CONSTRUCTABILITY IMPLEMENTATION STATE OF PRACTICE IN SAUDI CONSTRUCTION PROJECTS

BY

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This work is dedicated to my daughter Alanoud.

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ABSTRACT

Full Name : Abdulrahman A. Al-Mussad

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Constructability is defined as the optimum use of construction knowledge and experience in conceptual planning, design, procurement and field operations to achieve overall project objectives. This research addresses the state of practice of constructability study among government and private project owners in Saudi Arabia. The study addresses the practice of constructability concepts during the conceptual planning, the effectiveness of the implementation at corporate levels, the benefits behind the implementation at project levels, and the barriers toward implementing constructability.

A questionnaire was sent to various project owners operating in the study region, soliciting the required information for this study. Also, two different case studies that implemented constructability were selected and rigorously examined. Results were analyzed qualitatively and statistically.

The concept of constructability in the Saudi construction industry has a moderate level of utilization among private project owners and a low level among government project owners. It is being implemented on some selected projects without corporate level support. Projects implementing constructability showed a reduction of 40% in change orders values in both organizations as well as a remarkable improvement in the performance of schedule, budget, quality and safety; lack of documentation, unwillingness to expend additional cost and change resistance were the key barriers identified.

ملخص الرسالة

الاسم الكامل: عبدالرحمن بن عابد المسعد

عنوان الرسالة: حالة ممارسة دراسة قابلية التشييد في مشاريع البناء السعودية

التخصص: هندسة وإدارة التشييد

تاريخ الدرجة العلمية: رمضان 1439 هـ

تعرّف دراسة قابليّة التشييد بالاستخدام الأمثل لمعارف البناء وخبرته في التخطيط المفاهيمي والتصميم والمشتريات والعمليات الميدانية لتحقيق أهداف المشروع الإجمالية. يتناول هذا المشروع البحثي حالة تطبيق دراسة قابليّة التشييد في الجهات المالكة للمشاريع الحكومية ومشاريع القطاع الخاص في المملكة العربية السعودية. ويتناول أيضاً تقييم ممارسة مفاهيم التشييد خلال التخطيط المفاهيمي للمشاريع، وفعالية التنفيذ على المستوى الإداري، والفوائد الكامنة وراء تطبيق قابليّة التشييد على جميع مستويات المشروع، والعوائق التي تحول دون تنفيذها.

تم إرسال استبيان إلى مختلف الجهات المالكة للمشاريع العاملة في منطقة الدراسة، والتماس المعلومات المطلوبة لهذا البحث. أيضا، تم دراسة حالتي مشروعين مختلفين تم تطبيق قابليّة التشييد بهما وتم تحليل النتائج نوعيا وإحصائيا.

إنَّ لمفاهيم التشييد في صناعة البناء في السعودية مستوى معتدل من الاستخدام بين الجهات المالكة للمشاريع الخاصة ومستوى منخفض بين الجهات المالكة للمشاريع الحكومية حيث يتم تطبيق الدراسة في بعض المشاريع المختارة ولكن دون دعم على المستوى الإداري في القطاعين. وأظهرت المشاريع التي نفذّت دراسة قابلية التشييد انخفاضاً بنسبة 40٪ في قيم أوامر التغيير في القطاعين، فضلاً عن تحسن ملحوظ في أداء الجدول الزمني والميزانية والجودة والسلامة. العقبات الرئيسية التي تم تحديدها لتطبيق دراسة قابليّة التشييد هي الافتقار إلى الوثائق، وعدم الرغبة في إنفاق تكاليف إضافية، ومقاومة التغيير.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Construction is the coordinated team effort that is carried out to execute the work in accordance with the contract documents. This effort includes two types of activities:

- Construction Contract Administration: the set of activities related to the management of the contract for the purpose of construction; and

- Project Management Activities: the set of activities related to the management of associated processes to achieve the project objectives (The CSI Construction Contract Administration Practice Guide 2011).

