aims to explore the current scenario of building commissioning in the Ethiopian construction industry and develop a potential framework to improve building commissioning for construction projects in Ethiopia by conducting case studies on selected public institution building construction projects in Addis Ababa.

The research findings indicated that, building commission is vital to confirm the final outcome of a project is in compliance with the design and specified requirements and Cx should be handled as integral part of project life-cycle. Also problems during commissioning are mostly interrelated with problems during construction stage and some of these problems are significance in affecting the handing over of the project and tend to recur from project to project.

The framework aims to provide a more holistic view and better insight on building commissioning for the Ethiopia context by eliminating these unattended problems. This study also intends to generate a guideline for the construction practitioners on the common activities of commissioning that needs to be planned even during the construction stage to improve projects performance.

Keywords – Building, Commissioning, Construction

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LIST OF ACRONYMS

ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers

BCx = Building Commissioning

Cx = Commissioning

CxA = Commissioning Authority

CPC = Certificate of Practical Completion

LD = Liquidated Damage

OPR = Owner's Project Requirement

MBCx = Monitored Building Commissioning

O&M = Operation and Manual

CHAPTER I: INTRODUCTION

1.1 Background of the research

Ethiopia is the fastest-growing, non-oil driven economy among African countries. The country has showed a remarkable growth over the past ten years with average annual growth GDP of 10.9% (UNDP, 2014). The construction industry is a very important part; it highly contributes to the growth and development of the economy in developing countries like Ethiopia. According to (Addis Mesfin, 2014), the construction industry plays a major role in developing countries since it constitutes a significant portion of Gross national product and employment. The vital role of construction industry as an economy contributor recognizes the need to address typical shortfalls of the construction industry where it relates to the need for proper commissioning. As such, the issues related to BCx in the Ethiopian construction industry must be addressed to spur growth in the construction sector.

Commissioning (Cx) is a systematic process of ensuring that all building and facility systems perform interactively in accordance with the design documentation and intent. Cx begins with planning and includes design, construction, start-up, acceptance and training, and should be applied throughout the life of the building (Djuric & Novakovic, 2007).

Building commissioning (BCx) can be defined in a general way as a quality assurance process with the aim to ensure that the building and its system meets the owner's needs and requirements. The reason why the need for Cx in the building industry originally originated can be linked to the dissatisfaction among owners regarding how the buildings were when they were handed over from the contractor.

According to U.S. Department of Energy, Cx is the key to quality assurance in more than one way; it prevents problems from developing, anticipates and regulates system interactions, and implements a systematic method of meeting the buildings mechanical, electrical, and control requirements. A thorough Cx effort results in fewer installation call backs, long-term tenant satisfaction, lower energy bills, avoided equipment replacement costs, and an increased profit margin for building owners.

Cx is directly related to the building operational efficiency (Kjelgaard, 2005) and it involves team effort that includes not only the commissioning authority (CxA) but also many others associated with the design, construction, and future operation of the commissioned systems (Ellis, 2010). Cx fills the gaps of conventional maintenance programs and addresses the anomalies that form the achilles' heel of planned preventive maintenance (Wilkinson, 2011). According to ASHRAE Guideline 1-1996 (1998), improved understanding of the Cx process can provide commissioning savings. These savings are resulted from the understanding of the purpose of the facility and the reason for its existence to serve the end-user in Cx. It is seemed that the basic nature of the project definition process is poorly understood and modeled as compared with the later stages in project management. This has unavoidably led to unsatisfactory practical implementation of the project (Kalle, 1999).

Avots (1969) conducted a theoretical study to understand the reasons for project failure and concludes that the unplanned project termination is among the main reasons for failure. Moreover, there are no researches which have been done in Ethiopia in relation to BCx. Hence, this study aims to explore the current scenario of BCx in the Ethiopian construction industry and focuses on the issues during project termination by looking into the problems of BCx.

1.2 Statement of the Problem

Building commissioning is recognized as an important tool in quality control of building projects. Good system design does not guarantee the system to have optimal performance. The purpose of the Cx process is to verify the performance of the systems and to provide documentation evidence that all equipment and systems are installed and functioned according to the design intents, standards and requirements of the client. Through the Cx process, all equipment and systems must be identified, labelled and set up. They are ready for efficient service and maintenance after handover. However, in Ethiopia BCx has never been systematically and strategically promoted in the ‘program’, ‘design’, ‘construction’ and ‘acceptance’ stages and usually misunderstood as a process performed after the completion of construction. This has not been properly addressed. Very often, Cx is overlooked by owners, architects and engineers, contractors and operators mainly due to mis-conception on Cx as a “less technical and lower level task”.

As a result, commissioning process is implemented differently from project to project, firm to firm, and sometimes polarized by "personal expertise".

Thus, the first research problem is the overlook and negligence of project Cx as an integral part of the project life-cycle. According to (Kho Mei Ye, 2013), only a few researchers shared that project Cx, when the projects outcome is handed over to its customers for use, is perceived as an essential part of the project life-cycle. This is probably the cause for the lack of research on this issue. The transfer or handing over phase to the success of projects is very important, not only as the residual attitudes toward the project. Projects do not usually accomplish this condition because the collaboration ends with project completion, and future collaboration is uncertain (Branconia & Lochc, 2004). There is also lack of proper attention in the planning of Cx (Dvir, 2005) as an essential part of the project life-cycle. Hence, this has emphasized the need to conduct this study to mitigate the residual attitudes towards handing over of projects in the Ethiopian public institutions construction projects. This will also help to enhance the perceived understanding of Cx and to improve the building performance.

Secondly, the reality to building owners is that there seem to be an absence of quality in the finished product and to a vast majority of building owners, buildings performance is not as anticipated. Cx is expected by owners to result in a high-performance building and to ensure the building systems work as intended.

Unfortunately, the result of Cx is not as expected. This unmet expectation together with the perceived high cost of commissioning have created gap between elevated expectation and delivered result (Tseng, 2005). Substantial completion on many projects is merely the start of a lengthy shakedown period for a myriad of building system problems that often take a year or longer time to sort out the bugs and defects (Tseng, 1998).

Besides that, lack of awareness on the impact of poor Cx on building has affected the performance of many projects. Faulty construction, malfunctioning equipment, incorrectly configured control systems and inappropriate operating procedures have increased realization that many buildings do not perform as intended by their designers (Haves, Claridge & Lui, 2001). Therefore, it is of necessary to identify the effects of poor commissioning on the projects performance.

Thirdly, project Cx is considered as a mere administrative formality to obtain the construction license for the party involved. This ignorance of what a project really is has implied that quality is not the prerequisite of it, and it is also deemed to be not important (Merchan, 2000). This ignorance of the party on the importance BCx might negatively impact the building performance without having insight.

Apart from this, accumulated delays from previous phases may lead to operational errors during execution of Cx procedures. Delays can result in time constraint and impose pressure that could affect project scheduling prior to final delivery to the customer (Cagno, Caron & Mancini, 2002).

The basic Cx process is integrated with the phases of construction and should begin in the pre-design phase and continue through construction and the warranty period. Cx enhances communication among project team members and ensures that they all understand the project goals. This allows the project team to identify problems early, before they can affect later phases of the project and cause delays (Oregon Office of Energy, 2000). Without having insight into these problems of building Cx in the construction industry, it is hard to improve the project timely completion.

Some of the issues or problems observed by the researcher that is related to the conduct of building commissioning in Ethiopian construction projects are: equipment's have yet to be integrated with the building due to delay in building construction, poor quality work, the issuance of Certificate of Practical Completion (CPC) without proper justification, (CPC) was issued before the works were completed, works were done not in accordance with specifications and projects were not properly planned and (CPC) was issued for the project which failed its main component testing and commissioning. The ultimate goal of Cx is to obtain the (CPC) and to ensure the constructed facilities are in accordance with all the specifications and design intent. All these problems have further highlighted the necessity to know what goes wrong with building commissioning and the reasons for it.

1.3 Objectives of the Study

The aim of this research is to explore the current scenario of BCx in the Ethiopian construction industry and add new insight to the existing understanding of Cx from the perspective contractors' and consultants' in the Ethiopian construction industry.

To achieve the research aims, the research objectives are defined as follows:

1. To redefine the scope and understanding of BCx from the perspective of contractor's and consultant's in the Ethiopian construction industry;
2. To identify problems during Cx and the relationships of these problems with other phases of the project life-cycle;
3. To determine the underlying causes of identified Cx problems;
4. To measure the importance of BCx and its effect on project completion by using Earned Value Analysis; and
5. To develop a framework model to improve BCx for construction projects of the public institution in Ethiopia.

1.4 Research Questions

Research questions for this study are stated as follows to provide a clear direction to achieve the research objectives. Therefore, this research will seek to answer these research questions.

1. How is BCx being perceived in the Ethiopian construction industry from the contractor's and consultant's perspective?
2. How are problems related during Cx stage to planning, design and construction stages?
3. How do the underlying causes for these problems affect the conduct of Cx? Or are these problems derived from Cx stage itself?
4. How to measure the importance of BCx and its effect on project completion by using Earned Value Analysis?

1.5 Significance of the Study

This research paper will address the importance of having a proper building commissioning instead of the conventional ways of perceiving commission and add new insight to the existing understanding of BCx in Ethiopia by highlighting the current scenario of Cx problems on public institution buildings and make future advancement of knowledge feasible with this to serve as an initial study. The research also Provides valuable evidence on the possible influence of Cx might have on the project timely completion and to enrich the existing body of knowledge on Cx and fills the gap between existing theories and practical application of Cx in the Ethiopian construction industry for the public institution towards project timely completion.

In addition, it Provides useful information to draw attention on the essentiality of Cx problems that need to be focused in handing over the construction project to ensure functionality and to complete the project in a timely manner and present some lessons learned for future projects so that appropriate precautious method can be taken to avoid or mitigate these Cx problems even during the inception stage of the project.

1.6 Scopes and Limitations of the Study

Most of the time, only design and construction during the realization stage of the building life-cycle are taken into account for the process analysis focuses on design for construction. Other life-cycle stages, such as maintenance, operation, renovation, demolition, and retrofit, are not included. Thus, by taking into account of this shortcoming, the scope of this study is BCx during the project termination phase by investigating the problems of BCx in the Ethiopian construction industry of the public institutions.

Most importantly, Cx is underutilized in public institution deployment programs and research and development activities. Thus, the scope of research was on-going public institution building construction projects around Addis Ababa which were scheduled to have testing and Cx regardless whether these projects are behind schedule or projects with the percentage of completion more than 90% from year 2014 till 2018.

The main components of Earned Value analysis are Planned Value (PV), Earned Value (EV), Actual Value (AV) and others and each component are quantifiable. Nevertheless,

tracking actual data for Earned Value (EV) and Actual Value (AV) requires significant effort as only qualified staffs that have the proper experience and knowledge are able to collect reliable data. Since the collected data are at best estimates of work in hand and the final results are estimated projections, the Earned Value Analysis is usually not considered the ultimate assessment of the project progress. When Earned Analysis is adopted, an essential element is the successful use of a realistically shaped baseline plan S-Curve.

Besides that, the construct of this study is to develop a framework to improve BCx excluding the quantifiable magnitude of the improvement of project performance. The magnitude of this improvement is not in the scope of this study.

Apart from this, the outcome of this study does not take into consideration the influence of project information such as: types of procurement method and contract sum of the project.

1.7 Structure of the Thesis

The structure of the thesis comprises of seven major chapters as follows. Figure 1.1 illustrated a general structure of the thesis for this study.

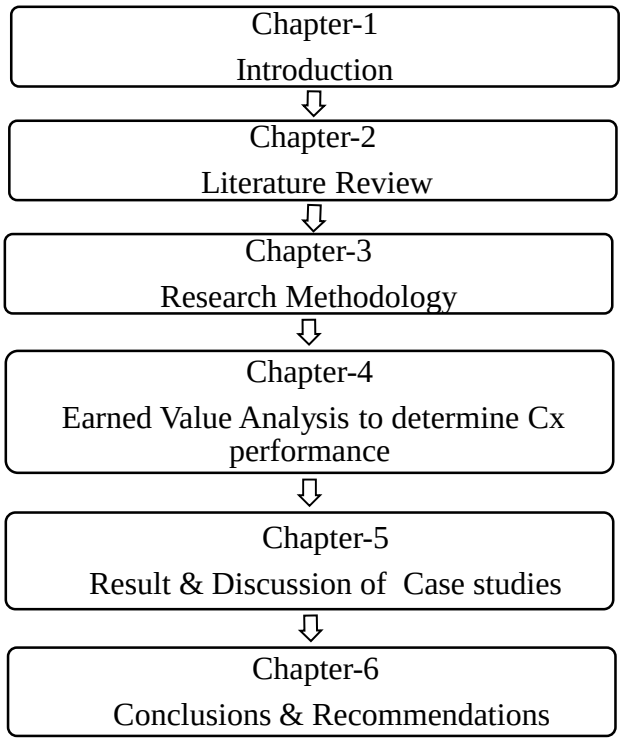


Figure 1.1: Structure of the Thesis

CHAPTER II: LITERATURE REVIEW

2.1 General

A solid understanding of the Cx process, what it is and how it works can provide a range of benefits for building owners and facility managers. Cx is a process designed to optimize the built environment for energy efficiency, leading to reduced energy costs and enhanced building performance. It is also a way to verify that a new building's processes operate according to the owner's project requirements (OPR).

The ASHRAE (1998) defines Cx as "a quality-oriented process for achieving, verifying and documenting that the performance of facilities, systems and assemblies meets defined objectives and criteria." Cx is the integration of the planning, delivery, verification and risk management of a building's functions. It is not another layer or step in the design-build process; rather, it is a means to produce buildings that do everything they are supposed to do throughout the building's life cycle.

Building commissioning can be described in a general way as a quality assurance process that ensures that a building and its technical systems meet the needs and requirements defined in the Owner's Project Requirements (OPR). The following points further describe what building commissioning involves (Grondzik, 2009, California Commissioning Collaborative, 2006, and Heinz & Casault, 2004):

- Enforces co-operation between participants of the building process.
- Encourages and documents communications between owner, designers, contractor and operation and maintenance (O&M) personnel.
- Documents all problems that contradict the OPR and their solutions in a structural way.
- A systematic quality assurance process which through test and verification ensures that the building meets the OPR.
- Ensures that O&M personnel are provided with needed training to be able to maintain the building at owner's intended performance level.
- A process that focuses on outcome first then what equipment is used to achieve the outcome.

The following points describes what building commissioning is not (Grondzik, 2009 and California Commissioning Collaborative, 2006):

- It is not a replacement for existing quality inspection process, but an addition to that process.
- It is not an additional phase to the existing building process phases - it runs parallel with the building process.
- It is not an isolated testing event of single equipment.
- It is not a testing, adjusting and balancing tool.

Other benefits include a more comfortable environment for building occupants, improved air quality, increased reliability and uptime, reduced maintenance and longer life cycles for building equipment. Cx can be implemented with many systems across a range of projects and at any stage of a facility's life cycle.

2.2 Background of Building Commissioning

The premise that the usual quality assurance processes needed further development was derived mainly from the dissatisfaction of building owners resulting from the fact that their buildings rarely fulfilled their initial requirements or operational needs and the time it took to work out the faults that were overlooked in the building process (Grondzik,2009) Cx is, and has been, a part of the production process in most high technology production industries to ensure a high standard of quality due to the high cost of products being called in to fix failure or flaws created during the assembly period. The general ideology behind the Cx process has been around for decades and can be traced back to the early years of ship building where ships equipment and systems were tested in a controlled environment to verify they worked as intended before they were taken on actual journeys.

Cx, as it is defined today, is not a new term or concept. It can be said to have developed with the increasing project complexity. Cx has been used for decades in ship building industries (Wikimedia Foundation, 2010). One of the reasons it may have been easier to sell the idea that Cx should be an essential part of the ship building process is due to the high risk of life lost if systems or equipment fail. Therefore, it is extremely important that no flaw is overlooked.

When a ship has been commissioned it is declared ready for usage. Before that can be done it has to pass several Cx milestones. Installed systems and equipment are tested, problems are identified and corrected and the crew of the ship is thoroughly trained to be able to maintain and use the ship. So if a ship passes a Cx process it has been ensured that the equipment, systems and personal have successfully completed a thorough quality assurance process and the ship is ready to be used (California Cx Collaborative, 2006).

Cx takes the same approach on newly construction projects as done on ships. It begins in the pre-design phase and goes through design, construction and occupancy and an operation phase and ensures through intensive quality assurance processes that requirements and needs defined by the owner are met.

The development of commissioning is tabulated in Table 2.1.

Table 2.1: Development of Commissioning (Source: Xiao & Wang, 2009)

Year	Evolution of Building Commissioning
1950	Commissioning introduction in Europe
1960	Growth of environmental consciousness
1970	Testing, Adjusting and Balancing (TAB) introduction in North America Energy crisis
1980	Commissioning introduction in North America
1990	US Energy Policy Act of 1992 ASHRAE Guideline 1-1996 CIBSE Commissioning codes
2000-	Testing, Adjusting and Balancing (TAB) of automatic controls and building commissioning growth all over the world

2.3 Definition of Commissioning

As always with a definition of a concept there are numerous different definitions. However most of them carry a quite similar message. In general, most of these definitions refer to Cx as a process that ensures that buildings systems performance meets the intended requirements and needs defined by the owner.

The definition presented at the summary report from the 1993 National Conference on BCx is a good example of what the definition of BCx is:

"Cx is a systematic process of assuring that building performs

in accordance with the design intent and the owner's operation needs."

The Cx process is defined in more detail in the ASHRAE Guideline 0-2005 and there the definition is:

> "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."

Although the definitions have it in common to state that Cx ensures that building performance is in accordance with the design intent and the owners operations need, it should be stated that no quality assurance process, including Cx, is that good that it does not oversee any mistakes or problems. Time has proved that most of the quality assurance processes used in today's building industry discovers most of the problems at last but the timing is often as bad as it gets, and often it is too late to correct the problems and/or the solutions are too expensive and therefore changes are made to work around the problems. By doing that the owner will not be able to achieve his requirements and operational needs for the building.

One of the things that Cx has over other quality assurance processes is that it forces discoveries of mistakes and problems to be revealed as early as possible, under controlled conditions and at time when massive consequences are least likely to occur.

2.4 Types of Commissioning

It is crucial to understand the different terms related to the "Cx" and it can be divided into four different categories, which two of them deal with new buildings and the other two existing buildings. Below is shown a list of these categories with a short description:

New construction Cx: - This begins when the building is just an idea, a drawing or a schematic and is typically just called "commissioning." It is a systematic process of verifying and documenting that a facility and all of its systems and assemblies are planned, designed, installed, tested, operated and maintained to meet the owner's project requirements (OPR). Ideally, the Cx process begins in predesign, continues into the warranty period for a minimum of one year after construction, and involves the proper preparation of operations personnel.

Re-Cx: - Also known as ongoing Cx, the Cx process is repeated after a project has been commissioned previously. This may be preferred option as system performance drifts and/or technologies change and advance over time, making it possible to restore the efficiency of a previously commissioned building and potentially enhance optimization further.

Retro-Cx: - When the Cx process begins after a building has already been built but has not been put through the Cx process; a building's systems are tested and tuned to perform optimally for the current facility requirements. Low-cost and no-cost improvements such as energy conservation measures or reliability enhancements are also recommended, implemented and then commissioned to ensure proper performance.

Monitoring-based Cx (continuous): - Known as MBCX, this process involves innovative commissioning techniques combined with new technology to integrate energy management, utility and building automation data with analytical and diagnostic algorithms that identify actual energy savings and performance enhancement opportunities in real time and ongoing. MBCx seeks to resolve performance issues as they surface and continually refine facilities so that greater than design performance (i.e. technical potential) is achieved over time.

2.5 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.

2.5.1 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 2.1 provides a summary of the main activities that are to be carried out during the pre-design phase (ASHRAE, 2005, CCC, 2006, Grondzik, 2009).

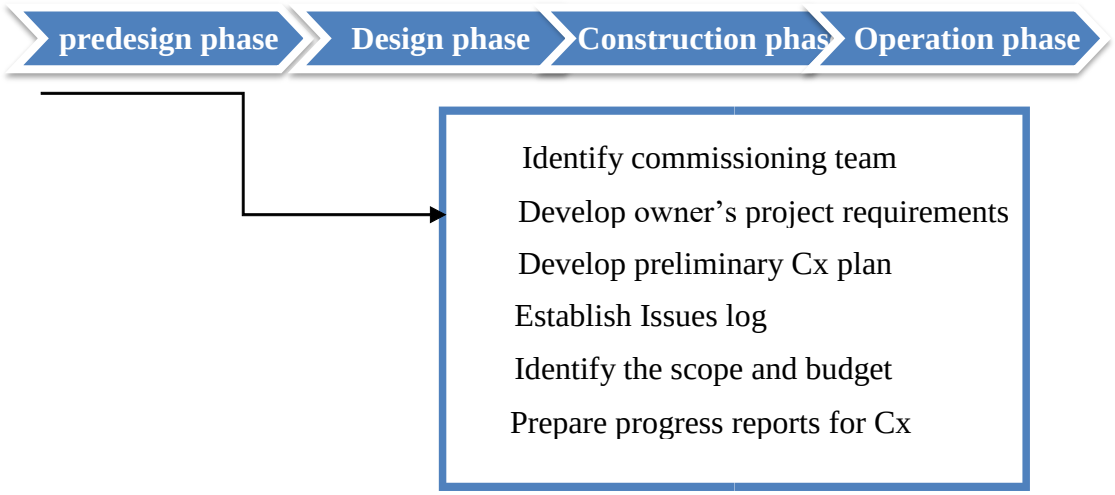


Figure 2.1: A summary of the main activities to be performed by the commissioning team during the pre-design phase (Grondzik, 2009; ASHRAE, 2005; CCC. 2006)

2.5.1.1 Identify Commissioning Team

Identifying the Cx 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
- 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 Cx team are mentioned. More details can be seen in ASHRAE guideline 0-2005.