Despite each construction project being unique and having a different level of complexity, a common systematic project management approach is habitually applied on all construction projects (Alalawi, et al. 2015). The Project Management Institute (PMI) has divided projects into five process groups: initiation, planning, execution, monitoring and controlling, and closing, in addition to ten knowledge areas that are performed integrally in these processes throughout the project lifecycle (PMBOK® Guide 2013). On the other hand, construction type projects are very complex, incredibly versatile, and are subject to a lot of challenges including: the activities being performed in the place of the final product, the influence of nature and geology, and the hefty involvement of manpower and equipment (Pellicer, et al. 2014). However, the construction industry has certainly impacted economies by producing infrastructure for the public and sustaining a vital source of employment (Myers 2008). The UN National Accounts Database report shows that Saudi Arabia has a bulk construction output of $3,200 MM (World Development Indicators 2015).

As construction projects become more complicated due to market needs, an extensive planning effort is required for the separate design and construction stages in order to meet the projects' anticipated schedule and allocated budget (Pulaski and Horman 2005). Constructability, which integrates the knowledge and experience of construction in the early project's phases, is a useful construction planning technique that has the potential to optimize the project objectives and avoid field operation obstructions (Jergeas and Van der Put 2001).

1.2 STATEMENT OF THE PROBLEM

The execution phase of construction projects has been conventionally separated into design and construction, and both activities have been carried out separately since the 1960s (F. W. Wong, et al. 2007). Over time, that separation has caused failure in the consideration of the construction requirements during the design phase, resulting in schedule delays, budget overruns, and contractual disputes (Langkemper, Al-Jibouri and Reymen 2003). Currently, there is a lack of communication and coordination during the design stage between engineering firms who are not experts in the methodologies of construction and construction contractors who are classically not involved in the design, and this is the root of several constructability problems (McDowall 2008). The research and practice of constructability implementation in the local construction industry has not been given sufficient attention, which has promoted this research study.

1.3 STUDY OBJECTIVES

The main objective of this study was to measure the level of utilization of constructability and to investigate the procedures that are followed in applying constructability among private and government construction project owner organizations in Saudi Arabia. Specifically, the research has been conducted:

1. To measure the level of utilization of constructability concepts in project owner organizations;

2. To identify the procedures that are followed in applying constructability in project owner organizations;

3. To determine the benefits that private and government project owners gain from the implementation of constructability in their projects; and

4. To explore the barriers, if any, of applying constructability in private and government projects.

1.4 SIGNIFICANCE OF THE STUDY

This study would be a significant attempt toward promoting the Saudi construction industry and assessing more efficient capital investment in industrial and non-industrial projects by:

- Indicating the level of utilization of constructability concepts among project owners and stipulating the magnitude of improvements required for a better level of implementation;
- Elaborating the common implementation barriers of constructability in project owner organizations and recommending how to overcome them; and
- Suggesting further areas of research that emphasize constructability implementation among local construction stakeholders.

Saudi government organizations, Saudi companies and numerous groups from the local construction industry, in addition to others, will benefit from this study. These groups of beneficiaries may also include consultants, engineering firms, construction contractors, project management teams, and the interested people from academia. Furthermore, it will also expand the existing literature and serve as a future reference for researchers interested in investigating and improving constructability practices in the country.

1.5 SCOPE AND LIMITATIONS

The research was limited to private and government projects in the three major cities of Dammam, Dhahran, and Khobar, Eastern Province, Kingdom of Saudi Arabia, due to time and cost limitations. Also, the research is limited to recent construction projects that have been executed during the last five years in order to present more accurate outcomes. The limitation of financial data accessibility and construction statistics was faced during the execution of the study and it took longer than had been anticipated.