2.5.1.2 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).

2.5.1.3 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).

2.5.1.4 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 owner’s project requirements not being fulfilled (ASHRAE, 2005).

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

2.5.2 Pre-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 2.2.

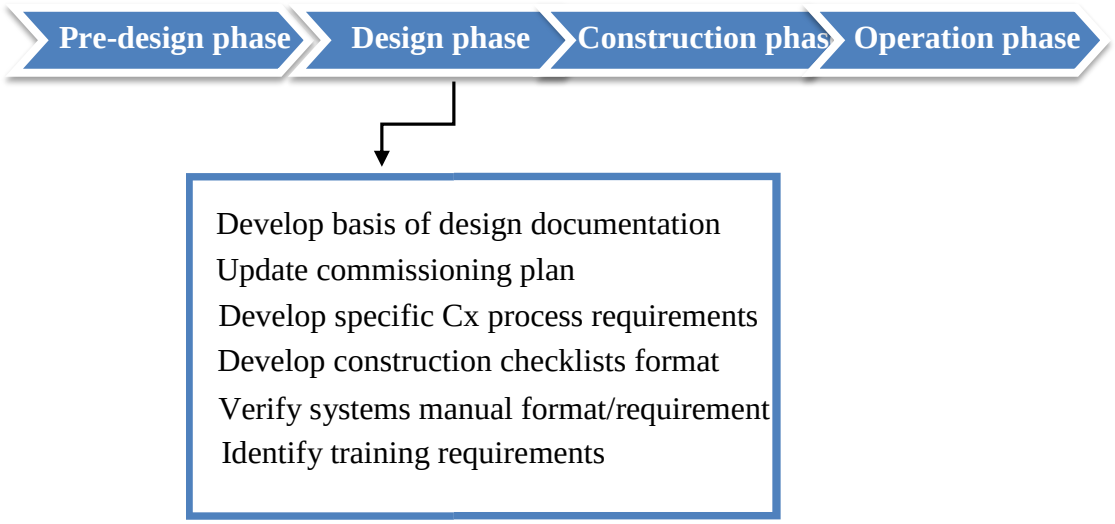


Figure 2.2: A summary of the main activities to be performed by the commissioning team during the design phase (Grondzik, 2009; ASHRAE, 2005; CCC, 2006).

2.5.2.1 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).

2.5.2.2 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.

2.5.2.3 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).

2.5.2.4 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.

2.5.2.5 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).

2.5.3 Construction phase

During the construction phase the Cx 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 2.3: provides a summary of the main activities that are to be carried out during the construction phase (ASHRAE, 2005, CCC, 2006, Grondzik, 2009).

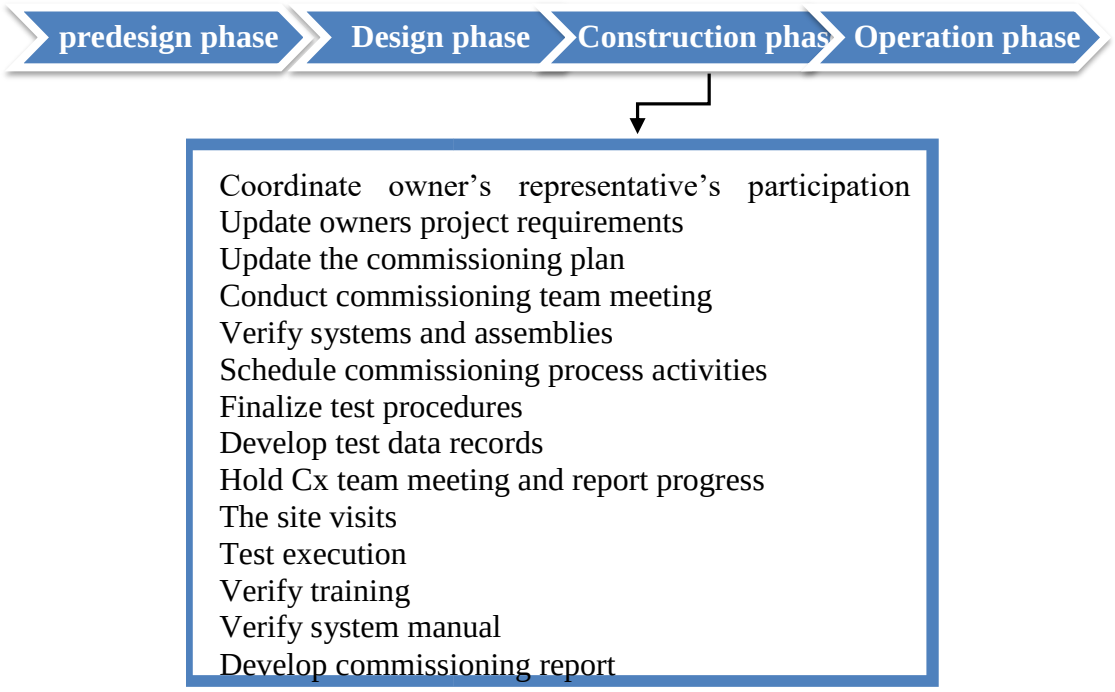


Figure 2.3: A summary of the main activities to be performed by the commissioning team during the construction phase (Grondzik, 2009; ASHRAE, 2005; CCC, 2006).

2.5.3.1 Update Owners Project Requirements

The OPR 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).

2.5.3.2 Systems and Equipment Verification

Systems and equipment verification is one of the most important parts of the Cx 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.

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.

2.5.3.3 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).

2.5.3.4 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.

2.5.3.5 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.

2.5.4 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 2.4 (ASHRAE, 2005; CCC, 2006; Grondzik, 2009).

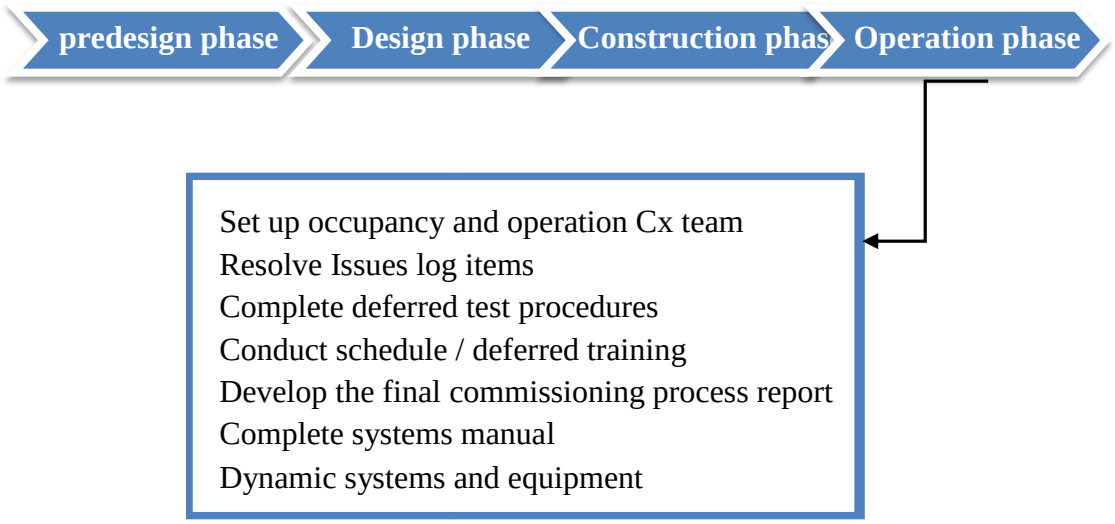


Figure 2.4: A summary of the main activities to be performed by the Cx team during the Occupancy and Operation phase (Grondzik, 2009; ASHRAE, 2005; CCC, 2006).

2.5.4.1 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 lists 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.

This process represents a typical approach to Cx a new facility. An appropriately planned and executed process should be adapted suit project scale, complexity, criticality and unique client needs regarding level of assurance required. Variants of the process exist for specialty industries such as mission critical, health care, pharmaceutical and others; they should be considered when scoping Cx and selecting a CxA.

2.6 Goals of Commissioning in the Ethiopian Scenario

The essential purpose of commissioning is to provide a quality-based process with documented confirmation that all project systems are planned, designed, installed, tested, operated, and maintained in compliance with the owner's project requirements (Shoop, 2006). Cx helps an owner to get what they have paid for (James, 2005). In this paper, the standard forms of contract for the Public procurement Works form (PPA rev.2011) are to be used due to the fact that the government is the client for these public projects in Ethiopia. Apart from this, the ultimate goal of the Cx process is to obtain the CPA. Therefore, it is necessary to mention these clauses related to Cx. This forms are referred depends on the procurement method being selected for that particular project.

Clause 85. Tests on Completion

85.1 The works shall not be accepted until the prescribed verifications and tests have been carried out at the expense of the Contractor. The Contractor shall notify the Engineer of the date on which such verification and tests may commence.

85.2 Works which do not satisfy the terms and conditions of the Contract, or in

the absence of such terms and conditions, which are not carried out in accordance with trade practices in the Federal Democratic Republic of Ethiopia, shall, if required, be demolished and rebuilt by the Contractor or repaired to the satisfaction of the Engineer, otherwise this shall be done as of right after due notice at the expense of the Contractor, by order of the Engineer. The Engineer may also require the demolition and reconstruction by the Contractor, or repair to the satisfaction of the Engineer, under the same conditions of work, in which unacceptable materials have been used, or carried out in the periods of suspension provided for in GCC Clause 20.

Clause 87. Provisional Acceptance

87.1 The works shall be taken over by the Public Body when they have satisfactorily passed the tests on completion and a certificate of provisional acceptance has been issued or is deemed to have been issued.

87.2 The Contractor may apply, by notice to the Engineer, for a certificate of provisional acceptance not earlier than 15 days before the works, in the Contractor's opinion, are complete and ready for provisional acceptance. The Engineer shall within 30 days after the receipt of the Contractor's application either:

a)

ssue the certificate of provisional acceptance to the Contractor with a copy to the Public Body stating, where appropriate, his reservations, and, inter alia, the date on which, in his opinion, the works were completed in accordance with the Contract and ready for provisional acceptance; or

b)

eject the application giving his reasons and specifying the action which, in his opinion, is required of the Contractor for the certificate to be issued.

87.3 If the Engineer fails either to issue the certificate of provisional acceptance or to reject the Contractor's application within the period of 30 days, he shall be deemed to have issued the certificate on the last day of that period. The certificate of provisional acceptance shall not be deemed to be an admission that the works have been completed in every respect. If the works

are divided by the contract into sections, the Contractor shall be entitled to apply for separate certificates for each of the sections.

87.4 Upon provisional acceptance of the works, the Contractor shall dismantle and remove temporary structures as well as materials no longer required for use in connection with the performance of the contract. He shall also remove any litter or obstruction and redress any change in the condition of the Site as required by the contract.

Immediately after provisional acceptance, the Public Body may make use of all the works as completed.

BCx during project handing over is important as the issuance of the Certificate of Practical Completion also fixes the date for the release of the first moiety of the retention to the contractor.

Therefore, any failure of the contractor to carry out the aforementioned work satisfactorily will eventually lead to delay in the project completion.

2.7 Project Life-Cycle in Construction Projects

The construction process today is not a continuous process. As a result, numerous problems can arise during and between the design, construction or occupancy and operations phase. These can for example be linked to a flaw in the design, lack of communication or unclear responsibilities. These flaws are clearly visible in high numbers of request for information, change orders or in problems reported by the occupants of the project after handover. All these examples are contributory causes of cost overruns, time delays and OPR not being completely fulfilled. Because the OPR is not fulfilled the performance of the construction projects is often not maximized and greater energy costs due to lack of efficiency and flaws in projects design are experienced. This in the end decreases the value of the building and reduces the cost effectiveness of the project for the owner.

As shown in Figure 2.1, to ease the information loss and interface problem, the project information loses considerably between different project phases, such as concept phase, design phase, construction phase, and occupancy phase even within the construction project itself. The loss of information during the last phase, occupancy phase, is the most

significance compared to other phases (Hu, 2008).

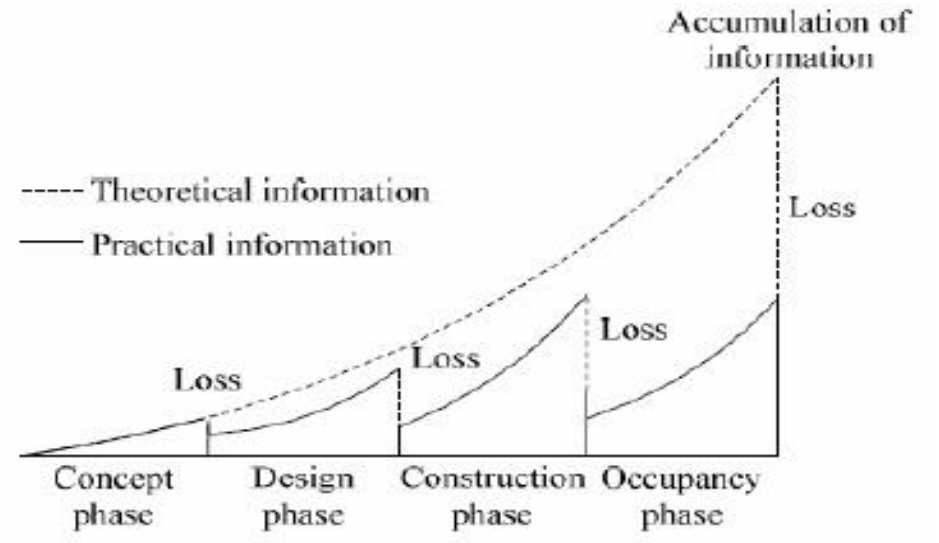


Figure 2.5: Information Losses in Construction Project Lifecycle

(Source: Hu, 2008:373)

As an intermediate process between construction and occupation or operation, testing and commissioning which was carried out during handing over of the project, integrate all the delivery systems for the first time. Testing and commissioning took place from the transition of construction phase to occupation or operation phase.

Therefore, the integration of all these items would be of necessity to ensure building and infrastructure works performance and functionality in handing over them to the client.

According to (Kho Mei Ye, 2013), Professional inconsistencies at the project design and construction interface are identified by many researchers. These researchers such as Assaf and Al-Hammad (1988), Al-Hammad and Assaf (1992), Al-Hammad (2000), Al-Yousif (2001) and Arain (2002) have found that these inconsistencies can be deemed as looking at projects from front forwards. In conjunction with this, little research has been done to identify inconsistencies at the construction and commissioning interface which implies a necessity to look at projects from the end backwards. This will enable clearer visualization of outstanding works that hinder the project handing over.

Therefore, integration of construction and commissioning are needed to ensure good interfaces for achieving customer satisfaction when handing over the project.

It also could be argued that most, if not all, measurable success factors from the subsequent phases of the project can be related back to the initial success variable project mission that is, clearly defined goals and direction (Hamilton, 2003).

Eliminating the existence of inconsistencies can enable projects to be completed successfully. Inconsistencies at the interfaces between parties can either result in delay in project duration, compromise on quality, or increase in cost. Considering these disagreements which can ultimately affect any construction project, there is a need to institute better and comprehensive solutions to coordinate activities at the interface. It is important to determine the potential causes of inconsistencies in the project life-cycle. These potential causes of inconsistencies can hinder the progress of a building project substantially (Arain, Low & Assaf, 2006).

One of the most accepted project life-cycle frameworks have been suggested by Adams and Bamdt (1983) and King and Cleland (1983). The initial stage, conceptualization, refers to the time frame at which a strategic need has been recognized by top management. In general, alternative courses of action and preliminary goals are established at this point, along with discovering the availability of the means to accomplish these activities. The second stage is planning. In this stage, a set of more formalized plans to achieve the initially developed goals are established. Among the important activities in the planning phase is the enlisting of top management support to commit a variety of organizational resources (human, budgetary, etc.) as required. The third stage in the project life-cycle is execution. During this stage, the actual work of the project is carried out. Materials and resources are procured and transformed into the intended project result. Further, performance capabilities are verified. The fourth and final stage in the project life- cycle is the termination phase. Once the project has been completed, resources allocate to the project must be released, personnel from the project team are usually reassigned to other duties, and the project is transferred to its intended users (Adams & Bamdt, 1978; King & Cleland, 1983).

2.8 Problems and Deficiencies in Cx

Without specialized training and attention in Cx problems would never have been caught in a timely manner until the project team was trying to finish up the systems. That early catch of problems could have saved the project from delays and potential change orders:

once the ceilings are installed, going back and forth for troubleshoot of problems will incur more costs to be borne by the owner. Normally, contractors will simply submit report and to see if it gets spot-checked without conducting proper verification because the Cx comes through once the construction works are done. If the Cx has been done properly, there is no need to create as many punch lists when the Testing. This is because all those details have been hashed out before Cx (Chichester, 2006).

These steps of Cx such as design review, preparation of functional testing, implementation of functional tests, and review of trends and tests are part of an iterative process that must react to problems uncovered in the field of commissioning. No script can cover all of the contingences that include field installation, control sequences, equipment internal controls and configuration, unit delays and unanticipated issues uncovered in the commissioning process (Hydeman, 2005).

Cx is a valid means to ensure heating; ventilation and air-conditioning (HVAC) systems perform in building compliance with design intent, consequently to enhance the building sustainability. Heating, ventilation and air-conditioning (HVAC) systems seldom performs as well in practice as anticipated in design due to incomplete documentation for verification, insufficient information exchange among different roles (such as architects, consultants, suppliers, contractors and operators), improper equipment selection and installation, lacking of proper and prompt maintenance, poor feedback on operation performance, performance degradation and even complete failure of components, etc. (Xiao & Wang, 2009).

2.8.1 Risk of Delay and Cx

Commissioning enhances communication among project team members and ensures that they all understand the project goals. This allows the project team to detect the problems earlier, before these problems can affect later phases of the project and cause delays. To prevent the project and the commissioning work from being delayed, the project manager must tail the contractors to correct each deficiency (Oregon Office of Energy, 2000). In order to minimize potential delay, project participants should anticipate risk of delays in any project due to the occurrence of delays or problems in the project commissioning.

2.8.2 Project Efficiency and Delays

Project success was conceived by management using four a distinct dimension in which among these was project efficiency. This dimension expressed the short-term measure of efficiency wherein the project process has been managed and to inform whether the project was completed on time and within the specified budget. However, success in this dimension may indicate an efficient and well managed project but it may not indicate long term success nor benefit to the organization.

Therefore, enhanced of project efficiency should be seen as adding to product competitiveness with shorter product life-cycles, time to market (time from initial concept to market introduction) becomes a critical competitive component to increase competition. Nonetheless, all of these project success measures relate only to project successful implementation of project execution and not necessarily mean total success (Shenhar, Levy &Dvir, 1997). Thus, identification of problems in Cx which might cause delay in handing over is expecting to increase the project efficiency.

2.9 The Needs for Commissioning

Commissioning is an effective approach for system synergy because all construction project systems are interrelated and integrated in function and operation. Deficiency in one component can result in suboptimal operation and performance among other components. Some component deficiency may even lead to system failure and project shutdown. Therefore, the underlying forces of interdependence and synergy need to be harnessed and respected in the application of Cx (Tseng, 2005). Some of the traditional factors supporting the need for a Cx program and making the Cx of construction projects necessary are as follows (GSA Building CxGuide, 1997):

- Unclear design intent;
- Complex building systems;
- Unclear standards and criteria for gauging system;
- Lack of functional performance testing;
- Conflicts between drawings/specifications and applicable codes;
- Inadequate system documentation;
- Maintainability and equipment accessibility problems;

- Inadequate provision for maintenance;
- Inadequate operation and maintenance manuals;
- Inadequate training of Operation & Maintenance staffs; and
- Numerous change orders and cost overruns (GSA Building Cx Guide, 1997).

With these factors as mentioned above, remedying of these deficiencies may results in a variety of benefits such as (Tseng, 2005).

- Improved occupant comfort and productivity;
- Important energy and operating cost savings;
- Significantly improved indoor environmental quality;
- Improved system and equipment reliability:
- Improved building operation and maintenance;
- Improved building and worker productivity; and
- Enhanced the market re-sale value for building owners (Tseng, 2005).

2.9.1 Benefits of Commissioning

Commissioning is being increasingly recognized by owners as an effective means to reduce costs and ensuring quality as well as performance in building systems. The growth of the Cx movement is a long overdue effort to impart quality into this flawed process. This is mainly due to the plan-spec- bid-build process, which is typical and seriously flawed in most public, institutional, and private sector projects. The conventional plan-spec-bid process disperses responsibilities, muddies the performance measures, and does not allow for an integrated process for the delivery of the final product – a functioning, high performance building (Tseng, 1998). With the absence of an experienced commissioning providers in the Ethiopian construction industry as compared with the overseas' practice, the benefits of Cx might have to be re-emphasized. In view of this deficiency, it is of necessary to relook into the misconceptions of commissioning and what Cx really is in the Ethiopian construction industry.

Elzarka (2009) found that unqualified consultants without proper training, knowledge, and credentials in the Cx market have had a negative effect on some owners' perceptions of the benefits of Cx. For a building to produce the anticipated environmental benefits, the owner has to ensure the building actually operates as designed (Elzarka, 2009).

In the United States' scenarios, the need for verifying building operational performance has created a need for involving a party experienced in building operations during the design and construction phases of a building. This party is referred to as the commissioning agent. The involvement of the Cx agent is a natural development of alternative project delivery systems that require a party knowledgeable in construction (the contractor) to participate during the design phase in order to perform constructability studies and develop realistic budgets and schedules. The participation of both the contractor and the Cx agent during the design phase creates a project team with experience in design, construction, and operation that is capable of using integrated design techniques to improve both the constructability and operability of the new building (Elzarka, 2009).

Through the completion of construction, the direct and indirect benefits of commissioning after taken into consideration the payback periods and returns on investment include (James, 2005):

- Savings in energy cost and improved building performance;
- Improved indoor-air quality and comfort and increased productivity on the part of building users;
- Early detection of potential problems (the sooner problems are resolved, the less expensive they are to fix);
- Fewer change orders during construction;
- Precise tune up and operation of systems and applicable controls;
- Better building documentation;
- Trained building operators and maintenance workers;
- Shortened occupancy-transition period; and
- Reduced maintenance, operation, and equipment - replacement costs (James,2005).

The overall goals and benefits of the construction commissioning process included: improved occupant comfort (temperature and indoor air quality); sustained and increased energy and environmental efficiency; reduced maintenance burden and costs; and extended equipment life (Bowman & Wolpert, 2006).

2.10 The Relationship between Cx and Project Success

There is an absence of empirical studies which highlighted or portrayed the relationship between Cx and project success specifically. With the presence of this scarcity, it can be inferred that the revelation of this relationship between Cx and project success is highly noticeable. This relatively new insight can be significant to highlight the lack of attentiveness on Cx in the Ethiopian construction industry. Empirically, no direct relationship is found between Cx and project success. However, from the reviews of literature, it can be postulated that there is relationship between Cx and project efficiency; and between project efficiency and project success. Therefore, the presences of this indirect relationship among Cx, project efficiency and project success have deduced the relationship of Cx and project success. The presence of relationship between Cx and project efficiency; and between project efficiency and project success are discussed in details in section 2.10.1 to 2.10.2. Combining these variables from literature reviews conducted will serves as base to yield a better insight on the possible influence of commissioning on the project success.

2.10.1 Cx and Project Efficiency

It is essential to clearly define the roles and scopes of Cx for all members of the design and construction team. By following recommendations from the CxA, this will then lead to the most efficient, effective, and positive Cx process for all project team members (Ellis, 2010). In the Ethiopia's scenario, there is no Cx authority for commissioning process.

2.10.2 Project Efficiency and Project Success

According to (Kho Mei Ye, 2013), the concept of success in a construction project is corresponding to the efficiency and effectiveness measures (Brudney& England, 1982; de Wit, 1988; Pinto &Slevin, 1988: 1989; Smith, 1998; Belout, 1998; Atkinson, 1999; Crawford & Bryce, 2003). Efficiency is broadly known as the maximization of output for a given level of input or resources (Takim& Adnan, 2008). Efficiency measures refer to internal organizational structures (adherence to schedule and budget, and basic performance expectations) and strong management. In other words, efficiency measures deal with 'time, budget and specifications'. The efficiency of a project would only be

achieved by having a standard system and methodology put in place (George, 1968). This is in alignment with what have been found by Smith (1998) and Nyhan and Martin (1999) that project efficiency is concerned with the utilization of equipment and workforce. Maloney (1990) also emphasized that the construction projects' efficiency entailed the utilization of resources, which may be represented by the ratio of the resources expected to be consumed divided by the resources actually consumed.

2.11 Variables of Cx

According to (Kho Mei Ye, 2013), there are interrelationships among commissioning and productivity, functionality, integration and quality assurance. Therefore, commissioning is utmost important to enhance productivity, functionality, integration and quality assurance in construction projects.

2.11.1 Cx and Productivity-Related Variable

Buildings are created to provide a productive and healthy indoor environment (Scott, 2010). The increment of productivity on the part of building users is one of the direct and indirect benefits of commissioning. The benefits of commissioning which can be factor into return of investment and pay back periods such as the improvement of indoor air quality and comfort of the building (James, 2005). Besides that, the benefits of post-occupancy commissioning also include the increased productivity of facility staff by reducing their burden (Bowman &Wolpert, 2006).

2.11.2 Cx and Project Functionality and 'Fitness for Purpose'

Chan (2000) considers project 'functionality' as one of the success measures in the post-construction phase when the project is completed and delivered. According to Chan (2000), project functionality with expectations of project participant and can be best measured by the degree of conformance to all technical specifications.

Projects are formed to accomplish objectives and success is measured in terms of how well these objectives have been met. Criteria such as meeting project time, budget, technical specification and mission to be performed are the top priorities of project objectives.

The competent design and construction management teams should be able to deliver

these services with minimal or no oversight if the commissioning scope of work is defined clearly in the contract document but apparently not all design teams or construction management teams have the necessary experience (Kjelgaard, 2005).

2.11.3 Cx and Integration

A construction program, or project plan, comprises of a series of interrelated and sometimes inter dependent processes or activities. Every process requires a set of inputs and produces a set of outputs (Sun & Meng, 2009). This is most similar to the function of commissioning wherein the main purpose of commissioning is to integrate all elements together (Energy Design Resources, Building Commissioning Guidelines: A Source Book on Building Systems Performance).

The Cx process integrates and enhances the traditionally separate functions of design peer review, equipment start-up, control system calibration, testing, adjusting and balancing, equipment documentation and facilitates staff training, and adds the activities of documented functional testing and verification. Testing, adjusting and balancing measures building air and water flows, but Cx encompasses a much broader scope of work. Although Cx can begin during the construction phase, owners receive the most cost-effective benefits when the process begins during the pre-design phase at the time the project team is assembled. Cx also assures that the buildings operational staff is properly trained and that the operations and maintenance manuals are compiled correctly at project handing over.

Cx allows for a broad perspective and consistent focus throughout the design and construction process on whether the building will function as intended and identifies the best long-term solutions for problems that arise during project. Cx can facilitate improved integration and communication among team members throughout these phases and can ensure that correctly sized systems function as intended and specified.

2.11.4 Cx and Quality Assurance

Three key attributes about Cx need to be emphasized. First, Cx is a process. Second, Cx is about quality. Third Cx focuses on performance. Two adages about the Cx and quality assurance process are: quality cannot be inspected into a product. Quality must be infused throughout the formation and construction phases of a project. Cx also means to

shift away from inspection mode to quality integration (Tseng, 2005).

"Cx refers to the formalization of each of these quality control processes into a phased quality assurance program with supporting documentation and accountability, ideally by an objective third-party entity" (Rodgers, 2005: 621). Fortunately, an emerging form of quality assurance- commissioning—can detect and remedy most deficiencies. The ultimate impact of energy efficiency research-and-development portfolios, deployment programs, and in-house energy- management initiatives lies in no small part in the extent to which they are coupled with cost-effective quality assurance (i.e.: commissioning) (Mills, Bourassa, Piette, Friedman, Haasl, Powell &Claridge, 2005).

The premise that the usual quality assurance processes needed further development was derived mainly from the dissatisfaction of building owners resulting from that fact that their buildings rarely fulfilled their initial requirements or operational needs and the time it took to work out the faults that were overlooked in the building process (Grondzik, 2009). In order to achieve this, commissioning needs to be emphasized.

Cx is a quality assurance process. It is distinctive from construction inspection, code compliance or construction administration visits by designers. Its emergence is the result of the needs of building owners. Its growth is a reaction to an industry wide problem of failed performance in newly constructed buildings and a response to the increasing complexity of building systems and their interdependency. The fledgling field of Cx provides great opportunity to owners in substantial improvements in the quality and the performance of their building stock (Tseng, 2005).

2.12 Review of Empirical Studies and Knowledge Gaps

Cx is directly related to the building operational efficiency (Kjelgaard, 2005) and it involves team effort that includes not only the CxA but also many others associated with the design, construction, and future operation of the commissioned systems (Ellis, 2010). Cx fills the gaps of conventional maintenance programs and addresses the anomalies that form the achilles' heel of planned preventive maintenance (Wilkinson, 2011). According to ASHRAE Guideline 1-1996 (1998), improved understanding of the Cx process can provide Cx savings. This savings is resulted from the understanding of the purpose of the facility and the reason for its existence to serve the end-user in Cx. It is seemed that the

basic nature of the project definition process is poorly understood and modeled as compared with the later stages in project management. This has unavoidably led to unsatisfactory practical implementation of the project (Kalle, 1999). Avots (1969) conducted a theoretical study to understand the reasons for project failure and concludes that the unplanned project termination is among the main reasons for failure. Thus, this highlighted the need to explore the current scenario of BCx in the Ethiopian construction industry and focuses on the issues during project termination by looking into the problems of BCx. Moreover, there are no researches which have been done in Ethiopia in relation to BCX. Subsequently, the first research gap is the need to determine the perceived understanding of BCx from the contractors' and consultants' perspectives in the Ethiopian construction industry.

Cx is perceived by many as a process to solve problems for project, rather than the start-up of the equipment, or the preparation for the handing over to the client (Kirsila et al., 2007). Some people perceive Cx as a luxury and "added" cost in which it is only a measurement or barometer of the cost of mistakes promulgated by other parties previously involved in the design, construction, or operation of buildings (Mills, Bourassa, Piette, Friedman, Haasl, Powell & Claridge, 2005). The presence of this ambiguity further highlighted the need to re-define the perceived understanding of BCx from the contractors' and consultants' perspective for the Ethiopian construction industry.

So, limiting the investigation of BCx solely relying on these available definitions of BCx may not result in a holistic view that reflect the current scenario of Cx for the Ethiopian construction industry. Therefore, conceptualizing the model of BCx classifications is utmost important to achieve a shared opinion and understanding on BCx.

Lack of awareness on the impact of poor Cx has affected the performance of many projects. Faulty construction, malfunctioning equipment, incorrectly configured control systems and inappropriate operating procedures have increased realization that many projects do not perform as intended by their designers. The problem has become more evident when the project Cx is considered as a mere administrative formality to obtain the construction license for the party involved. This ignorance of what a project really is implies that quality is not the prerequisite of it, and it is deemed unimportant. Lacking awareness of the Cx party has negatively impact the project performance and this causes

a continuum exists in the degradation of projects performance [J.E. Woods (1990)]. Therefore, it is of necessary to identify the effects of poor Cx on the projects performance.

A study conducted by the University of Wisconsin, found that 81 percent of building owners surveyed encountered problems with new heating and air conditioning systems. Another study of 60 buildings by the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL), found that nearly half of building owners surveyed were experiencing controls problems. In addition, 40 percent had heating, ventilation and air conditioning (HVAC) equipment problems, 15 percent had missing equipment, and 25 percent had energy management systems, economizers, and/or variable speed drives that were not functioning properly (Claridge 2003). This shows us there might be problems in the conduct of Cx which has led to these problems.

Apart from this, accumulated delays from previous phases may lead to operational errors during execution of Cx procedures. Delays can result in time constraint and impose pressure that could affect project scheduling prior to final delivery to the customer (Cagno, Caron & Mancini, 2002). The research done by (Haasl and Friedmann, 2001) identified that education is needed on the Cx process, since the majority of owners define Cx as primarily the testing of systems. Therefore, the objective of the research is to identify the significance of delay during Cx in the Ethiopian construction industry from the perspectives of contractors, consultants and others.

Some previous empirical works on construction delays and the findings from these studies shows that most of these studies failed to specify from which stage of the project life-cycle these delays were derived. These studies also remain anonymous in delineating the interrelatedness of these delay factors with other stages in the project life-cycle.

There is a rising recognition that many projects do not perform as intended. Reasons include faulty construction, design flaws, malfunctioning equipment, incorrectly configured control systems and inappropriate operating procedures. But, there is an obvious shortage of empirical studies to address Cx problems for building construction. Thus, the focuses of this study are to determine the causes of these Cx glitches.

Furthermore, there is lack of information on the adherence of this project with the scopes of Cx. Therefore, this study attempts to fill this gap by identifying problems that arise

during Cx. These problems whether is due to Cx-related problem or non-Cx related problem, will aid future projects in the Ethiopian public institutions to adhere with the scopes of commissioning.

Some of the issues or problems observed by the researcher that is related to the conduct of BCx in the Ethiopian building construction projects are: equipment's have yet to be integrated with the building due to delay in building construction, poor quality work, the issuance of Certificate of Practical Completion (CPC) without proper justification, (CPC) was issued before the works were completed, works were done not in accordance with specifications and projects were not properly planned and (CPC) was issued for the project which failed its main component testing and commissioning. The ultimate goal of Cx is to obtain the (CPC) and to ensure the constructed facilities are in accordance with all the specifications and design intent. All these problems have further highlighted the necessity to know what goes wrong with building Cx and the reasons for it.

2.13 Earned Value Analysis

2.13.1 Earned Value

Earned Value is a well-known project management tool that uses information on cost, schedule and work performance to establish the current status of the project. By means of a few simple rates, it allows the manager to extrapolate current trends to predict their likely final effect. The method is based on a simplified model of a project, but proved to be useful in practice of cost control. It is being developed to account better for schedule and time aspects.

Earned value management was also known as "integrated cost and schedule control", because it brought together a way of measuring achievement against both time and cost goals (Webb, 2003).

2.13.2 Definition of Earned Value

Adding the value generated as time passes gives a greater insight into the project than simply comparing the planned and actual values. The worth in financial terms associated with the value generated is termed the 'earned value' (Webb, 2003). The definition of Earned Value is "A method for measuring project performance. It compares the amount

of work that was planned with what was actually accomplished to determine if cost and schedule performance is as planned". Moreover, Earned Value Analysis integrates the many important areas in project management such as project organization, scheduling, planning, budgeting; accounting, analysis, reporting and charge control (Fleming & Koppelman, 2000). Earned Value Analysis utilizes a few tools such as performance curve, work breakdown structure and a few defined formulas to depict the overall performance (Marshall, 2007).

2.13.3 Purpose of Earned Value

The Earned Value method has been developed as a tool facilitating project progress control. It is used for determining a project's status (is it behind or ahead of schedule? is it over or under budget?) and the scale of current variances from the plan. Moreover, it allows a project manager to make inferences on the final effect of the project in terms of cost and, to some extent, in terms of duration, by extrapolating current trends (John Wiley & Sons, 2006).

As 'Earned Value Roles' has been clearly stated by PMI (2005), we can summarize that Earned Value Analysis has an essential role in determining the accurate measurement of physical performance against a detailed plan to allow for the accurate prediction of the final costs and schedule results for a given project. This is in agreement with Fleming and Koppelman (2000). Moreover, in any project, Earned Value Analysis has a significant role in the total management of project variables such as project scope, time, progress, cost and risks and the procurement of the main project supplies and services.

2.14 Objective of Earned Value in Building Commissioning

1. Using Earned Value Analysis to measure the importance of Cx by clearly defining the tools used in Earned Value Analysis such as Planned Value (PV), Earned Value (EV) and Actual Value (AV);
2. Comparing the importance of each stage in a construction project using Earned Value Analysis and relating the outcome with Cx;
3. Create a derivation for comparison based on x, y and z; and
4. Analyze and deduce a conclusion based on findings of analysis using Earned Value Analysis.

2.15 Idea of Earned Value Analysis and Interpretation of Its Results

2.15.1 Input data's

Figure 2.6 presents the idea of the Earned Value project control. The analysis requires following inputs (John Wiley & Sons, 2006):

Planned Value (PV)

BCWS – Budgeted Cost of Works Scheduled – the baseline for the analysis, cumulated planned costs related to time of their incurrence;

Earned Value (EV)

BCWP – Budgeted Cost of Work Performed – a measure of physical progress of works expressed by cumulated planned cost of works actually done related to time, it is also called Earned Value (like the method it is used by);

Actual Cost (AC)

ACWP – Actual Cost of Work Performed – cumulated amount payable for works done related to time;

Rate of Performance (RP)

It is the rate at which the project is progressing. Mathematically, it is the percentage of the work actually completed out of the total work that was scheduled to be completed till that point of time.

Cost Variance (CV)

Cost Variance calculates the difference between the actual cost incurred and the planned cost. It checks for over budget or under budget.

Cost Performance Index (CPI)

Cost Performance is used to estimate the projected or actual cost of completing the project based on the performance to date.

CPI = EV/AC

2.15.2 Formulas Used in Earned Value Analysis

As tabulated in Table 2.2 are formulas in Earned Value Analysis being used in the measurement of building commissioning performance to determine the importance of building commissioning on the project timely completion.

Table 2.2: Formulas in Earned Value Analysis (Source: developed from PMI, 2005)

Term	Formula
Earned Value	EV = PV to date x RP
Cost Variance	CV = EV – AC
Schedule Variance	SV = EV – PV
Cost Performance Index	CPI = EV/ AC

2.15.3 S-Curve

S- Curve depicts the cumulative costs or other performance metrics against time. Typically, an Earned Value Management S-Curve is displayed on an X-Y axis with Time as X-axis and Performance Metrics as Y –Axis. S-Curve shape usually is flatter at the beginning and end and steeper in the middle which is typical of most projects especially in construction. The initial part of S-Curve represents a slow, starting point for the project and accelerates once work is in progress and normally decelerates at the end for typical projects (Wideman, 1994).

According to Webb (2003), S-Curve can be divided into three stages, which are:

Stage 1: Start Up

- Preliminary preparatory stage which includes planning, preparing work force as well as ordering of materials, etc.
- After the initial preparatory work has been laid, the project will move on to Stage 2.

Stage 2: Steady Stage

- Work is progressing steadily.

- Working environment has reached optimum conditions for balanced performance and repetition.
- Further contractors and workers are added as project progress. Integration of every process becomes more complicated.

Stage 3: Wind Down

- There is pressure to complete the project on time.
- Testing and commissioning stage.
- Project completion.

As mentioned previously, S-Curve represents a slow, starting point for the project and accelerates once work is in progress and normally decelerates at the end for typical projects. But, occasionally, the S-Curve may display steep curve at the end if the project if the project is not running smoothly due to problems either in stage 1 or stage 2. This steep end has an interesting S-Curve shape and can be due to many reasons. The end of the project is usually associated with project commissioning and this is where an analysis will be done to examine the impact of project commissioning towards the whole project progress.

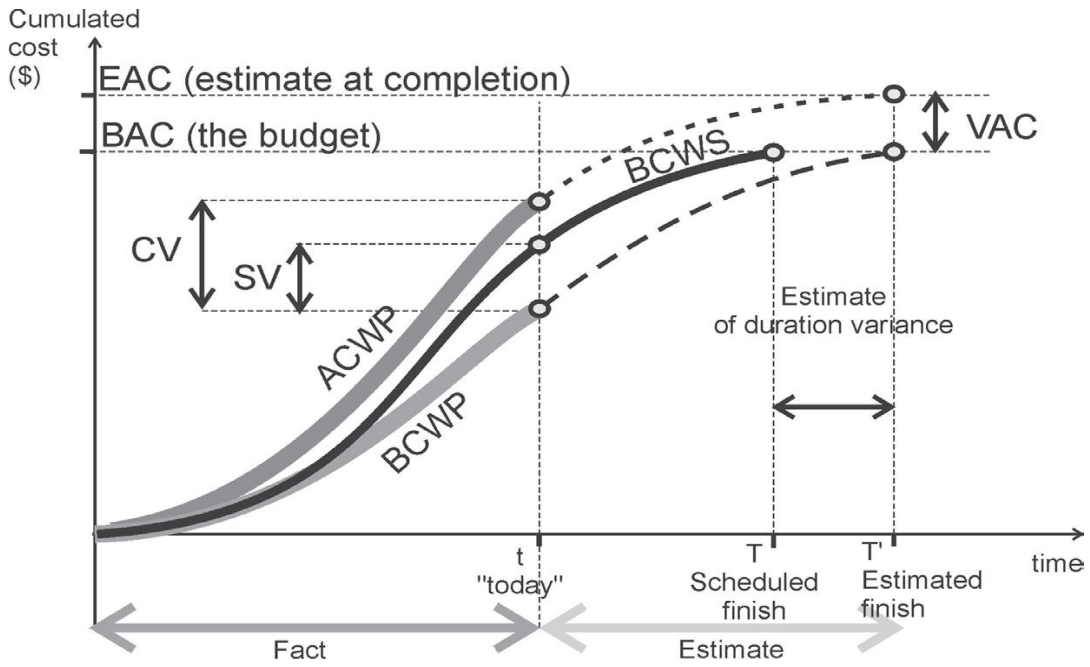


Figure 2.6: Earned Value curves; (Source: John Wiley & Sons, 2006):

2.16 Summary of Literature Review

From the extensive literature reviews that have been carried out, it was found that Cx of buildings in the construction industry are worth to be studied to add merit to the existing literatures. The effects of poor BCx can affect construction projects in terms of time, cost and quality. Thus, reviews of literature on remedies to mitigate this problem were described in this section. Firstly, the existing literature indicates the relevance and significance of this research to deal with this problem and to address the vagueness which has caused these problems in the following aspects:

1. Some of the previous researches on BCx have overlooked the essentiality of Cx as an integral part of the project in the construction industry;
2. Most of the existing literatures merely identified that construction delays are among the most common causes of delay in construction projects and span throughout the project life-cycle;
3. What is considered as BCx from the contractors' and consultants' perspective? Do they perceived the essentiality of Cx or merely Cx is just treated as a pre-requisite to obtain the Certificate of Practical Completion (CPC)? Why?
4. How does this problem of poor Cx and construction problems affect the project performance and the project timely completion? and
5. Do problems or delays from construction affect the Cx of the construction projects? How?
6. How does Cx affect the project performance? How do they interrelate?