CHAPTER 2

LITERATURE REVIEW

2.1 DEVELOPMENT OF CONSTRUCTABILITY

2.1.1 Introduction

In the past, the design itself was the main driver in the selection of a suitable construction methodology. The entire execution cycle was performed by one entity called the "master builder" who conducted the work at that time based on whether the general rules were typically followed in the industry or by performing iterations. When architecture came into sight as a standalone specialization, master builders no longer existed due to the separation that occurred between design and construction disciplines. The complexity level of construction projects increased dramatically after the industrial revolution because of several factors including:

- the variety of construction materials that could be utilized;
- the remarkable development of science and technology;
- the diversity of construction standards and codes; and
- the dissimilarity of objectives among construction professions (Uhlik and Lores 1998).

Thus, it was difficult for a single professional to perform planning, design, and construction. Nevertheless, the participation of all interested entities in projects in the early project phases i.e. owner, designer, constructor, and material suppliers is very important to deliver the optimum design (Trigunarsyah 2004).

An Official Report developed by the UK government in the 1960s addressed the gap of communication between design and construction teams as the principle obstacle that was causing major problems in the construction industry. Banwell conducted a study that recommended assembling the design and the knowledge of construction together in the contract procurement process. In 1967, the Economic Development Council conducted a further study and found that Banwell's recommendations had not been implemented in the industry. Afterward, the Construction Industry Research and Information Association (CIRIA) carried out a research emphasizing the major construction problems and evolved the term Buildability (Griffith and Sidwell 1997).

In addition, cost efficiency in US construction projects became a real concern in the early 1980s. In 1983, a construction industry cost effectiveness project was published by the Business Roundtable which consisted of collective studies conducted by construction professionals and academicians in order to enhance the construction industry in terms of cost efficiency and execution methodology. They found that there is a potential for cost saving and schedule optimization if construction knowledge was utilized in the engineering phase of construction projects under a process called Constructability. This effort was the initiation of the Construction Industry Institute (CII) establishment based at the University of Texas (Pocock, et al. 2006).

The detailed constructability concept and its formal definition were established back in 1986 by amalgamating the outputs of three principle studies conducted by CII (Griffith and

Sidwell 1997). Yet, several definitions were introduced afterward; all these definitions focused on the importance of the integration of construction knowledge throughout the project processes (Jergeas and Van der Put 2001).

2.1.2 Explication of Buildability and Constructability

In the 1970s, constructability in the US and buildability in the UK received attention due to their remarkable contribution to the improvement in construction projects (Trigunarsyah 2004). Despite both terminologies drawing attention to the importance of the use of construction expertise in the early project phases, buildability focuses only on the design stage while constructability focuses on all project stages (F. W. Wong, et al. 2007).

2.1.2.1 Augmentation of Buildability Concept

CIRIA has defined buildability as "the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building" (F. Wong, et al. 2006). “Buildability; An Assessment” is the official report developed by CIRIA which has illustrated the following seven principles to meet buildability requirements:

1. Investigation and design development;
2. Planning for site requirements;
3. Planning for the chain of operation activities;
4. Planning for the ease of assembly;
5. Detailing for standardization;
6. Detailing for tolerances; and
7. Specifying appropriate construction materials (Griffith and Sidwell 1997).

Additionally, the terminology was exported to Asia when Singapore launched the Buildable Design Appraisal System in 2001 which required a minimum score of buildability prior to design approval (F. Wong, et al. 2006). Also, in Hong Kong the Construction Industry Review Committee (CIRC) was appointed to study ongoing constructions and provide recommendations for improvements. CIRC developed the Buildability Assessment Model that evaluates design drawings and specifications against a standardized checklist to provide an overall buildability score (F. Wong, et al. 2006).