CHAPTER III: THE RESEARCH DESIGN AND METHODOLOGY

3.1 Framework for the Methodology

This research attempted to identify problems of building commissioning from each individual being investigated and the influences of this problem on the project handing over. The research also tried to construct a better understanding on building commissioning from the lived experience of human beings. Thus, exploratory research is the most appropriate approach to become fully involved in this subject on building commissioning. This approach also allowed the researcher to uncover the socially constructed meaning as it is understood by an individual or a group of individuals on the perceived meaning of building commissioning. Exploratory research provides general, predictive laws about human behavior, and presents a rich and complex description of how people think, feel and react under certain contextually specific situations. As this research adopted the exploratory approach, case studies have been selected to uncover the issues of building commissioning in the Ethiopian construction industry. Qualitative method is chosen for this study given the exploratory paradigm and inductive approach for the research justification.

As illustrated in Figure 3.1, preliminary information is gathered by conducting extensive literature reviews to gain a better understanding on building commissioning in the Ethiopian construction industry. The research process began with review of previous empirical work on building commissioning to identify problems and gaps for the present research. After the research problem and questions were developed, in-depth literature review was conducted on the concept of building commissioning. This early stage is necessary to determine the worthiness of this study to be investigated and to address the problem in a clearer manner.

The second phase aimed at generation of research questions and research objectives to enhance building commissioning for the public institution in Ethiopia. By conducting extensive literature reviews and complemented with the researcher’s knowledge on this subject matter, the interview questions are refined for the actual case study. Case study protocol is developed in this phase as well. This phase is of essentiality to provide a fundamental direction for the later research investigation as well as its overall

importance. The issue concerned was defined clearer and to narrow down the research from its broad base to look into this problem from the contractors' and consultants' perspective in the construction industry. It is critical to identify the potential problem before finding solutions to vex issues.

The third phase aimed to collect data from the construction projects by conducting case studies which was achieved through semi-structured interviews, reviewed of archive records and the conduct of participant observations at site meeting. The resulted findings are of extremely high value to aid the development of the building commissioning model later on.

The last phase concerned with development of the proposed conceptual framework for building commissioning derived from the previous phase. In this phase, a systematic combining of the proposed conceptual framework, previous empirical work, the case of the public institution construction projects around Addis Ababa and theory related to building commissioning are matched and combined. The results derived from this approach will be discussed and presented to achieve the specified research objectives.

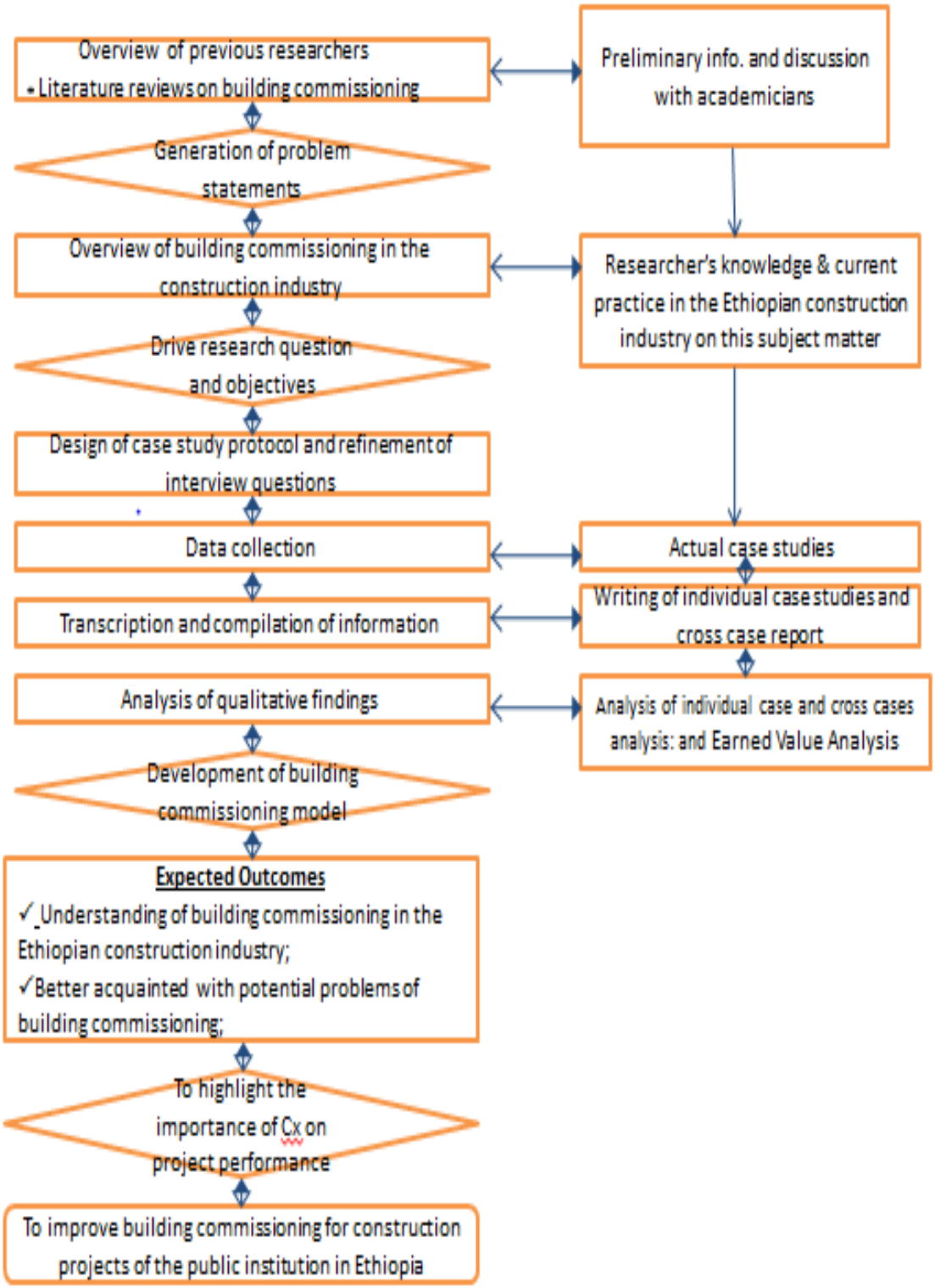


Figure 3.1: Framework for the methodology

3.2 The Research Area and Cross Sectional Design

For this research, a cross-sectional study which involved observation of a sample of public institution on-going construction projects around Addis Ababa which were scheduled to have testing and Cx regardless whether these projects are behind schedule or projects with the percentage of completion more than 90% from year 2014 till 2018.

3.3 Deciding the Number of Cases

This study employed a holistic design as it only examined the issue of building commissioning for the public institutions construction projects around Addis Ababa. In interpretive research the number of participants is relatively small (Holloway, 1997). Yin (2009) highly recommends that novice researchers begin "with a simple and straightforward case study" (p. 162) because of the complexity of managing and analyzing the large volumes of data. However, evidence from multiple cases is "often considered more compelling and the overall study is therefore regarded as being more robust" (Yin, 2009, p. 53) and provides a valid basis for understanding (Levy & Powell, 2005). Although there is no ideal number of cases, there are several recommendations:

- Eisenhardt (1989, p. 545) believes that between four and ten cases often works well.
- Crabtree and Miller (1992) advocate a sample size of six to eight subjects for homogenous samples.
- Curran and Blackburn (2001) indicate that case studies in small business research are of-ten fewer than ten.

While there is no ideal number of cases, a number between four and ten cases will usually work out well (Eisenhardt, 1989). Thereafter, this research opts to select six cases for the multiple-case deigns. This study covers several construction projects in a public institution around Addis Ababa. Each of these construction projects is the subject of an individual case study. Lessons from each case study will be compared and common explanation that emerged will be used to characterize building commissioning problems for construction projects in a public institution of in Ethiopia.

3.4 Rationale for the Selection of Case Study on Public institution building construction projects around Addis Ababa.

The current process for the construction of buildings for public institutions was generally inefficient and most importantly, commissioning is underutilized in public-interest deployment programs and research and development activities.

Besides that, the ease of accessibility of information to these construction projects was one of the criteria for selecting construction projects in the public institutions in Ethiopia. These construction projects were selected as these projects were actually managed and participated by various external construction teams, such as: external client's representative from the government, external architect, engineers and contractor. Therefore, by studying these projects would enable an effective use of non-campus expertise and knowledge simultaneously. Most importantly was no study has been done on BCx for public institutions construction projects in Ethiopia. Building construction in public buildings employ the same method and process in procurement, design, construction and Cx stage. Therefore, we can show the trend or pattern using samples taken from the public institutions construction projects in Ethiopia as the case study.

The approached interviewees were those working for the contracting companies and consultants, who are contractors and consultants such as: construction manager's, engineer's, project manager's, project coordinator and Contract and supervision head's with a minimum of eight to more than forty years of experience. These disciplines among interviewees which comprised of the contractors and consultants enabled a more compelling comparison to be made among those who are in the realm of commissioning.

3.5 Case Study Questions

The questions are reminders concerning the information that needs to be collected to answer the research objectives which is to explore the current scenario of BCx in order to determine the perceived understanding of BCx and to determine the performance rate for Cx using Earned Value Analysis.

An in-depth interview questions are prepared to investigate and identify the main causes for Cx problems and to define the areas for Cx, as well as to identify occurrences of inhibitor and the causes for these impediments to deliver building projects in a timely

manner. This research has ignited the emergence of the question of 'why' and 'how' in context of commissioning research. The emergence of 'why' and 'how' questions resulted in the selection of interviews, review of documents, and observations as the research method.

The design of an in-depth case study interview questions was based on a combination of an extensive review of literatures dealing with project commissioning and the researcher's knowledge on the current BCx practices in Ethiopia and will be conducted by using open-ended question to gain broader views on the relevant subject.
The interview questions are shown in Annex A. and the form includes names of the site to be visited, contact person's information, project duration and the type of construction contract.

3.6 Method of Data Collection

Data will be collected from people and institutions in their everyday situations. Therefore, it is necessarily to integrate real- world events with the needs of the data collection plan. The field procedures of the protocol need to highlight these major tasks, such as: gaining access to key organizations or interviewees, physical progress and outstanding works of the projects, progress reports, milestones for testing and Cx programmed, available minutes of meeting on testing and Cx and having sufficient resources while in the field i.e. Writing instruments, voice recorder and pre-established answer sheets.

3.7 Theory Development

Development of theory as part of the design phase is vital for case studies (Yin, 1994). The complete research design will increasingly cover the five components of the needed research design such as the questions, propositions, units of analysis, logic connecting data to propositions and criteria for interpreting the findings. It also embodies a theory of what is being studied. Theory development prior to the collection of any case study data is a vital step in doing case studies (Yin, 2009). The simple goal of theory development is to have sufficient blueprint of the study which requires theoretical propositions (Yin, 2009) and this is noted by Sutton and Staw (1995) as "hypothetical" story about why acts, events, structures and thoughts occur. Literature reviews related to BCx are

reviewed in preparing the case study for theory development. For the multiple-case study, the mode of generalization is analytic generalization. Previously developed theories are used as a guide to compare the empirical results of the case study in this kind of generalization (Yin, 2009). Details for this are described further in the following section.

3.7.1 Systematic Combining

A multiple method approach was used to permit a "triangulation" (van Maanen, 1979) of data collection to provide valid observations of coordinated purchasing activities and decisions. Data from direct observation, a review of company records, personal interviews, and a literature review were compared and contrasted in an attempt to produce clarity in understanding information processing and decision making in corporate purchasing agreements.

As demonstrated in Figure 3.2, the main characteristic of systematic combining is a continuous movement between an empirical world and a model world. During this process, the research issues and the analytical framework are successively reoriented when they are confronted with the empirical world. Systematic combining is a process where theoretical framework, empirical fieldwork, and case analysis evolve simultaneously. The proposed systematic combining is an argument for a stronger reliance on theory than is suggested by true induction (Dubois & Gaide, 2002).

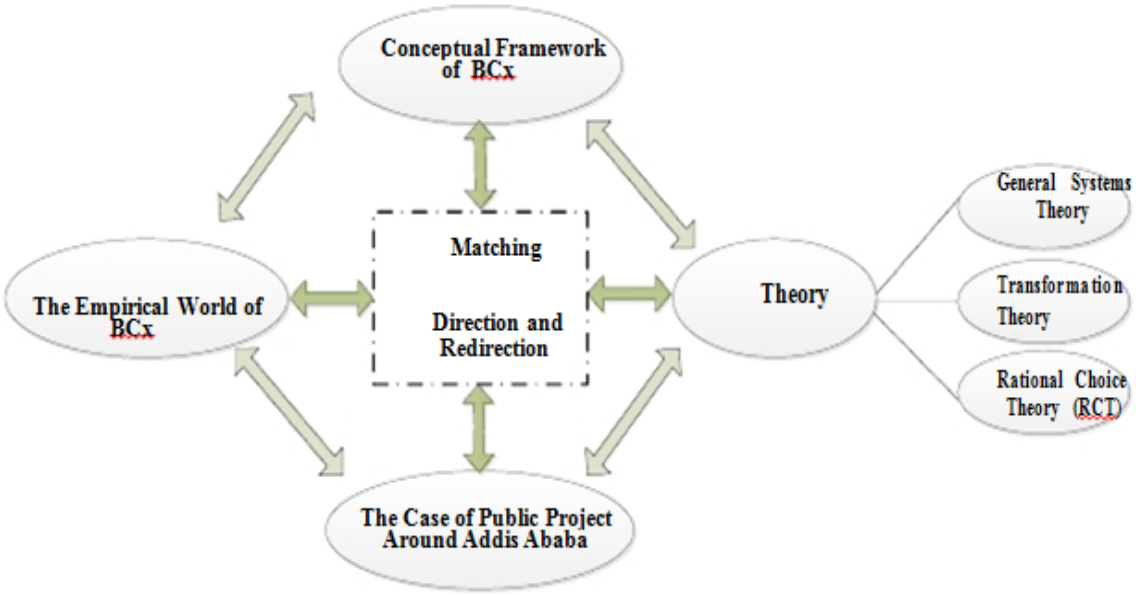


Figure 3.2: Systematic Combining (Source: Kho Mei Ye, 2013)

3.8 Case Studies Analysis

Six case studies selected for this study. The first purpose of these case studies is to explore the current scenario of building commissioning and to determine the perceived understanding of building. The second purpose is to determine the performance rate for commissioning using Earned Value Analysis. This performance rate for commissioning is then compared with the performance rate for construction to deduce derivation for these case studies.

The purpose of an in-depth interview study is to understand the experience of those who are interviewed, not to predict or to control that experience (van Manen, 1990: 22). In qualitative research, the researcher is trying to understand the speech patterns and behavior of actors or agents and the specific context in which these behaviors occur.

The purpose of qualitative research is to get at the world of the agent or subject. The goal of qualitative research is to discover patterns which emerge after close observation, careful documentation, and thoughtful analysis of the research topic. What can be discovered by qualitative research is not sweeping generalizations but contextual findings. From the point of view of the phenomenological perspective, to the question of how one finds out about the complexities of problems and persons is indwelling; the proposed research framework is the posture taken by a qualitative researcher, by the human-as-instrument (Maykut & Morehouse, 1994).

Each of these six cases were handled by different contracting companies who are in-charged to construct buildings with different functions as required by the end-user for the public institution in Ethiopia. The interviewees were practitioners in these construction projects and were selected and appointed by government and public institutions of Ethiopia to participate in these projects. These interviewees were chosen for their specific knowledge in commissioning and experience to provide relevant information about commissioning. The interviewees whom participated in this research are practitioners with at least 8 years of working experience in the construction industry with some of them are practitioners with more than 40 years of experience in the field. The cost of these projects ranges from (ETB) 24 Million to 359 Million.

Table 3.1 is the summary list of case studies selected for this study. The first purpose of these case studies is to explore the current scenario of building commissioning and to determine the perceived understanding of building. The second purpose is to determine the performance rate for commissioning using Earned Value Analysis. This performance rate for commissioning is then compared with the performance rate for construction to deduce derivation for these case studies.

Table 3.1: List of Selected Case Studies

Case Study	Project Description	Contract Type	Contract Value (ETB Million)	Contract Duration (Months)	Expected Completion Date	Interviewees
1	Construction of G+4 Laboratory Building of Addis Ababa Science Technology University.	Add - Measurement	24	5	Jun, 2017	Building Contractor: Consultant
2	Construction of Addis Ababa University Commerce Project.	Add - Measurement	342	24	Sept, 2017	Building Contractor: Consultant
3	Construction of Maternity and Pediatrics Hospital of St. Paul's Hospital.	Add - Measurement	356	24	Jan, 2018	Building Contractor: Consultant
4	Construction of Addis Ababa University Library Complex Building.	Add - Measurement	67	7	Oct, 2017	Building Contractor: Consultant
5	Construction of Different Buildings in Health Science College of Addis Ababa University.	Add - Measurement	359	20	Feb, 2015	Building Contractor: Consultant
6	Construction of Wolkite University General Hospital.	Add - Measurement	182	18	Apr, 2018	Building Contractor: Consultant

IE1ab1-5 is a source code for each of these interviews so that any future reference can be traced easily to each piece of raw data. The first code segment refers to the type of data (I for interview). The second segment, for example E1a, describes the first engineer interviewed for the contractor. The third segment refers to the number of the interaction if there was more than one interaction for the respondent. For instance, E1a for the first interaction with engineer and E1b for the second interaction. The last segment is a page number if the raw data cover more than one page (for example from page 1 – 5 of a transcription of an interview). So, 1E1ab1-5 is the source code for page 1 to 5 of a transcription of an interview with the engineer 1 (Cavana et al., 2001).

3.8.1 Analyzing and Interpreting Data

When analyzing data, the qualitative researcher attempts to make sense and interpret the phenomena in terms of the meaning the participants place on them (Creswell, 2009). A variety of qualitative data analysis methods such as content analysis, constant comparison and pattern matching can be used. Whichever approach is chosen qualitative researchers should make the process involved in their collection and analysis of data as explicit as possible. Researchers employing qualitative methods that fail to do so "do little to encourage theory development or progress current knowledge and understanding" (Shaw, 1999).

The qualitative interview data were analyzed using Cope's (2005) four levels of analysis (Levels 1 through 4) with an additional level that considers the data collection and recording process itself as the first level of analysis (Level 0) as is discussed explicitly below. (Note that data collection and analysis is an iterative process and that the researcher iterates between the different levels of analysis throughout the data collection process even though it is discussed consecutively.)

Level 0: Conducting interviews

The process of inductively analyzing data commences as soon as the researcher starts collecting data, that is, during the interviews (Shaw, 1999). For this reason, whenever possible, the researcher(s) should conduct all interviews. Alvesson (2003), furthermore, encourages researchers to consider the impact of the social setting in which the interview takes place (e.g., interviewer's background, experience, gender, age, and nationality), the

physical setting, and the impact of language use on the interview, for example, use of terminology with which the interviewee is unfamiliar.

Level 1: Transcribing and capturing of notes

Level 1 analysis comprises the reading of each transcript and set of notes several times with the researcher making detailed notes to highlight potentially significant issues and experiences (Pat-ton, 2002). This serves to familiarize the researcher with the data (Easterby-Smith et al, 1991) and to begin the process of organizing and structuring the data and increases the researcher's aware-ness of the patterns, themes, and categories in the data.

Level 2: Writing up case study narratives and within-case analysis

During Level 2 analysis the transcripts and notes are developed into coherent and manageable yet rich write-ups for each case structured according to the descriptive framework in order to allow subsequent cross-case analysis. Rich descriptions in the form of case narratives allow the reader to judge the transferability of the interpretation and also the results, thereby also increasing dependability. Case studies can be presented chronologically, thematically, or both. In these research project the case study narrative was both thematic and chronological because the narrative explains the use of data, systems, and information in relation to decision-making within the context of the interviewee's.

1. General background of the of case study
2. Owner/manager profile; and
3. Other related issues to the case study

Level 3: Determining findings through cross-case analysis

The third level of analysis is concerned with cross-case comparisons to seek out what is common and what is particular in the cases (Stake, 2005). This level of analysis can result in a unified description across cases, categories, themes, or typologies that conceptualize the data across all the cases, or in building a substantive theory that offers an integrated framework covering multiple cases (Merriam, 2009).

A frequently used method of cross-case analysis is qualitative content analysis. Qualitative con-tent analysis involves identifying coherent and important themes and

patterns in the data: the researcher looks for "quotations or observations that go together, that are examples of the same underlying idea, issue, or concept" (Patton, 1987, p. 149). The themes and categories are constructed through coding, and researchers can choose from a variety of approaches. Two main approaches are an emergent approach, which is the more conventional grounded theory approach, or an a priori directed approach. In emergent coding no prior themes are established and themes emerge through repetitive scrutiny and comparison of the data. With a priori coding themes are established prior to the analysis based upon literature and the themes are then applied to the collected data. The outcome of this level of analysis is the findings based on the collected data.

Level 4: Interpreting and enfolding findings in literature

In order to develop a deeper understanding of the data collected Level 3 analysis involves the "clustering" together of findings (Hycner, 1985) without the use of any relevant theoretical literature. In Level 4 the findings are discussed in the context of extant literature, a process that Eisenhardt (1989) calls enfolding literature and the outcome of this level of analysis is the interpretation of the findings.

CHAPTER IV: EARNED VALUE ANALYSIS TO DETERMINE BUILDING COMMISSIONING PERFORMANCE

4.1 Measuring Commissioning with Earned Value Analysis

As the study approach is to gauge the importance of Cx in a construction project, the necessary data is needed to validate the importance of commissioning in construction projects. Planned Value (PV), Earned Value (EV) and Actual Value (AV) data of a construction project in Ethiopia was collected. By using Earned Value Analysis to measure the Rate of Performance (RP) of Planned Value (PV), Earned Value (EV) and Actual Value (AV) for Cx stage, an S- Curve was constructed to show the relevant parameters.