Several buildability researches and studies were performed and the following quotations are further common definitions of buildability:

- "Buildability is the ability to construct a building efficiently, economically and to agreed levels from its constituent materials, components and sub-assemblies" (Ferguson 1989).
- "Buildability is the extent to which decisions are made during the whole building procurement process in response to factors influencing the project and other project goals, ultimately facilitating the ease of construction and the quality of the completed project" (McGeorge, Chen and Ostwald 1992).
- "Buildable design will lead to improvements in quality ... the 3S principles of Standardization, Simplicity, and Single integrated elements to achieve buildable design" (Code of Practice on Buildable Design 2005).

2.1.2.2 Augmentation of Constructability Concept

The first definition of constructability was developed by CII in the US as "the optimum use of construction knowledge and experience in conceptual planning, design, procurement and field operations to achieve overall project objectives" (Constructability; A Primer

1986). After a number of studies, Australia also capitalized on the US CII effort and implemented constructability in line with the establishment of CII Australia (CIIA) in Brisbane, Australia. The main intent of the CIIA establishment was to close the design–construction gap and improve the project management throughout the project's lifecycle. In 1992, CII Australia developed a constructability principles file to improve the concept of constructability. Four years later, they published a constructability manual which offers guidelines on constructability implementation. In recent times, constructability researches have been conducted in Malaysia, Indonesia, and Nigeria to ascertain the state of practice and the potential for process improvement (F. W. Wong, et al. 2007).

The following quotations are further definitions of constructability stated by different authors:

- "Constructability was defined as a measure of the ease or expediency with which a facility can be constructed" (Hugo, O'Connor and Ward 1990).
- "Constructability is the integration of construction knowledge in the project delivery process and balancing the various project and environmental constrains to achieve project goals and building performance at an optimal level" (Constructabilty Principles File 1992).
- "Constructability programs aimed at integrating engineering, construction, and operation knowledge and experience to better achieve project objectives" (Arditi, Elhassan and Toklu 2002).
- "The constructability VIP is the facilitated systematic implementation of the latest engineering, procurement, construction concepts, and lessons learned consistent

with the facility's operations and maintenance requirements to enhance construction safety, scope, cost, schedule, and quality" (Sam 2012).

2.1.2.3 Boundaries of Buildability and Constructability

Both terms emphasize the valuable contribution of assimilating construction knowledge during early project development stages. Nevertheless, buildability focuses principally on construction improvement by only integrating construction expertise into the design while studies show that constructability considers the improvement of construction through implementing its principles, during the entire project lifecycle, with the involvement of the project's owner, project management team, and contractors (Griffith and Sidwell 1997).

2.1.3 Evolution of Constructability

During the 1980s, CII conducted three major study projects and their outputs were amalgamated together into the Constructability Concepts File which addressed six constructability concepts to be practiced in conceptual planning, seven in design and procurement, and one in construction operations (Griffith and Sidwell 1997). Later, three additional constructability concepts were added (Trigunarsyah 2004).

In the early 1990s, CIIA examined constructability researches performed in the US, the UK, and Australia and evaluated them in opposition to pre-chosen case studies in the construction industry. Like CII US, CIIA developed twelve concepts adopted for their local industry to be implemented through project phases. The CIIA concepts covered constructability program establishment and the implementation process through a developed flowchart (Griffith and Sidwell 1997).

In 1991, the Construction Management Committee of the American Society of Civil Engineers (ASCE) split constructability into two main concepts: constructability and constructability program. The committee developed definitions for both terms, as the capability of being constructed, and the application of a systematic optimization of construction related aspects during project processes, respectively. The ultimate intent of a newly introduced constructability program is to improve project objectives. Moreover, ASCE conducted a large study intended to examine the status of constructability implementation among US construction industry practitioners (Alalawi, et al. 2015). In 2002, The Construction Institute (CI) established by ASCE, appointed a committee from construction industry and academia in order to communicate constructability topics in civil engineering projects and also to enlarge its body of knowledge. The committee launched an online catalog consisting of constructability related articles and references and published the Constructability State of Practice report which predominantly defined constructability, identified its implementation phases, described its execution methodology, determined its beneficiaries and performers, clarified its advantages and barriers, distinguished its contributor objectives, and stated its level of practice (Pocock, et al. 2006).