The data will provide solid backing that Cx has a significant role in the entire project construction and should not be treated as a trivial part in the project construction. Failure to grasp the importance of building commissioning will increase the risk in the project safety, jeopardizing project cost and result in the inoperability of electrical and mechanical equipment.

Data from one Public institution construction project identified and collected for this study. And the values for Planned Value (PV), Earned Value (EV) and Actual Value (AV) were tabulated and the related ratios such as Rate of Performance (RP), Cost Variance (CV), Schedule Variance (SV) and Cost Performance Index (CPI) were calculated. Tables and S-Curve for Project B, is illustrated as follows in Figure 4.1.

4.1.1 Case Study 2a (IPM1a1-4)

4.1.1.1 Back Ground of Case Study

A case study interview was conducted with a project manager (contractor) for the construction of Addis Ababa University Commerce Project. This interview was conducted on 15th June, 2017 at 03:.20 a.m. at the project office of AAU Commerce.

Years of Experience: - 19 Years

Project Duration: - 730 days

Type of Construction Contract: - Conventional/Add-Measurement

4.1.1.2 Issues Related to the Case Study

1. The actual project completion date was supposed to be on 11th February, 2016 but it was extended with 445 days of an Extension of Time (EOT), by the client. Therefore, the new completion date was shifted to 1st May, 2017 and expected completion date of the project is 12th September, 2017.
2. According to the interviewee, it is a challenging task to close- out the project because towards the end, problems such as outstanding works, defects, availability of equipment, availability of a stable power supply for testing, adequateness of manpower, contactable personnel involved, quality of workmanship, leakage, coordination among different trades of work and etc. arises. This complex coordination of work towards the end of the project impedes the project handing over in a timely manner.
3. For this relevant project, the contract value was changed fifteen times.
4. According to the interviewee, the total number of Variations Order (V.O.) for this project might be increased further as some of the V.O. has not been settled yet. The interviewee indirectly admitted that the delay for the project was due to additional works or variation orders.
5. The interviewee claimed the high number of changes and V.O. has affected the execution of the actual contract work as much time has been spent to tackle these V.O. works.
6. The interviewee said that the delay for the project was mostly due to design changes. According to him, a delay of testing and commissioning were mainly caused by electrical works such as changes in end-user requirements and due to outdated information as this project might was designed in years behind and there was a lack of updated information from the end-user.
7. According to the interviewee, delays usually occur during construction and result in the construction schedule being pushed behind and this will subsequently affect the testing and commissioning date.

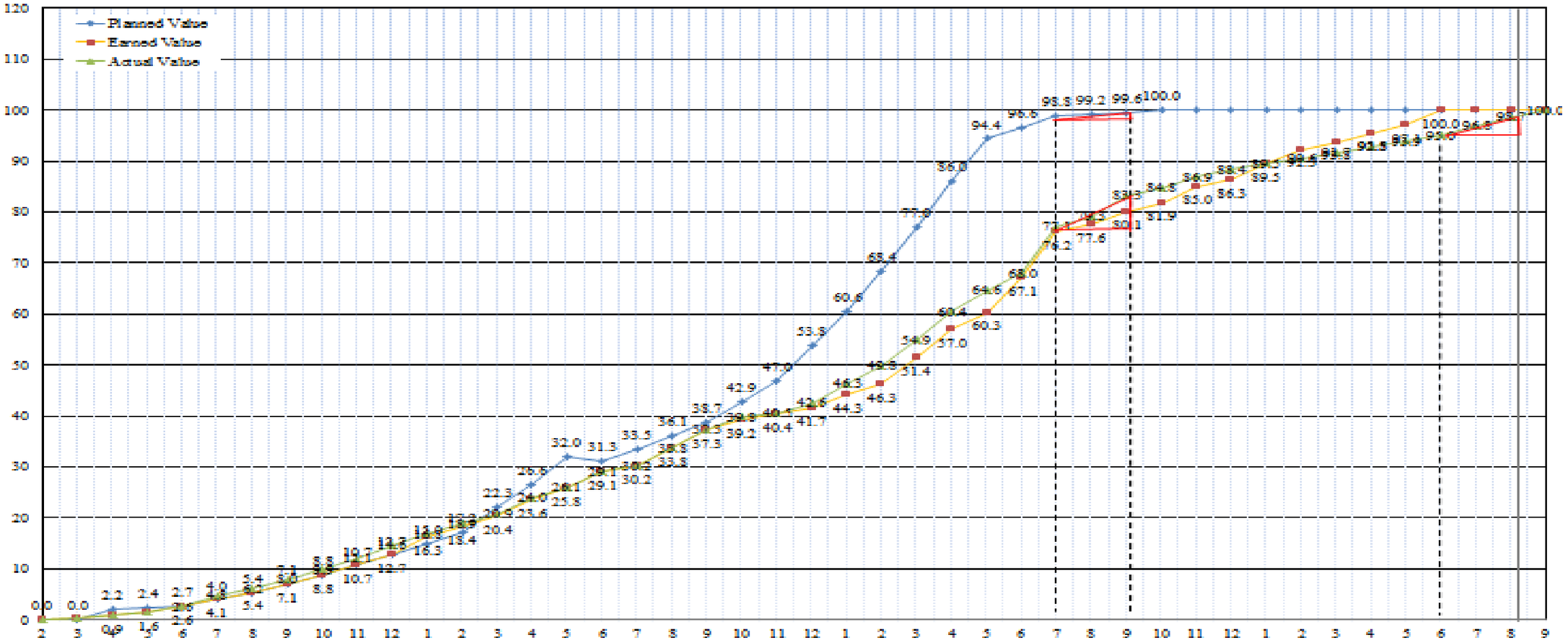
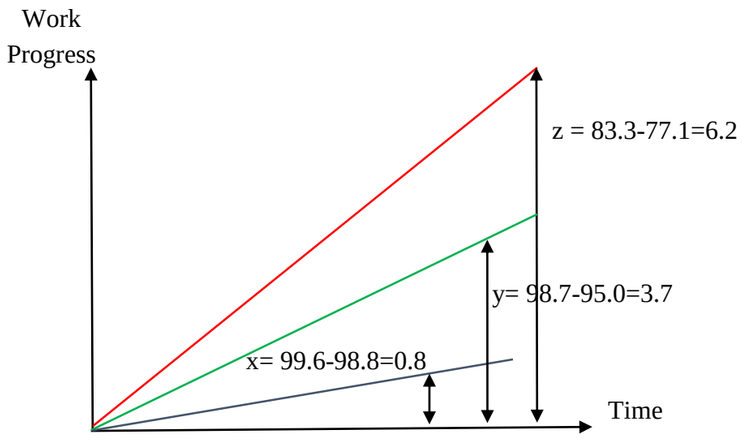


Figure 4.1: S-Curve for Project B

The commencement of Cx activities was delayed to June, 2017 from July, 2016.



Legend:	
	Planned commencement of commissioning, x
	Actual commencement of commissioning activities, y
	Execution of construction activities instead of planned commissioning activities, z

z>y>x

Table 4.1: The Importance of Each Stage in Construction Project Using Earned

Project Stage	Year	Month	PV in %	EV in %	AV in %	RP	CV	SV	CPI
Stage 1	2014	2	0.0	0.0	0.0	0	0.00	0.00	0
		3	0.0	0.3	0.3	0	0.00	0.27	1.00
		4	2.2	0.9	0.9	0.38	0.00	-1.38	1.00
		5	2.4	1.6	1.6	0.64	0.00	-0.86	1.00
		6	2.7	2.6	2.6	0.99	-0.01	-0.03	1.00
		7	4.0	4.1	4.8	1.01	-0.72	0.04	0.85
		8	5.4	5.4	6.2	1.00	-0.74	0.00	0.88
		9	7.1	7.1	8.0	1.00	-0.92	0.00	0.89
		10	8.8	8.8	9.9	1.00	-1.17	0.00	0.88
		11	10.7	10.7	12.1	1.00	-1.39	0.00	0.89
Stage 2		12	12.7	12.7	14.6	1.00	-1.90	0.00	0.87
	2015	1	15.0	16.3	16.8	1.09	-0.50	1.29	0.97
		2	17.2	18.4	18.9	1.07	-0.50	1.16	0.97
		3	22.3	20.4	20.9	0.92	-0.50	-1.89	0.98
		4	26.6	23.6	24.0	0.89	-0.44	-3.01	0.98
		5	32.0	25.8	26.1	0.81	-0.25	-6.13	0.99
		6	31.3	29.1	29.1	0.93	0.00	-2.19	1.00
		7	33.5	30.2	30.2	0.90	0.00	-3.24	1.00
		8	36.1	33.8	33.8	0.94	0.00	-2.33	1.00
		9	38.7	37.3	37.3	0.96	0.00	-1.42	1.00
		10	42.9	39.2	39.8	0.91	-0.58	-3.68	0.99
		11	47.0	40.4	40.5	0.86	-0.10	-6.57	1.00
		12	53.8	41.7	42.6	0.77	-0.93	-12.12	0.98
	2016	1	60.6	44.3	46.3	0.73	-2.06	-16.31	0.96
		2	68.4	46.3	49.8	0.68	-3.49	-22.10	0.93
		3	77.0	51.4	54.9	0.67	-3.49	-25.62	0.94
		4	86.0	57.0	60.4	0.66	-3.49	-29.05	0.94
		5	94.4	60.3	64.6	0.64	-4.34	-34.10	0.93
		6	96.6	67.1	68.0	0.69	-0.89	-29.48	0.99
		7	98.8	76.2	77.1	0.77	-0.88	-22.58	0.99
		8	99.2	77.6	79.3	0.78	-1.62	-21.56	0.98
		9	99.6	80.1	83.3	0.80	-3.21	-19.54	0.96
		10	100.0	81.9	84.8	0.82	-2.90	-18.13	0.97
		11	100.0	85.0	86.9	0.85	-1.92	-15.01	0.98
		12	100.0	86.3	88.4	0.86	-2.04	-13.66	0.98
	2017	1	100.0	89.5	89.5	0.89	0.00	-10.52	1.00
		2	100.0	92.3	90.6	0.92	1.74	-7.67	1.02
		3	100.0	93.8	91.7	0.94	2.09	-6.22	1.02
Stage 3		4	100.0	95.5	92.8	0.96	2.74	-4.47	1.03
		5	100.0	97.1	93.9	0.97	3.21	-2.89	1.03
		6	100.0	100.0	95.0	1.00	5.00	0.00	1.05
		7	100.0	100.0	96.8	1.00	3.16	0.00	1.03
		8	100.0	100.0	98.7	1.00	1.33	0.00	1.01
		9	100.0	100.0	100.0	1.00	0.00	0.00	1.00

As tabulated in Table 4.1, in stage 1, planning and preparatory work is initiated. The rate of performance, RP is above 1, implying Planned Value, PV ≈ Earned Value, EV, which means stage 1 work, is progressing accordingly. The Cost of Variance is less than 0 implying no cost overrun, and Schedule Variance, SV is 0 implying no project delay.

In Stage 2, construction work is progressing. But, the rate of performance, RP is below 1, implying Planned Value, PV < Earned Value, EV, which means work is not progressing smoothly according to plan. The Cost of Variance < 0 implying no cost overrun. But this is due to actual work progressing slowly and behind schedule, in other words there is a potential for project delay. Schedule Variance, SV is negative implying potential project delay in the final stage.

In Stage 3, the project was delayed due to problems in stage 2. As a result, the project final stage which was supposed to be completed in February, 2016 was shifted to September, 2017. In stage 3, the rate of performance, RP is mostly below 1, implying Planned Value, PV < Earned Value, EV. The Cost of Variance is slightly positive implying slight cost overrun. The Schedule Variance, SV is also negative implying project delay.

As referred to S-Curve Graph for Project B in Figure 4.1. To examine the consequences of project delay towards commissioning in Project B, the gradient for Planned commencement of commissioning, x, Actual Commencement of commissioning activities, y and execution of construction activities instead of planned commissioning activities, z were plotted.

The result is

z= 6.2 > y= 3.7 > x = 0.8

Besides that, z > y (6.2 > 3.7) or equivalent to z: y = 6.2: 3.7. This implied that the ratio of the execution of construction activities instead of planned Cx activities to the ratio of actual commencement of Cx activities, which are equals to z = 1.68y. It can be deduced that the rate of performance for execution of construction activities instead of Cx activities is 1.68 multiply the rate of performance for actual commencement of Cx activities, y. In other words, the rate of performance for execution of construction activities instead of Cx activities is higher than the rate of performance for actual commencement of commissioning activities. Supposedly, the rate of performance for

execution of construction activities should be slower towards the end when the project almost completed. This also implies that project is rushing to catch up the deadline by speeding up the rate of performance for uncompleted or unsettled construction activities.

With y > x, it means that the project is being rushed during the commissioning stage. This is due to project delay. Based on the result of y, the gradient at the final stage is also steep implying project delay in stage 2 which results in commissioning to be rushed.

Besides that, y > x (3.7 > 0.8) or equivalent to y: x = 3.7: 0.8. This implied that the ratio of the actual commencement of commissioning activities to the ratio of planned commissioning activities are equals to y = 4.62x. It can be deduced that the rate of performance for actual commissioning activities, y is 4.62 times multiply the rate of performance for planned commissioning activities, x. In other words, actual commissioning activities are rushing to catch up to complete the project when there is delay or problem during the execution of planned commissioning. When the planned commissioning activities are delayed, the performance rate for actual commissioning has to be speeded up to hand over the project to the client.

4.1.9 Discussions

Earned Value is a useful tool to predict the overall project progress. On top of that, with Earned Value Analysis, we are able to predict the manner in which testing and commissioning stage is to be done. Based on the results in Project B, we can conclude that the project commissioning will be rushed when there is a project delay in the middle of the project during the planned construction stage. By referring to the gradient of commissioning stage in Earned Value Analysis graph, we can see the difference in gradient for commissioning for different projects. The higher the gradient value, the faster the commissioning has to be performed to complete the project in a timely manner.

Table 4.2: Derivation of Formula for x, y and z Based on Earned Value Analysis

Project	**Derivation of Formulas**	
	Actual construction activities vs. Actual Commissioning Activities	**Actual Commissioning Activities vs. Planned Commissioning**
B	z = 1.68y	y = 4.62x

CHAPTER V: RESULT AND DISCUSSIONS OF CASE STUDIES

5.1 Introduction

The chapter begins with the reports of cross case analysis for the case studies to make comparisons between results from the contractors' and consultants' perspectives. Comparisons were made to identify any similarities or differences among these feedbacks from different group of interviewees. Extensive discussions of these findings were reported to analyze the findings with previous empirical studies which have been done on this subject matter. Subsequently, the findings of these case studies related to building commissioning problems, significance problems and recurrence problems of commissioning are presented in tables. Subsequently, a commissioning model based on this analysis is developed to enhance building commissioning for construction projects of the public institutions in Ethiopia.

5.2 Discussion of Case Studies Results

5.2.1 Perceived Understanding of BCx from the Contractor's Perspective

From the contractors' perspectives on BCx in the Ethiopian construction industry for public institution projects, generally, four themes were generated. The first theme and foremost theme outlines the pre- requisites to be accomplished for Cx before the commencement of commissioning. The second theme specifies the components of building commissioning. The third theme is related to actions that need to be taken or tasks to perform in order to execute BCx. The last theme is associated with the objectives to be attained in BCx.

From these findings, it can be deduced there were pre-requisites to be accomplished before the commencement of commissioning. The commencement of commissioning depends on the completion of antecedents' activities such as structural and architectural installations or completion of physical work. These installations and inspections have to be completed beforehand and to ensure there are no defects or leakages. In other words, the project must be almost completed and towards project handing over to the client with at least 90% of completion or more. Without prior completion of these antecedents'

activities, it is almost impossible to carry out these commissioning activities.

Secondly, the components of commissioning are explained. These include building structural, mechanical, electrical and sanitary works. The scope of commissioning is alleged to be more structured towards sanitary, mechanical, electrical works and services.

The third theme is related to actions that need to be taken or tasks to be performed in order to execute building commissioning. Cx includes checking of outstanding work, final check for the whole system of sanitary, mechanical and electrical, building is functioning, the equipment's are running, and to other amenities are in service.

Lastly, BCx is perceived as a guideline to ensure that the building has been constructed in accordance with the design intent and specification. It is also the objective of commissioning to inspect the operation and functional situation- to power up or start up the available equipment's, thus ensuring the equipment's are in functional conditions.

Cx also verifies that the building is performing in full functionality upon handing over. It is also aimed to ensure and verify that all the services are functioning as per specification. Building structural works have to be complied with specifications and requirements so that the building is suitable to be used by the end-user in order to handover the building with all design intent. Figure 5.1 illustrates the elements which form the understanding of building commissioning from the contractors' perspectives. This Figure is mapped from the responses and feedbacks given by the contractors involved in this research.

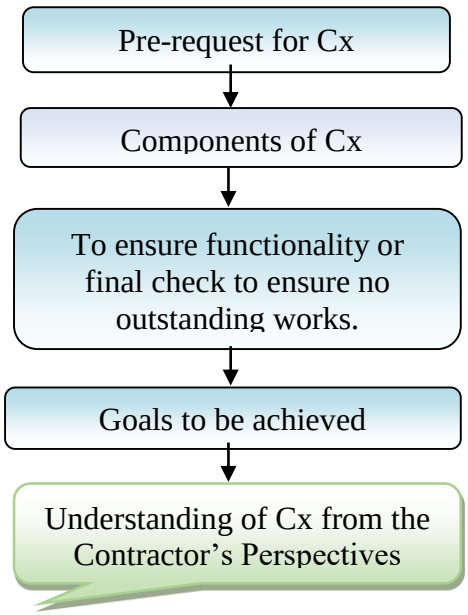


Figure 5.1:Understanding of BCx from the Contractor's Perspectives

5.2.1.1 Perceived Understanding of BCx from the Consultant's Perspective

In comparison with the contractors' perception on BCx, the consultants' perspectives does not contradict with the contractor's perspective and in fact these two perceptions can be deemed as complementary to each other's to provide a better understanding for BCx in the Ethiopian construction industry for public institution projects. In Figure 5.2, an additional theme is derived from the consultants' perception which is the characteristics of BCx. It can be deduced that the consultants' seemed to emphasize more on these aspects of commissioning such as: pre-requisites and goals or objectives of BCx.

The first characteristic of BCx is perceived as an essential part of contract and is mostly related to sanitary, mechanical and electrical works. It is an essential part of contract and involves sanitary, mechanical and electrical work, building work, and finishes work.

Cx is also perceived as the execution of work as stipulated in contract. Basically, building work and finishes work are not as intensive as mechanical and electrical work because they have to be really tested to deal with all the circumstances.

This is followed by the second characteristics of BCx when it is part of construction and has to be done before the Certificate of Practical Completion (CPC) is issued. Cx is actually part of the construction and must be done before CPC is issued so that building can be used as intended. For example, the building must be functioning for its purpose or usable.

In this regard, the pre-requisite for BCx in this sense depends on the types of building to be commissioned. Items for Cx depends on the types of building, not necessarily limited to mechanical and electrical items (includes architectural items). When talking about Cx, most of the items fall under mechanical and electrical categories with some of parts falling under civil and structural. Certain buildings also have items under architectural but this is very rare.

It depends on the types of building to be handed over to the client.

From the consultant's perspective, it can be deduced that there are three goals to be achieved in BCx. These goals include testing and Cx mandatory components of building, ensuring the building is safe and fit for occupancy, and to hand over the building to the client with the building being built in accordance to customer's specification.

As mentioned earlier, BCx includes testing and to Cx mandatory components of building for operation purposes. When talking about mandatory purposes, it does not merely comprise of items under architectural components, but also includes civil and structural, infrastructure, sanitary, mechanical and electrical items. Besides, Cx is an on-going process even after construction is completed as Cx includes testing and checking on the working condition and operating function of the building. Without Cx, the building will be unfit for occupancy. Consequently, there are so many interpretations for commissioning. One of these includes handing over the whole building to the client with the basic structure completed. Another interpretation is that the building is handed over to client with the complete equipment and trainings related to the building occupancy. Figure 5.2 illustrate the elements which forms the understanding of BCx from the contractors' and consultants' perspective.

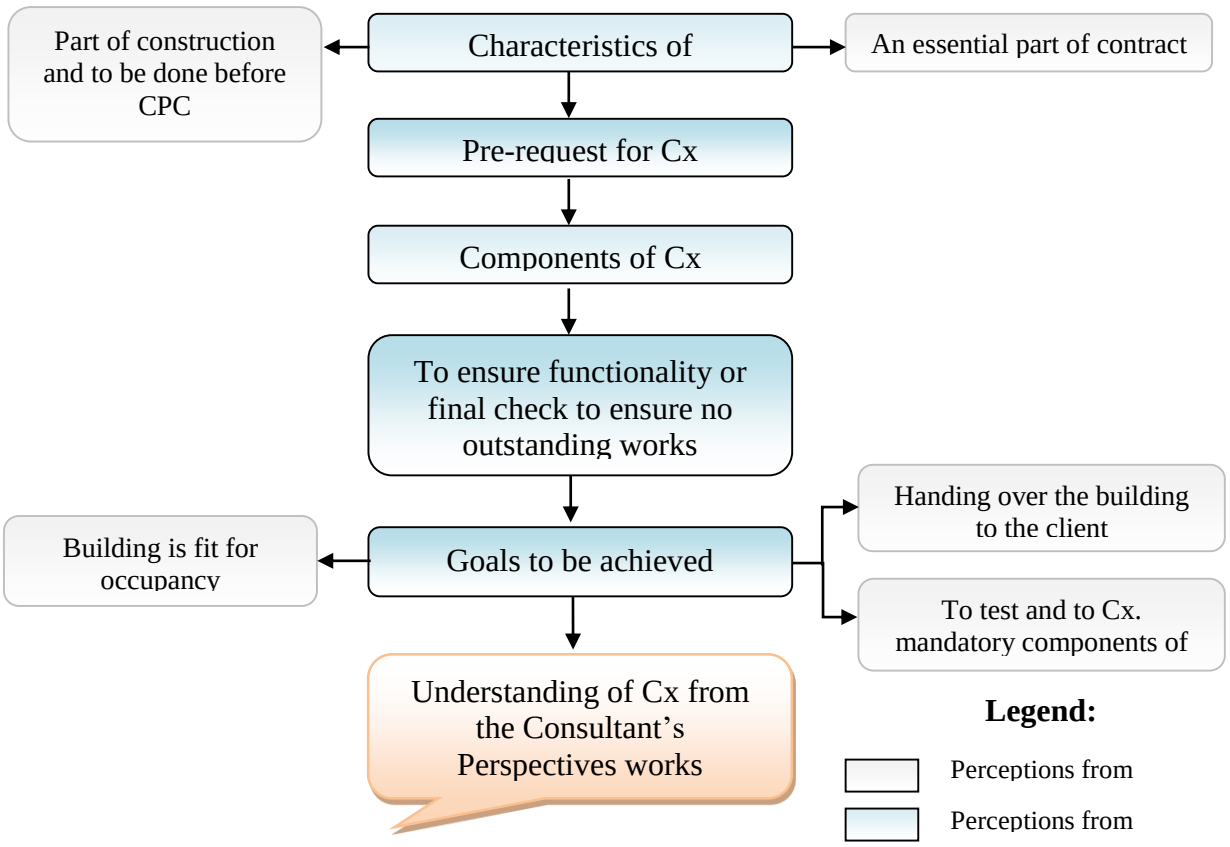


Figure 5.2: Understanding of BCx from the Consultants 'and Contractors' Perspective

5.2.2 Activities/Scopes of Cx from the Contractor's Perspective

The scope of Cx from the contractor's perspective the theme relates to the sanitary, mechanical and electrical systems. Before ensuring the sanitary, electrical and mechanical parts, the contractor has to ensure all equipment's and systems have been installed according to manufacturer's requirements before running any test. This is to ensure that the system has been fully completed according to specifications. Testing and commissioning is to visualize any defective works such as broken glass or door, cracking and leakage. During testing and commissioning, the basic work comprise of:

- Visualize according to the stipulated design;
- Prepare for testing; i.e.: pressure test for plumbing; and
- Testing for functionality.

It also includes activities like preparing shop drawings; operation manuals for generator, compact sub-station manuals etc…) which are useful to the client.

Basically, there are three major elements to be tested which are mechanical, electrical and sanitary works. There were a few main parts involved other than sanitary, mechanical and electrical works. The scopes of commissioning comprised of these elements. The elements are as follows:

a) Structural and civil works :- to ensure structure is durable and no leakages on roof

   Other civil work activities like roofs, ceilings, window & doors etc…

b) Mechanical, electrical and sanitary – all services are functioning, have been tested and are in working condition;

i) Mechanical

- Lift- to ensure proper functionality. For example, when someone presses the button for ground floor, the lift will stop at that particular floor and not the other floor;
- Air-conditioning such as temperature test and balancing for chiller and air handling unit;
- Lighting;

- Gas- centralized system and gas pipe (pressure test and flush test), medical gas for hospital; and
- Pneumatic tubes for hospital.

ii) Electrical

- Power (high and low voltage)
- Continuity of wiring (continuity test and mega ohm test)
- Alarm systems

iii) Sanitary

- Plumbing and sanitary fittings; such as: functioning, pressure test and no leakage
- Water and water reticulation-hot and cold water;
- Firefighting/fire protection;

c) Architectural works such as the straightness, jointing, alignment and the finishes were not damaged.

5.2.2.1 Activities/Scopes of Cx from the Consultants' Perspective

a) Initial work at the beginning of the project

Before commissioning, the activities involved are initial works from the beginning of the project. Commissioning is the end part of the construction. And, before that, most of the activities have already taken place. For example, if there are 100 items in the checklist, by the time commissioning is performed, there will only be 5 items left in the checklist. Commissioning is performed at the final stage. During commissioning, testing and some minor installation for some leftover items are done.

b) Commissioning does not necessary confined to sanitary, mechanical and electrical works

Normally, testing and commissioning is always related to equipment but then again the building itself, apart from the mechanical and electrical equipment can be deemed as commissioning as well. This is because without the building functioning, one cannot commission the building to the end-user. Thus, there are a few interpretations on commissioning. Commissioning comprised of the following items:

- Architecture scopes have their own items (one can deem this as commissioning); for example: if windows and doors are not functioning and if water infiltrates from the roof, it would be deemed that the building has not been commissioned and one would not be able to hand over this building to the end user. Main thing of commissioning is to ensure functionality;
- Structural
- Part of commissioning is inspection because without inspection one would not know whether it is functioning. In terms of sanitary, mechanical and electrical, other than testing, it is also important to inspect whether each item is functioning properly. This was is how inspection is related to testing and commissioning.

c) To progressively check the work done

It is the duty of sanitary, mechanical and electrical engineers to check each work done progressively. This is to ensure the whole system is running accordingly, such as continuity of the circuit, water pressure test and flow test to ensure the pipe is not leaking and all air-conditioner are in working order. For commissioning, the activities involved comprised of: firefighting, plumbing, sanitary, electrical, lift installations, alarm systems, air conditioning systems and etc. According to the interviewee, it is also the scope of commissioning to obtain Certificate of Practical Completion (CPC) and to hand over the building to the client and to obtain all supporting letters from every authorities and consultants to issue the Certificate of Practical Completion (CPC).

Commissioning activities or tasks to be performed during commissioning also includes

- ✓ Preparing check list for commissioning works
- ✓ Checking of outstanding works
- ✓ Making visual or physical inspections
- ✓ Referring recorded data's of inspection or testing
- ✓ Checking electrical, mechanical and sanitary systems are installed as per the approved materials
- ✓ Checking all works are completed as per the contract document, drawing and specification.
- ✓ Taking necessary tests
- ✓ Checking functionality of systems

The elements to be commissioned in this stage are:

a) Mechanical and electrical systems and services (the most important);

- Lift services;
- Air-Conditioning and Mechanical Ventilation systems; and
- Fire protection services (second most important) such as firemen intercom.

b) Sanitary and plumbing services;

c) Gas pipeline;

d) ICT-PA system;

e) Road access to the building and hydrant;

f) Sewerage;

g) Structural works; and

h) Architectural works such as the straightness, jointing, alignment and the finishes were not damaged.

5.2.3 Duration for Cx: Contractors' Perspective

The time needed for commissioning depends on:

a) Sub-contractors' work performance

Depends on the performance of the sub-contractor who had carried out the work.

b) Problems that occur in commissioning phase

Depends on the Problems occur in commissioning and the time it takes to rectify these problems. But usually it takes up to 2 weeks.

c) Depends on the size of the project. Delay from previous stages or problems may affect the commissioning phase itself

The time needed for commissioning depends on the size of the project or building and has to be progressively followed.

d) Depends on project control system in the previous phase

It depends on project control system in the previous phase. If proper inspection and checking was done in previous phase, it usually takes 1 up 2 months. But if proper inspection and checking was not done, it might take up to 6 months.

e) The commencement of commissioning:

It depends on the commencement of commissioning before the project building is handed over to the client. It also depends on the quantity of the equipment's to be tested, the duration may vary.

f) Estimated duration for commissioning:

It ranges from 2 weeks up 2 months, provided there is no system failure. If the system encounters failure, troubleshooting of problems or replacement or proposal of a new system has to be carried out to solve the problems.

Based on an overview perspective from the contractors, the duration needed and the elements encountered for the duration of commissioning work chart can be demonstrated as follows in Figure 5.3.

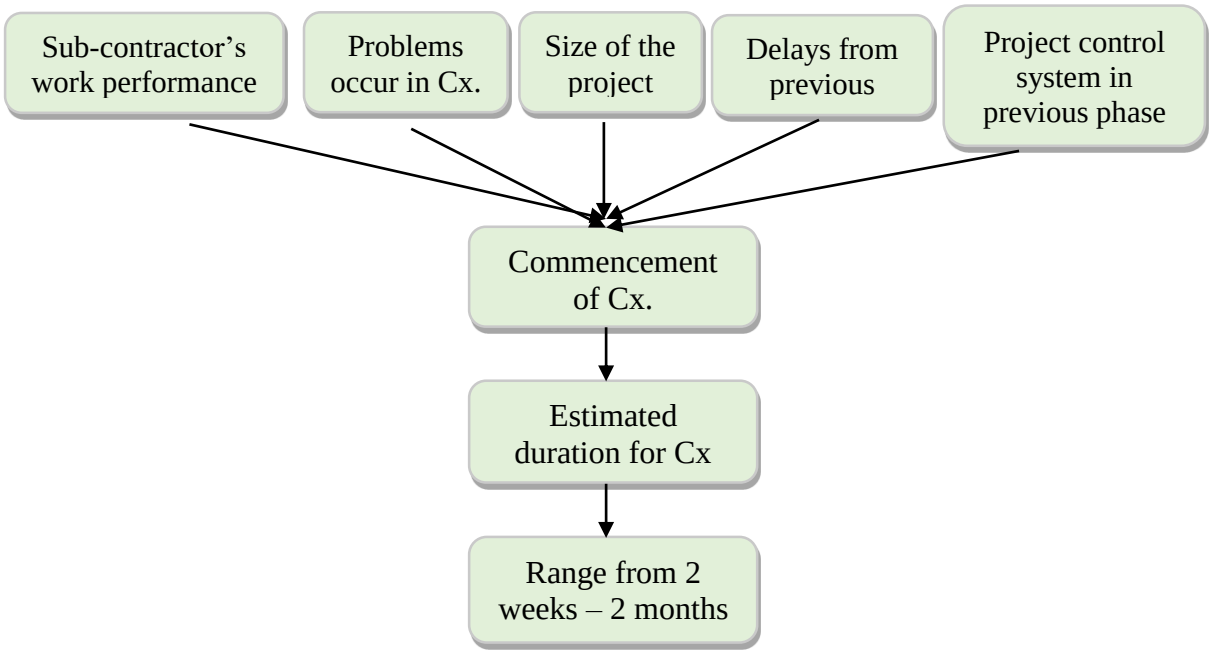


Figure 5.3: Duration for Cx: Contractors' Perspective

5.2.3.1 Duration for Cx: Consultants' Perspective

a) Sometimes duration of Cx depends on the scope and size of project

Duration of commissioning varies and depends on the size of the project. The easiest item to be compared is the equipment's. The more equipment is embedded within the building, the longer time it is required to do the inspection and testing. Sometimes when testing is carried out, the equipment fails in the first test and re-testing need to be done again before re-commissioning. It might take 2-3 month.

b) Varies from case by case basis and depends on the type and complexity of the projects

Cx depends on the type of building and the activities to be carried out and also on the complexity of project. For example: - hospitals will take a much longer time due to complex services when compare to conventional types of services. But maximum it takes up to 2 months

c) Duration of Cx depends on the coordination for the project

The size of the project is very subjective. If everything is in order, the size of the project does not matter. Even for a small project, if the project is not coordinated, commissioning will encounter problem. As mentioned by the interviewee, commissioning usually takes around 2 months.

d) Pending ELPA's approval for electrical supply (external authorities)

According to the interviewee, the construction must be completed before any electrical power is provided. Duration of commissioning depends heavily on the decisions of local power company.

e) Estimated duration for commissioning:

It ranges from 1 up 2 months, provided there is no system failure. If the system encounters failure, troubleshooting of problems or replacement or proposal of a new system has to be carried out to solve the problems.

Therefore, to perform commissioning in an orderly manner, it is important to analyze all those determinants which can affect the execution of commissioning as shown in Figure 5.4.

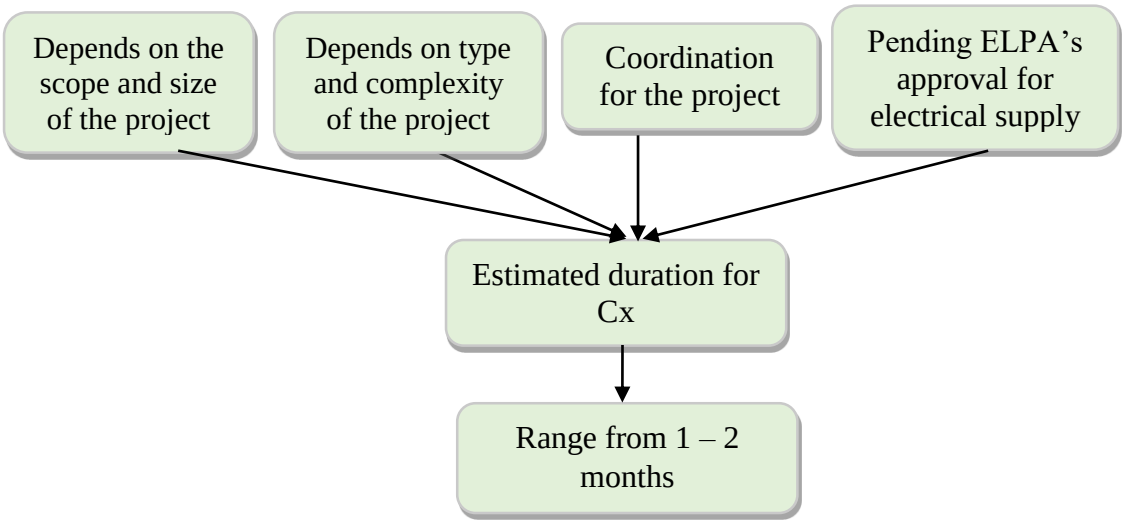


Figure 5.4: Duration for Commissioning: Consultants' Perspective

5.2.3.2 Cx starts at which stage of the project life-cycle?

From the contractors' and consultants' perspective, commissioning starts:

a) Progressively all through the stages/all along the way/continuous process

Cx is done progressively all through the stages but it is called "testing" in these stages. It is only towards the end where the final and total commissioning is done as a final confirmation for all the systems. For example, approval of electric and sanitary materials to be used and pressure test for leakage of piping and electric line continuity tests will be checked progressively during construction and after they have lain. This will quicken the time needed for testing and commissioning at the end stage of the project. Consequently, fewer problems would occur.

Inspections are carried out all along the way to assure quality of work and also to ensure no system failure during testing and commissioning. However, testing and commissioning is only carried out towards the end before handing over the project to the client.

b) After construction stage

Cx is done after everything has almost been completed. Usually commissioning is conducted after the construction stage.

Some interviewee mentioned that commissioning is done after the construction (towards the end) stage, where all fittings and piping have been installed. For example, if the piping is still not completed, commissioning cannot be started; and

- Towards the end of the project when work progress reaches about 90%.

5.3.3 Personnel Involved during the BCx Stage

There are two types of relationship for commissioning:

a) Internal relationship such as with client

b) External relationship such as with relevant authorities (Example: Standard requirement controllers like electric power supplier (ELPA), city administrates and health facility administrators like MOH for projects that also incorporate clinics and pharmacies in the building.

In general, Cx involves the following teams. The team can be categorized as follows:

- Architects, structural engineers, supervision co-coordinators, contract administrators, resident engineers, Mechanical and electrical engineers are the personnel's involved in this stage from the consultants.
- Project manager, project co-coordinators, site engineers, mechanical and electrical engineers, technicians and sub-contractors are the personnel's involved in this stage from the contractors.
- Client representatives, superintending officers (clients project office managers or engineers) and representative mechanical and electrical engineers and sometimes the end-user/client are the personnel's involved in this stage from the client.
- External authorities and manufactures also involve in this stage.

5.3.4 The Importance of BCx

All of the interviewees from contractors and consultants came into consensus that commissioning is very important to ensure conformance of the constructed facilities within the stipulated specifications.

5.3.4.1 Ranking from 1 (Least Significant) – 5 (Most Significant) on the Importance of BCx

The interviewees from contractors and consultants were asked to rank from 1 (least significant) – 5 (most significant) on the importance of commissioning. Almost all of the interviewees rated 5 (the most significance) when they were asked on the importance of commissioning.

Reasons given by these interviewees are:-

Cx is very important to detect problems and faulty workmanship and also to ensure functionality. Moreover, commissioning ensures the functionality and safety of the project. Commissioning is also done to ensure the system in the building is functioning, the building is constructed according to the design and specifications and safe for occupancy.

Cx is an essential part of contract which ensures deliverable of building projects as per the contract agreement and to ensure the building serves its intended designed purpose (fit for purpose), without commissioning, the building cannot be operated and the end-user cannot occupy the building if the building is not operational. The building cannot be handed over to the client without commissioning. Thus, commissioning ensures that the building serves its intended designed purpose and is functioning safely for the intended purpose. Without testing and commissioning, it is difficult to judge whether a building is safe for occupancy. It is hard to determine if the work has been satisfactorily completed as stipulated in the contract.

Cx is vital to obtain Certificate of Practical Completion (CPC). If commissioning is not conducted, the building cannot be handed over to the client and Certificate of Practical Completion (CPC) cannot be obtained.

5.3.4.2 Was Proper Inspection/Testing Done During Cx or is Cx Merely an Administrative Task to get the CPC?

Majority of both the contractor's and consultant's interviewees emphasized that proper inspection/testing should be done during commissioning. Commissioning is to ensure building is working properly in order to obtain CPC and to ensure the building it

functioning properly. Thus, proper inspection and testing must be carried out during commissioning and is not merely an administrative task to obtain CPC.

Among the reasons given is that commissioning ensures functionality, quality and the building complies with all the requirements in stipulated in the contract. Testing for commissioning is monitored closely by the main contractor and the consultant from the early stage of construction.

Nevertheless, there is some divergence on this matter by the interviewees. According to them, in some construction projects in Ethiopia it is just merely an administrative task to get CPC, because sometimes contracting parties did not give proper attention and overlook Cx. And this might be due to delay from previous phases, proper testing and commissioning might be jeopardized in the commissioning stage in order to make up for the delay incurred at the earlier stages. When the schedule is delayed, everyone is under constant pressure to deliver the project in order to avoid Liquidated Damages (LD) and the client and/or consultant in some construction project might not take proper testing and commissioning and compromise commissioning problems. Also if there is design problem, the consultant might jeopardize proper Cx in order not to take the blame for the problem. Moreover, proper Cx depends on the strength and experience of the consultants.

A minority group of consultants also claimed that commissioning is merely an administrative task to obtain CPC because it is perceived as a formality during actual completion date and prior testing has been done before commissioning is conducted. This is supported by Tseng (2005) who claimed that commissioning is distinctive from construction inspection, code compliance or merely construction administration visits by the architects. This perception needs to be eliminated to elevate the importance of commissioning in the Ethiopian construction industry.

Interestingly, apart from this point of view, one interviewee from the contractor's claimed that commissioning is merely an administrative task to obtain CPC because there are no reference made in Ethiopia on testing and commissioning in order to say proper testing and commissioning is being done.

5.3.4.3 The Influence of Cx on the Project Handing Over: Contractors' Perspective

As depicted in Figure 5.5, the perception from the contractors on whether Cx can cause delay. majority of the contractors' agreed that Cx can cause delay in handing over the building to the client but the other 33.3% of the contractors are uncertain about this because according to them it depends on the project follow up and inspection during construction stage. However, another 16.67% of the contractors deny there is influence of Cx on the project handover.

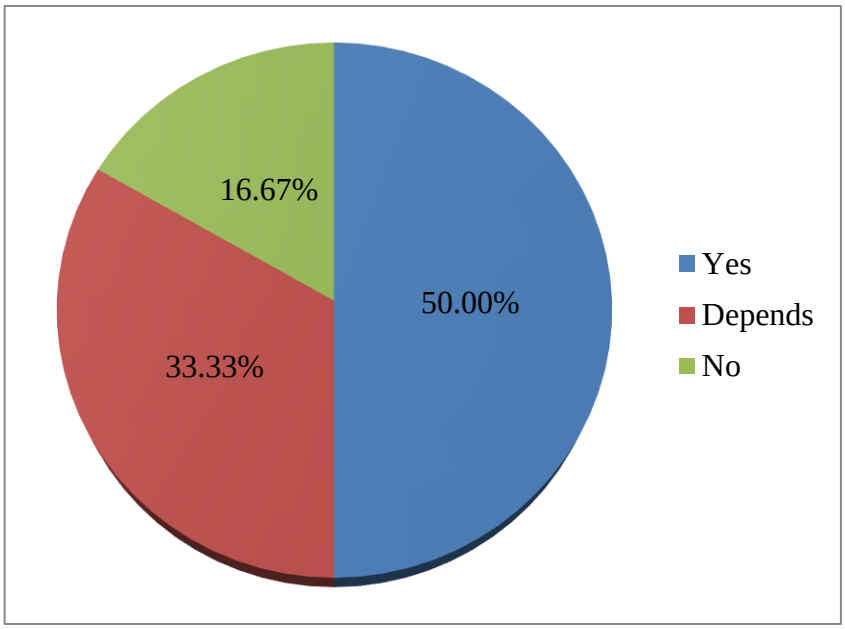


Figure 5.5: The Contractors' Perspective: The Influence of Cx on Project Handing Over

From the contractors' perspective who agreed with commissioning will cause delay to hand over the project, the reasons given are as follows:

When problems occur during testing and commissioning, a much longer time is needed for troubleshooting and to rectify these problems. Subsequently, the completion date will be delayed. Furthermore, completed work has to be re-do until the problem is solved. Moreover, when testing is done at a late stage and major defects are detected and no one wants to take the responsibility and blames each other. As a result, project delay is bound to occur.

5.3.4.4 The Influence of Cx on the Project Handing Over: Consultants' Perspective

As shown in Figure 5.6, the perception from the consultant on whether commissioning can cause delay or not is equal. Half of the consultants deny that there is influence of commissioning on the project hand and half of them agreed that commissioning can cause delay in handing over the building to the client.

From the consultants' perspective who agreed with commissioning will cause delay to hand over the project, the reasons given are as follows:

If construction is completed and the project is ready for Cx. but project follow up and control was poor during construction phase, problems and defects might exist during Cx phase and it might take additional time to solve or rectify these problems. In addition, handover might also delay if clients want re-commissioning to be made due to these problems or for unsatisfactory works.

In addition, some of the consultants who agree with commissioning have influence on project handing over; they mentioned that when testing is done at a late stage and major defects are detected and no one wants to take the responsibility and blames each other. As a result, project delay is bound to occur. Another reason provided is that, in terms of usage, without proper commissioning, buildings with lots of services cannot be used.

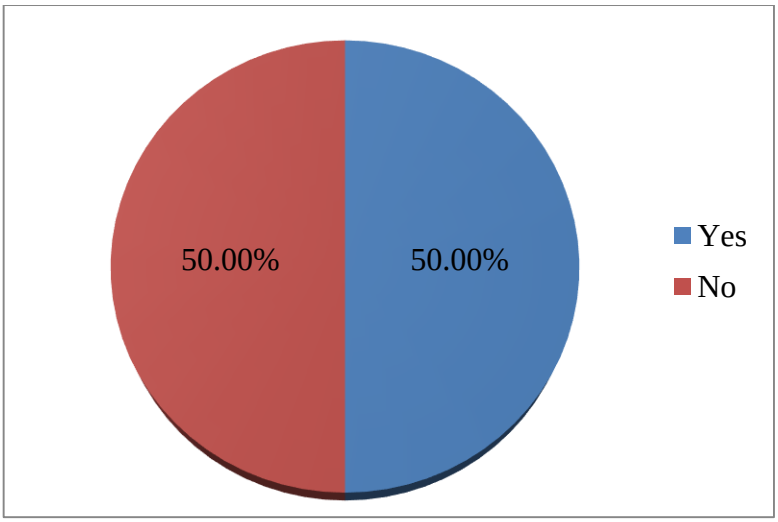


Figure 5.6: The Consultants' Perspective: The Influence of Commissioning on Project Handing Over

From the consultants' perspective who disagreed with commissioning will cause delay to hand over the project, the reasons given are as follows:

Commissioning will not cause delay by itself if inspection was made progressively and if there is proper follow up and coordination during construction stage, According to interviewees, construction is the main cause of delay. On its own, commissioning independently does not cause delay as construction progress and commissioning are not closely interrelated.

5.3.4.5 Magnitude of Delay in Cx

Most of the interviewees declined to answer this question. When the interviewees were probed further, the following answers were obtained:

- Around 2 weeks.
- It depends (it might range from 2 - 3 months);
- It might go up to 1 year but it usually goes up to 2 months
- It depends on the individual problem for the project;
- It depends on the problems found and the time it takes to rectify them
- It depends on the quality of work
- It depends on the project coordination, follow up and control.
- It depends on the contractor performance and skilled workmanship
- It depends on the project type and complexity
- It depends on the clients request to accept the building with its problems or change orders, additional work order/ variation work and the time it's given.

5.3.4.6 Please Rank the Seriousness of Delay in Cx from 1 (Least Serious) – 5 (Most Serious)

As depicted in Figure 5.7, it is illustrated that delay in commissioning is regarded as the most serious causes of delay by most of the interviewees participating in this study. The rest of the interviewees rated this as very serious, moderately serious and slightly serious.

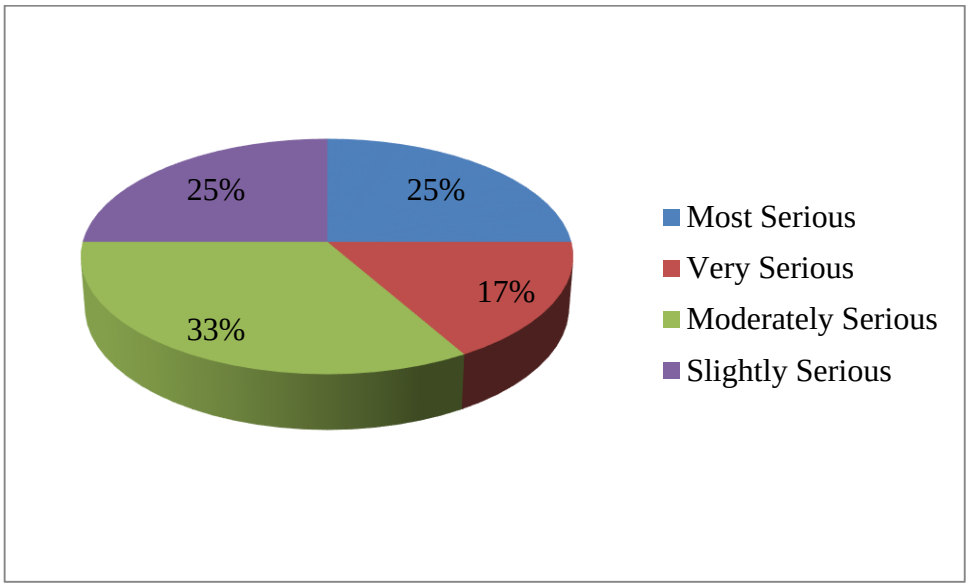


Figure 5.7: The Seriousness of Delay in Commissioning

5.3.4.7 Effects of Problems in Cx

From the contractors' perspective, when problems occur during testing and commissioning, a much longer time is needed for troubleshooting and to rectify defects and problems. Subsequently, the completion date will be delayed. Furthermore, completed work has to be re-do until the problem is solved. Delay in commissioning implies that the contractor will have problems in handing over of the building to the client on time and the end- user would not be able to occupy the building according to the contract time. One of the most significant impacts is that the contractor will have to pay for Liquidated Damages (LD) to the client. Late handing over of the building to the client will also impose cost impact to the contractor. Besides, the performance security period will expire and the contractor has to bear the extended period.

From the consultants' perspective, effects of problems in commissioning can causes delay in obtaining CPC and lead the contractor to pay liquidated damage to the client and. One has to redo and to rectify defects and problems if there is a problem during commissioning and might delay the handover. Delay in commissioning will deteriorate some parts of the constructed building or materials and will affect the revenue of the client if that building is to be rented out to tenants. Besides that, commissioning will also affect the overall completion of the project in terms of rental and usage. Late handing

over of the building to the client will also impose overhead cost to the contractor and retention money will not be released to the contractor.

5.3.4.8 The Influence of Cx Problems on Project Timely Manner

When there are outstanding works and problems in testing and commissioning, a much longer time is needed for troubleshooting and to rectify defects and problems. Subsequently, the commissioning will be delayed. It also means that the building is not ready to be handed over to the end user. This will delay the handing over of the project to the client. This will also cause delay in obtaining the Certificate of Practical Completion (CPC). As a result, retention money will not be released and Liquidated Damages (LD) will be imposed on the contractor.

5.3.5 The Discussions on the Perceived Understanding of BCx from the Contractors' and Consultants' Perspectives

The conceptualization model focuses on building commissioning which encompass the perception and the duration needed for building commissioning. Perception is regarded by Bruner (1957) as an inferential process, in which the perceiver plays a maximal and maximally idiosyncratic role in interpreting, categorizing, or transforming the stimulus input. According to Bruner (1957), perception involves an act of categorization. The nature of the inference from cue to identity in perception is, in no sense different from other kinds of categorical inferences based on defining attributes (Bruner, 1957: 123f.). Richardson and Pugh (1981), (Roberts, Andersen, Deal, Garet, & Shaffer, 1983), and Sterman (2000) accentuate that any modeling effort should be guided by a clear purpose and a set of questions. The purpose of the conceptualization model is to have a model capable of explaining the dynamic nature of building commissioning and its various characteristics. Therefore, to have a better perception on building commissioning for the public institutions in Ethiopia, a conceptualization model of building commissioning classifications needs to be constructed.

On the other hand, Brunswik (1956) mentioned that perception must simultaneously integrate many different avenues of approach, or cues. The various rivalries and compromises that characterize the dynamics of check and balance in perception must be seen as chiefly responsible for the relative infrequency of precision. This is due to the

machinelike precision of the reasoning processes. On the other hand, the organic multiplicity of factors entering the process constitutes an effective safeguard against drastic error (Brunswik, 1956: 91f.). Various similarities and differences on the perceptions of commissioning are drawn from the interviews' results. These similarities and differences are characterized and integrated to provide a check and balance for the conceptual model of building commissioning classifications. Brunswik (1956) mentioned that perception must concurrently integrate many different possibilities of approach.

From different definitions of building commissioning, it has been found that the common words used for the definitions of commissioning are: quality assurance, process, document, building systems, design, install, testing, functional, and operational. From these definitions, it can be proposed that, building commissioning can be defined as a quality assurance process to verify and document the building systems where the buildings are designed, installed, tested and function to meet the operational needs of the building's owner and the end-user. Commissioning has traditionally being viewed as a task performed after system assembly and before hand-over as a final check and acceptance test (Xiao & Wang, 2009). Therefore, a new definition model of building commissioning for construction projects is being proposed to suit the context in the Ethiopian construction industry; especially for projects of public institutions in Ethiopia. For the suggested commissioning definition, it is almost impossible to verify the definition model since most of the people interviewee does not share a common understanding about the definition in question.

The purpose of building commissioning to ensure all building facility systems function in accordance with all the design intent and documentation is aligned with the general systems theory. This theory highlights that systems are compose of interdependent components in some relationships. Therefore, the conceptual model in Figure 3.2 which combines empirical world, case studies, and theories is vital to generate Figure 5.8.

Transformation theory is also plays an important role in the systematic combining as commissioning is actually a process by which inputs are changed into outputs. The output in this context is referred to handing over of the building to the client.

Therefore, the commissioning process in which resources, assets, and competencies of an organization are put together to produce a desired output must be dwelled in carefully to

identify the potential problems which might affect the output. These commissioning problems can then be viewed as the constraints that need to be improved. When the constraint is minimized, variations will be reduced and the quality of the throughputs will improve.

These theories of transformation and general systems are interrelated to explain the rational choice theory. This is because when the planned commissioning is delayed, the contractor has to expedite the work progress and to take advantage of the commissioning period to avoid the penalty of Liquidated Damages (LD).

From Figure 3.2 (Page 42) on systematic combining, we can see that it has strong relationship with Figure 5.8 (page 85) on the conceptual model of building commissioning. As systematic combining is a process where theoretical framework, empirical fieldwork, and case analysis evolve simultaneously to construct a conceptual framework of commissioning, we can relate it to conceptual model of building commissioning which essentially identify the concept of building commissioning which is defined as a quality assurance process to verify and document the building systems where the buildings are designed, installed, tested and function to meet the operational needs of the building's owner and the end-user. As both Figure 3.2 and Figure 5.8, aims to complement, deepen and harmonize the general concept of building commissioning, there is an essential need to always improve the existing commissioning framework by always linking the theoretical aspects and matching it with the current demand based on empirical analysis. In short, Figure 5.8, conceptual model of building commissioning is a form of derivation of Figure 3.2 based on existing commissioning theory with empirical analysis and feedback from experienced contractors and consultants.

What is needed for the building commissioning in the Ethiopian construction industry is a simple and understandable model capable of explaining the dynamic nature of building commissioning and its various characteristics. For an organization, pivoting the definition of goals or objectives provides an obvious but crucial component on what constitutes an organization. The coordination of number of activities of individual towards some objective or goal has been designated as a distinctive feature of organizations (Parsons, 1956). The same proposition goes for the definition of goal or objective of what constitute building commissioning. Figure 5.8, is a conceptual model

of building commissioning. The framework comprise of a conceptual classifications which is used to explain the nature of building commissioning. The classification includes eight groups of characteristics, which are:

1. **Characteristics** affecting the coverage and activities of BCx;

2. **Pre-Requisites** or initial works to be done before actual BCx;

3. **Components** of BCx;

4. Ensuring **Functionality** or final check to ensure no outstanding works;

5. **Duration** for Cx for construction projects;

6. **Activities/Elements** of the BCx process to express the level of detail of the information and understanding to be gained;

7. **Personnel** involved in the BCx; and

8. **Goals** to be attained in BCx in which BCx completes each of these activities or elements and proceeds to the next detailed stage before project 'hand over'.

An important finding is that these eight characteristics together form a basis to better explain and understand the nature of building commissioning for public institutions in the Ethiopian construction industry. This model also aims to provide a more holistic view and better insight into building commissioning.

<table>
<tr><th colspan="2">CONCEPTUAL MODEL OF BUILDING COMMISSIONING</th></tr>
<tr><td>1. CHARACTERISTICS OF COMMISSIONING
An essential part of contract
Part of construction
The execution of works as stipulated in contract
To be done before Certificate of Practical completion (CPC)</td><td>2. PRE-REQUISITES FOR COMMISSIONING
a) Completion of physical works such as architectural and structural installations must be completed beforehand;
b) Completion of installations and inspections for necessary items; and
c) Work progress is at least 90% or more.</td></tr>
<tr><td>3. COMPONENTS OF COMMISSIONING
a) Architectural ,structural and civil works;
b) Mechanical, electrical and sanitary works.</td><td>4. FUNCTIONALITY
- To ensure functionality or final check to ensure no outstanding works.
a) Everything is functioning,
b) Project is running, equipment running, and
c) Services are available.</td></tr>
<tr><td colspan="2">5. DURATION</td></tr>
<tr><td colspan="2">It depends on the individual problem for the project;
It depends on the problems found and the time it takes to rectify them
It depends on the project coordination, follow up and control in previous phase
It depends on the sub-contractor or contractor performance and skilled workmanship
It depends on the project type and complexity
It depends on the clients request to accept the building with its problems or change orders, additional work order/ variation</td></tr>
</table>

work and the time it's given.

- Depends on the size of the project and can be affected by delay from previous stages and commissioning phase itself
- Depends on the number of equipment embedded within the building to be tested (scope of commissioning)
- Depends on the local power authority, ELPA's approval for electricity supply
- Estimated duration for commissioning: 2 weeks – 2 months
- Commencement of commissioning: 1 – 2 months before project handing over

6. ACTIVITIES

Commissioning activities or tasks to be performed during commissioning also includes

- ✓ Preparing check list for commissioning works
- ✓ Checking of outstanding works
- ✓ Making visual or physical inspections
- ✓ Referring recorded data's of inspection or testing
- ✓ Checking electrical, mechanical and sanitary systems are installed as per the approved materials
- ✓ Checking all works are completed as per the contract document, drawing and specification.
- ✓ Taking necessary tests
- ✓ Checking functionality of systems

a) Structural and civil works :- to ensure structure is durable and no leakages on roof

Other civil work activities like roofs, ceilings, window & doors etc…

b) Mechanical, electrical and sanitary – all services are functioning, have been tested and are in working condition;

i) Mechanical

- Lift- to ensure proper functionality. For example, when someone presses the button for ground floor, the lift will stop at that particular floor and not the other floor;
- Air-conditioning such as temperature test and balancing for chiller and air handling unit;
- Lighting;
- Gas- centralized system and gas pipe (pressure test and flush test), medical gas for hospital; and
- Pneumatic tubes for hospital and etc…….

ii) Electrical

- Power (high and low voltage)
- Continuity of wiring (continuity test and mega ohm test)
- Alarm systems
- ICT;
- PA system; and etc……..

iii) Sanitary

- Plumbing and sanitary fittings; such as: functioning, pressure test and no leakage
- Water and water reticulation-hot and cold water;

- Firefighting/fire protection;
- Sewerage (tennis ball test will be carried out to make sure no blockage at manholes); and etc……..

c) Architectural works such as the straightness, jointing, alignment and the finishes were not damaged.

7. PERSONNEL INVOLVED

There are two types of relationship for commissioning:

a) Internal relationship such as with client

b) External relationship such as with relevant authorities (Example: Standard requirement controllers like electric power supplier (ELPA), city administrates and health facility administrators like MOH for projects that also incorporate clinics and pharmacies in the building.

In general, commissioning involves the following teams. The team can be categorized as follows:

- Architects, structural engineers, supervision co-coordinators, contract administrators, resident engineers, Mechanical and electrical engineers are the personnel's involved in this stage from the consultants.
- Project manager, project co-coordinators, site engineers, mechanical and electrical engineers, technicians and sub-contractors are the personnel's involved in this stage from the contractors.
- Client representatives, superintending officers (clients project office managers or engineers) and representative mechanical and electrical engineers and sometimes the end-user/client are the personnel's involved in this stage from the client.
- External authorities and manufactures also involve in this stage.

8. GOALS OF COMMISSIONING
a) to ensure the designated building has been constructed in accordance with the design intent and to proper procedures has been followed as stated in contract; b) to obtain certification from the relevant authorities; c) it is also the objective of commissioning to ensure the operation and functional system-i.e.: to power up or start up an equipment and ensure its functional conditions; d) to verify that everything is fully functioning upon project handing over; e) to ensure and verify that all the services are functioning as per specification; and f) Building structural works are in compliance with specifications and requirements in order to ensure the building is suitable to be used by end-user and all the intended design are fulfilled upon handover of the building.

Figure 5.8: Conceptual Model of Building Commissioning

5.3.6 Validation of the Model

Normally, the term ‘model’ refers generally to computer simulation models, but many of the points are applicable to mathematical and theoretical models as well. According to Rykiel (1996), validation is not a vital activity for assessing research models, but is significant for building model reliability in the user community. Goodall (1972) associated validation with testing to determine the degree of conformity between a model and the real system, and proposed that the suitable questions to ask of a model is how good its predictions are, not whether it should be accepted or rejected in the sense of hypothesis testing. Although he stated that validation is never complete, he did not suggest any validation standards. Therefore, in this study, face validity is conducted. Four knowledgeable people in the industry with more than ten years of working experience in the industry were asked if the model and its behavior are reasonable. The four people were contractors and consultants in the construction industry. This test suggests that the model logic and input-output relationships appear reasonable ‘on the face of it’ given the model’s purpose. Some models have high face validity by virtue of their longevity and wide spread use (Sargent, 1984). The test is conducted by asking these people on the accuracy, user friendly, flexibility, compatibility and cost consuming of the conceptualization model of building commissioning classification. Majority of the interviewee agreed with the model in meeting the purpose of the research.

5.3.7 Cx Problems from the Contractors' Perspective

From the contractors' perspective, commissioning problems are presented in table 5.1. Results obtained from the semi-structured interviews conducted with the contractors involved in relevant projects are compiled and presented as follows.

Table 5.1: Commissioning Problems from the Contractors' Perspective

Problem type	Description of problems in commissioning
Coordination problem	Lack of coordination between the client and consultant causing delay in commencing commissioning. (Client's representatives are usually not available or ready when commissioning starts and they take too much time while forming a committee who participate in the testing and commissioning.
Construction problem	Patent defects (i.e.:- defective works such as cracks, uncompleted works and missing items)
Follow up problem	Materials that are installed not as per the specification
Technical problem	Lift problems, such as the lift movement is not smooth.
Technical problem	Systems failure (Gas or oxygen plant systems pipe failures)
Technical problem	Non-functionality of installed work /Errors during installations / poor installation
Technical problem	Low water pressure
Technical problem	Water leakage problem while conducting pressure test
Human errors	Poor workmanship problems/ Electric line shortage
Insufficient time	Too many items to be commissioning/ Overlook the importance of commissioning
Delay	Delay of civil, structural and installation works/ uncompleted works
Delay	Change of specification by the consultant or client /last minute changes
Culture	People blame each other when problem occurs and not give decisions on time

Culture	Lack of sense of responsibility
Nature of Cx.	Hard to detect problems once the ceiling is concealed (hard to trace problems)
Nature of Cx.	Wrong method or equipment used when testing /Sectional testing
Utilities supply shortage	Power supply shortages
Nature of Cx.	Damages on electrical fixtures during commissioning
Lack of knowledge	Use of Poor quality of material

5.3.7.1 Causes for Identified Cx Problems from the Contractors' Perspective

a) Monitoring

The main contractor monitors the testing and commissioning from the beginning of construction stage. Therefore, there are only some hiccups during commissioning. But, these are misstep are to be managed and to be rectified immediately.

- ✓ Lack of supervision

b) Workmanship

Untrained and Poor workmanships of contractor and sub-contractors. Sometimes, there are imperfections of work in installation due to human errors. (Errors during c) Sometimes people blame each other when problem occurs

This is because during installation of all construction items, mistakes or problems have not been arrested by the person in-charged in a timely manner. Besides that, poor supervision, untrained craftsmen and lack of sense of responsibility could be the reasons for this problem.

d) Lack of experience and lack of knowledge

Materials installed do not follow specifications, for example thickness of pipe. The availability of sanitary materials with the same brand but different in quality in the market and the use of poor quality from these different materials due to lack of experience or knowledge in selecting good quality sanitary materials.

e) Coordination

Lack of coordination between the client and consultant causing delay in commencing commissioning. (Client's representatives are usually not available or ready when commissioning starts and they take too much time while forming a committee who participate in the testing and commissioning.

Lack of coordination among personnel involves in civil, sanitary and electrical works.

- ✓ Once ceiling is concealed, it is very difficult to detect any problems above ceiling.

Also lack of coordination and not progressively making inspection and testing will result insufficient time for commissioning.

- ✓ too many items to be commissioning/ Overlook the importance of commissioning

Change of specification by the consultant or client /last minute changes and late in decision making

5.3.8 Cx Problems from the Consultants' Perspective

From the consultant's perspective, commissioning problems are presented in table 5.2 as follows.

Table 5.2: Commissioning Problems from the Consultants' Perspective

Problem type	Description of problems in commissioning
Change of scope	Change of intended purpose for the building by the owner
Communication problem	Discrepancy between the client's perspective and the consultant's perspective (Not fulfilling the client's requirement though it meets the requirement stipulated in the contract) / re-design are needed
Coordination problem	Lack of coordination causing delay in commencing commissioning. (Client's representatives are usually not available or ready when commissioning starts and they take too much time while forming a committee who participate in the testing and commissioning.

Capacity problem	Inexperience builder
Authority requirement	Booking of time for authority's inspection of commissioning
Construction problems and coordination	Patent defects (i.e.:- defective works such as cracks, uncompleted works and missing items)
Culture	Blaming each other when problem occurs and not give decisions on time
Coordination problem	Materials that are installed not as per the specification and without the approval of the consultant
Technical problem	Water leakage problem while conducting pressure test
Technical problem	Poor quality of works by the contractor and Take longer time to trace and rectify problems when problems found during commissioning stage
Insufficient time	Too many items to be commissioning/ Overlook the importance of commissioning
Delay	Delay of civil and structural works/ uncompleted works
Communication problem	Last minute changes and additional work (VO) orders by the client
Utilities supply shortage	Electric power and water supply shortages to take tests
Unclear scope/ Culture	Lack of sense of responsibility
Coordination problem	Testing equipment and technical personnel shortage by the contractor to take tests
Communication problem	Specified systems which are installed as the contract are no longer in used by the market (out dated)
Coordination problem	To have competent person to conduct testing for special items
Authority problems	Authorities impose new requirement

5.3.8.1 Causes for Identified Cx Problems from the Consultants' Perspective

a) Change of requirement by the client

For example: - changing seminar building into laboratory building.

b) Unclear scope of work (grey area)

When problems occur or equipment's or materials damaged there usually be confusion between sub-contractor and main contractor or between civil workers or/and mechanical and electrical engineers by blamed each other for the problems that occurred and it may take a long time to solve these problems. There is always an unclear scope of work in construction activities.

Parties not knowing their specific role and responsibility.

Local contractors' perspective towards quality of material and work is the main reason for Cx problems.

c) Nature of commissioning

Sometimes when a building is ready for commissioning, the owner might suddenly have a change of plans or change of specification for a designated building or might give additional work orders (VO).

Client's requirement might be subjective and differs from project to project

d) Communication and coordination problems by the parties

Communication problems: - if proper channels were set up earlier, this problem should not happen.

- ✓ Communication breakdown among construction team.
- ✓ Late decisions and unresolved issues by the client and consultant
- ✓ Sometimes, a non-qualified person is present when inspection is conducted with the consultant and the correct message was not directed to the correct person.

Coordination problems: - Lack of coordination causes delay in commencing commissioning. (Client's representatives are usually not available or ready when commissioning starts and they take too much time while forming a committee who participate in the testing and commissioning.

Also lack of coordination and not progressively making inspection and testing will result insufficient time for commissioning.

- ✓ Too many items to be commissioning/ Overlook the importance of commissioning.

e) Delayed due to some others problem

This problem can be caused by delayed due to site problem, contractor's problem, contractor's financial problem, additional work orders (VO), LC problems, materials no longer in production and lack of lead order specially for electrical and mechanical materials or equipment's etc.

f) Authority's related problems

External factor which is beyond control such as: authority's inspection and support letter.

Sometimes local authority or government body imposes new thing to match with new local rules.

Booking of time for authority's inspection of commissioning,

g) Coordination by the main contractor

Coordination by main contractor to coordinate all the nominated sub-contractors;

The appointment of competent person to coordinate testing and commissioning.

Right testing equipment delivery shortage by the contractor

h) Poor project follow up and control

Client representative not progressively check and follow up the project during construction stage and tends to make last minute changes

Poor project follow-up and control by the contractor and consultant

i) Electric power and water supply shortages to take tests

When doing testing and commissioning, things under scope of work such as electro-mechanical works and other items may be ready but if the electrical work is not energized, every item cannot be tested. Therefore, it is crucial to energize the power supply according to schedule. If not, items for mechanical and electrical such as firefighting cannot be tested. Local power supplier like ELPA is crucial in project commissioning.

Also due to electric power supply shortage, electrical systems usually tested by generator. As a result, electrical fixtures, breakers and fuses are being damaged due to

voltage drop or over voltage. And in order to rectify the damaged electrical systems it takes time while importing these damaged electrical accessories from other countries.

j) Inexperience builder

- ✓ Inexperience builders (construction team on site, it could be the main contractor and the sub-contractors) – sometimes, a non-qualified person is present when inspection is conducted with the consultant and the correct message was not directed to the correct person.
- ✓ Local contractors' perspective towards quality
- ✓ Depends on the quality of the main contractor to follow the designers' specifications.

k) Detailed work program for testing and commissioning

• All these items have to be meticulously discussed in the construction work program.

• Lack of proper and detail planning of the construction work program by the main contractor will cause project delay. Contractors do not plan properly and usually allocates no time for testing and commissioning.

5.3.9 Cx Problems with Most Significant Impact and Its Causes: Contractors' Perspective

The following comments are derived when the interviewees were asked on the commissioning problems with most significant impact to give a better insight on the significance commissioning problems for these case studies. Comments given by the interviewees are as follows:

• More towards electrical, mechanical and sanitary systems and it also includes metal windows and doors work.

• Sanitary systems

- ✓ Element related with water supply-water and sewerage systems leakage due to improper jointing, poor workmanship and poor quality sanitary materials;

- ✓ For example, leakage of concealed piping can damage the plaster ceilings and affect the entire work progress. When there is leakage, hacking has to be done to trace the problem and this will affect the wall, ceiling, and many other trades and re-works also takes additional time.

- Electrical systems

  - ✓ Every electrical fixtures, breakers, fuses, light and socket points must be checked and they are usually bulky and they take time.
  - ✓ Usually, electrical systems are being tested by own generator because of electrical energy power supply shortages. As a result, electrical fixtures, breakers and fuses are being damaged due to voltage drop or over voltage. And in order to rectify the damaged electrical systems it takes time while importing these damaged electrical accessories from other countries.

- Mechanical systems

  - ✓ Air-conditioning mechanical ventilation; workmanship and joint problems on ducts usually takes time to identify the where the problem is and to rectify it.
  - ✓ Lifts usually takes time to detect the problem and rectify the problem within allotted time and in addition testing has to be repeated till the performance of the services is up to the specified standard.

- Metal works

  - ✓ LTZ window and doors cause significant delay to rectify them after checking their functionality due to problems of rust and change of shape. It takes more time to rectify these problems.

a) Most items of work are integrated together and interrelated

Wet systems can affect other completed trades of work as well. For example, leakage of concealed piping can damage the plaster ceilings and affect the entire work progress. When there is leakage, hacking has to be done to trace the problem and this will affect the wall, ceiling, and many other trades.

b) Test done by an incompetent person

Commissioning is not done according to requirement where an unqualified person without proper qualification and experience performs the test especially for mechanical and sanitary systems. These poor commissioning can lead to system failures resulting additional time for maintenance and re-commissioning.

c) Coordination of work

The coordination of works is very important. Before final testing and commissioning, inspections during installation must be made in order not to damage other items work while finally checking.

Also, every electrical fixtures, breakers, fuses, light and socket points must be checked and they are usually bulky and they take time.

Therefore, planning commissioning and the steps in planning are necessary.

d) Poor workmanship

Workmanship problems during construction. For example: - Joint is done incorrectly

e) Electric power supply shortages to take tests

Usually, electrical systems are being tested by own generator because of electrical energy power supply shortages. As a result, electrical fixtures, breakers and fuses are being damaged due to voltage drop or over voltage. And in order to rectify the damaged electrical systems it takes time while importing these damaged electrical accessories from other countries.

5.3.9.1 Cx Problems with Most Significant Impact and Its Cause: Consultants' Perspective

According to the interviewees, these problems vary and the commissioning problems depend on the particular project. For example: for hospital', the most common problem is the air-conditioning system because the air-conditioning system is quite unique as they normal filter system cannot be used to filter germs. On the other hand, for office building, usually the main problem is the installation of the lift especially for high rise building.

It is the duty of the mechanical and electrical engineers to make sure everything is in working order. Without electrical power supply, no testing can be conducted. Therefore, electrical works are among the most significant problems in commissioning to be dealt with. Testing for others things are not possible without electric power supply.

Problems such as leakage and workmanship fall under the category of defects. But, it depends on the severity of the defects. If leakages are detected, these leakages have to be rectified immediately as the impact of leakages will affect testing and commissioning and will subsequently deteriorates the efficiency of the whole system.

For example, leakage of concealed piping can damage the plaster ceilings and affect the entire work progress. When there is leakage, hacking has to be done to trace the problem and this will affect the wall, ceiling, and many other trades and re-works also takes additional time.

From the perspective of consultants, building finishes is cited as one of the significant problems of commissioning. This is because:

• Sample of materials (submitted sample does not fulfill the standard and this problem is dragged for a long time);

• Lead time to order; and

• Constructed and rejected items (defects).

In general, it is almost impossible to determine the most significant problems of commissioning as these problems differ from each project. Nevertheless, coordination is very important during commissioning. If there is a lack of coordination, problems may arise and causes repetitive work and thus increase the cost and delay the entire schedule. For example, for ceiling, if electrical installations are not completed before ceiling is covered up, many problems will occur at a later stage. Consequently, interface trades problem can also affect the work progress.

5.3.10 Common Problems of Cx and Its Causes: Contractors' Perspective

The interviewees were asked to comment on common problems in commissioning that tend to recur from project to project. Accordingly, most of them claimed that the recurrence of problem is on sanitary systems due to water leakage. Problems of wet systems and electrical works are prone to recur from project to project such as leakage, and improper connection of cable or pipe.

Most of the time, the same problem occurs because contractors did not follow the specified or required standard procedures. From there perspective, there are two main elements in commissioning, which are: people and equipment. These services or systems are fixed and installed by human. Therefore, during the works of welding, screwing and coupling of the connection, some work might not have been done properly. Sometimes, testing is not conducted by certified personnel and the equipment was not calibrated properly resulting in malfunction of equipment. Some installation problems may also be caused by the attitude of the workers who are not serious in their work.

Lack of proper follow up and coordination can also cause many problems and further exacerbates the delay progress of the project.

Every commissioned item can be a contributor to delay. Thus, to catch or trace the problem is not easy. For examples, for leakages, many other trades might cause leakage such as drilling from other trades. It takes time to search for the root cause and leakage cannot be seen easily until there is water mark spot detected.

These problems may be due to the culture of the industry. Testing and commissioning is actually part of the requirement/specification of construction projects according to law and regulations. If it is not done according to procedures, re-do and rectifications might be needed if the customer does not accept the end product.

5.3.10.1 Common Problems of Commissioning and Its Causes: Consultants' Perspective

From the consultants' perspective: Problems that recur from projects to projects varies from project to project. Every project is unique and depends on the building typology.

For a hotel, the main commissioning issue would be plumbing; and for office building, the common problems are air-conditioning, lighting and lift problem.

But, Problems of wet systems and electrical works are mostly prone to recur from project to project such as leakage, and improper connection of cable or pipe. And the main reasons for these are lack recording data from previous experience and lack of coordination and supervision by both the contractor and consultant.

Also, it is the duty of the mechanical and electrical engineers to make sure everything is in working order. Without electrical power supply, no testing can be conducted. Therefore, electrical works are among the most significant problems in commissioning to be dealt with. Testing for others things are not possible without electric power supply.

5.3.11 Interrelationship of Cx Problems with Other Phases in the Project Life-Cycle

Summary of the interrelationships between the problems of construction and commissioning from the contractors' and consultants' perspective. Construction problems are one of the major inhibitor for the execution of commissioning. Interference from client, late completion of civil and structural works, variation orders, half-baked systems and lack of supervision are among the construction problems that has a big influence in commissioning.

a) Interference from client

Interference from client such as additional requirement from client and changes of room layout for services, delay in decision making and others have caused the project progress to be delayed.

b) Completion of civil and structural works

Without completion of structural and architectural works, it is almost impossible to run testing and commissioning. For testing and commissioning, power supply is needed to test the equipment. If the civil and structural works have not completed, the mechanical and electrical work cannot be tested. Delays in civil and structural works will also affect the architectural installation and mechanical and electrical works as well. Problems in

mechanical and electrical works will delay some civil work progress such as the completion of brick wall and ceiling finishes.

c) Variation Orders

Additional and the increased number of Variation Orders (V.O.) will affect the actual progress of work. Re-testing might be required due to additional variation orders such as change of layout from the end-user.

d) The system itself is half-baked and not ready for commissioning

Some of the system cannot be partially commissioned and must be tested in full swing mode (not fit for commissioning). The following are some of these problems:

Lift not running; and

No letter of support from authority.

e) Lack of supervision – Contractors overlooks some critical problems and this will have an adverse effect at the whole system at a later stage. As a result, all these construction problems will delay the handing over of the building to the client.

5.3.12 Recommendations to Mitigate Cx Problems

According to the interviewees, both the contractor and consultant must give proper attention in planning, executing and controlling the construction project. In addition, construction problems and delay in commissioning can be avoided by taking preliminary tests (inspections), deeply supervising the quality of work and checking the functionality of every item of works during construction stage and holding and reviewing recorded data of previous project to avoid these commissioning problems and delay.

It can be mitigate by giving proper attention in preparing workable project plan (schedule) which can be monitored and controlled. In addition, making constant design reviews, checking external factors during design and construction, allocating enough budgets and time for the project, resolving payment delay issues and progressively inspect every work during construction can mitigate this problem.

Consultant should create awareness to the contractor by briefing the scope of the work, expected out come and the design aspect and process as per clients need in order to help

the contractor to plan before hand to avoid commissioning problems and delay. Change contractor's perspective towards quality of material and work is also suggested by the consultants.

It might be difficult to control these problems and not easy to mitigate problems in commissioning. The interviewee highlighted that further study need in this matter.

5.3.13 Anticipation of Cx Problems before the Commencement of Project

Most of the interviewees from consultants and contractors claimed that it is very difficult to anticipate problems in commissioning. Among the reasons given by the interviewees are as follows:

- Peoples don not consider this Cx. problems before the commencement of a project because there is no record from previous experience or they do not usually record data's from previous projects of these problems. In other words, they did not give proper attention for these problems.
- Difficult to predict potential problems. For example, the issuance of Variation Orders is not part of the work program;
- Contractors always underestimate the complexity services installation;
- Problems usually found towards the end of investigation.

CHAPTER VI: CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The aim of this research paper which was to develop a model to improve building commissioning for construction projects in Ethiopia", is accomplished by conducting semi-structured interviews through case studies from a public institution building projects around Addis Ababa.

1. Definition of building commissioning is most comprehensive where it capable to combine these characters into the framework. There are eight groups of characters, such as: characteristics, pre-requisites, components, ensure functionality, durations, activities or elements, personnel involved and the goals to be attained in building commissioning have formed the basis for this framework.
2. Viewpoints of contractors and consultants are slightly differed among each other's but it does present some ideas on the current practice of commissioning for public construction projects in Ethiopia. Understanding of commissioning in the context of Ethiopian construction industry will definitely assist to improve the conduct of commissioning later on.
3. Comparisons of these interviews findings among contractors and consultants have revealed that problems during commissioning are due to: last minute changes and additional work orders, change of requirement or intended purpose of building by the client, time needed to make appointment with authorities for inspection, poor coordination and communication, occurrence of unforeseen problems, unpredictable nature of commission, unclear scope of works, delays of civil and structural works and electric power supply shortage. The consultants also further added on a few factors such as: contractors' perspective towards quality, in experience builder, lack of proper testing equipment and competent person, new requirement imposed by authority and unavailability of detailed work program. Apart from this, problems during commissioning are mostly interrelated with problems during construction stage.

4. Also some of these problems are significance in affecting the handing over of the project and tend to recur from project to project. Without knowing the underlying causes of these problems, it is hard to anticipate the occurrence of these problems in future projects.

5. The last objective of this research was, “to measure the importance of building commissioning and its effect on project completion by using Earned Value Analysis”. From the S-Curve plotted for Project B, it can be concluded that project commissioning will be rushed when there is a delay in the middle of the project. Therefore, it can be deduced that commissioning is utmost important in influencing the project completion and project performance.

6.2. Recommendations

1. It is possible that there may be significant differences in the findings, if data were collected from private institution construction projects. Therefore, more research on building commission should be made in Ethiopia.

2. As an extension of this study, additional quantitative evidence is needed to determine the relationships between commissioning problems and the project performance and project timely completion. A quantitative study in future would be a way to assess more accurately the influence of building commissioning on the project performance and to complete the project in a timely manner.

3. Also for future studies, it can be focused on certain types of procurement method to evaluate whether there are any similarities or differences found amongst different procurement method on BCx.
4. Moreover, the common activities of building commissioning that need to be taken into consideration even during construction stage shall be inspected by the relevant building authorities. This measure is vital to confirm the final outcome is in compliance with the specified requirements or specifications. Consequently, in the future, it is useful to study if inspections by the authorities and construction team can or should be outsourced to an independent third party.

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APPENDICES A

CASE STUDIES QUESTIONS

Case Study Questions to gain in-depth understanding of situations and meaning of Building Commissioning from the Contractors perspective.

Background Information

Name of the Construction Project: -

Name of the contact person: -

Job Title: -

Years of Experience: -

Company Name: -

Project Duration: -

Date: -

Types of Construction Contract: -

Time: -

No.			
1.	What is your understanding of building commissioning?	What are the activities involved? Or scope of Cx?	Usually how long it takes?
2.	Do you think commissioning stage is important to ensure conformance of the constructed facilities and building with specifications?	Please **rank** from **1** (least significant) - **5** (most significant) on the importance of building Commissioning.	Why?
3.	How is testing and commissioning being conducted in the Ethiopian construction industry? a) Progressively being done all through the project, **OR** It is carried out after construction, towards the end of the project handing over to the client but except for certain thing which was carried out progressively. b) Please give reasons for your selection in 3 (a). c) Please specify other reasons if the above statement in 3 (a) does not reflect your answer.	What are the problems in Commissioning?	What are the causes for these problems in commissioning?
4.	What are the elements to be commissioned in this stage? a)_____ b)_____	a) Which aspect has the most significant delay?	Why?
		b) From these aspects, which element	Why?

	c)_____ d)_____ e)_____	recurs from project to project? (common problem)	
5.	Is delay in commissioning derived from previous phases in the project life-cycle? Or the problem merely from commissioning phases itself?	If **Yes**, which stage of the project life-cycle and why? How to mitigate this problem?	What are the problems in this phase that will cause subsequent delay in commissioning phase?
6.	Who are the personnel involved in the Commissioning stage?	Commissioning started in which stage of the project life-cycle? And at what time it starts (days-months) before handover or the const. progress?	
7	Are proper inspection/testing being done during commissioning or commissioning is merely an administrative task to get the Certificate of Practical Completion?	Why?	
8.	Will commissioning cause delay in handing over of the building to the client?	Why?	
9	What are the effects/impacts of delay in commissioning? e.g.: rental and usage of the building.	How will it affect the project completion?	Do people consider this problem before they start the project?
10	What is the magnitude of delay in commissioning? How many days of delay in commissioning?	Please **rank** the seriousness of delay in Cx from **1** (least serious) – **5** (most serious).	

Case Study Questions to gain in-depth understanding of situations and meaning of Building Commissioning from the Consultants perspective.

Background Information

Name of the Construction Project:-

Name of the contact person: -

Job Title: -

Years of Experience: -

Company Name: -

Project Duration: - Date: -

Types of Construction Contract: - Time: -

No.			
1.	What is your understanding of building commissioning?	What are the activities involved? Or scope of Cx?	Usually how long it takes?
2.	Do you think commissioning stage is important to ensure conformance of the constructed facilities and building with specifications?	Please **rank** from **1** (least significant) - **5** (most significant) on the importance of building Commissioning.	Why?
3.	How is testing and commissioning being conducted in the Ethiopian construction industry? a) Progressively being done all through the project, **OR** It is carried out after construction, towards the end of the project handing over to the client but except for certain thing which was carried out progressively. b) Please give reasons for your selection in 3 (a). c) Please specify other reasons if the above statement in 3 (a) does not reflect your answer.	What are the problems in Commissioning?	What are the causes for these problems in commissioning?
4.	What are the elements to be commissioned in this stage? a)_____ b)_____	a) Which aspect has the most significant delay?	Why?
		b) From these aspects, which element	Why?

	c)_____ d)_____ e)_____	recurs from project to project? (common problem)	
5.	Is delay in commissioning derived from previous phases in the project life-cycle? Or the problem merely from commissioning phases itself?	If **Yes**, which stage of the project life-cycle and why? How to mitigate this problem?	What are the problems in this phase that will cause subsequent delay in commissioning phase?
6.	Who are the personnel involved in the Cx stage?	Commissioning started in which stage of the project life-cycle? And at what time it starts (days-months) before handover or the const. progress?	
7	Are proper inspection/testing being done during commissioning or commissioning is merely an administrative task to get the Certificate of Practical Completion?	Why?	
8.	Will commissioning cause delay in handing over of the building to the client?	Why?	
9	What are the effects/impacts of delay in commissioning? e.g.: rental and usage of the building.	How will it affect the project completion?	Do people consider this problem before they start the project?
10	What is the magnitude of delay in commissioning? How many days of delay in commissioning?	Please **rank** the seriousness of delay in Cx from **1** (least serious) – **5** (most serious).	