In addition, Gugel and Russell developed a model that assists owners in selecting the appropriate approach for constructability implementation. Three approaches were created based on the formal/informal nature of the implementation and owner/project characteristics assessment:

1. Informal Approach;
2. Formal Project Level; and
3. Comprehensive Tracking.

Seven different projects experimented with this model and the results were reliable compared to the developed variables (Jergeas and Van der Put 2001).

2.2 CONSTRUCTABILITY IMPLEMENTATION

2.2.1 Introduction

Constructability implementation assists projects in meeting their objectives in terms of cost and schedule. Studies have proved that it can save around 4.3 percent in cost and 7.5 percent in schedule. Also, it has the support effort to improve functionality, quality, safety, security, and risk management. Implementing constructability necessitates very heavy planning during the early project phases to capitalize on its full advantages (O'Connor 2006).

2.2.2 Constructability Methods and Approaches

2.2.2.1 Concepts of Constructability

CII has developed seventeen constructability concepts to be practiced in the major project phases of conceptual planning, design/procurement, and construction operations. The following are the concepts classified based on the vital stage of implementation:

<u>Conceptual Planning</u>

- A project execution plan considers a plan for constructability: the plan of how to achieve constructability in certain projects should be clearly written in that project's execution plan document at the early phase of the project.

- Construction knowledge is considered during early feasibility planning: the early involvement of construction experts in the planning phase of a project will lead to more accurate cost and schedule estimates as well as more viable project objectives.
- Construction knowledge is considered in the contracting strategy development: irrespective of which project delivery method or contract type is being selected, the expected qualifications of the construction personnel have to be obviously stated in the contract documents.
- Overall project schedule is construction/startup sensitive: The overall project schedule has to achieve a prime economic steadiness amid major project activities.
- Early design considers principle construction methodologies: the designer has to decide on principle construction methods such as preassembly and modularization which could impact the project’s budget or schedule if changed in the later stages. This selected method should be part of the design.
- Permanent and temporary facility layouts should be integrated: layouts of permanent facility should be effectively coordinated with temporary facility plans which will optimize storage, fabrication area, and site accessibility.
- Taking advantage of promoting information technology: this includes the use of advanced technologies such as 3D modelling, simulations, lessons learned database system, remote sensing, GPS, and material bar coding.
- Early formulation of the constructability team: as early as the project is commenced, a formal constructability team should be designated. This team has to be accountable on constructability coordination and implementation as well as tracking the achieved benefits.

Design and Procurement

- Schedules of design and procurement are construction sensitive: since construction is usually the largest cost fragment in projects, the development of a project's overall schedule must be held prior to the development of its design. Construction activity consequences should be considered during the development of design and procurement schedules.
- Design is configurable: preliminary design concepts need early exchange between construction and design personnel. Configurable design might include the simplicity of elements' configuration, insignificance of segmentation, design flexibility, instinctive alignment and arrangement, ease of accessibility, and reduction of high technicality operations.
- Standardizing the design of construction elements and material: standardizing project elements during design will result in time saving during the design stage, erection, installation, and construction. The standardization may include, but is not limited to element size, material type, and specifications. Resulting from the increase of purchased material quantities due to standardization, discounts in material procurement costs might be effectively achieved.
- Development of contract documents considers procurement, construction and startup: efficient field operations can be achieved by adopting construction expertise in the early development of a project's specifications. Equally, the preparation of design drawings should consider the simplification of field

operations including construction, material procurement, and start-ups, i.e., a number of startup systems were selected and should be included in design drawings.

- Design considers assembling, transportation, and installation: design should technically consider whether modularization or preassembling execution methodologies were selected for construction scope elements i.e. modularized control room or precast concrete structure. Designer also should consider where and when assembly will take place as well as transportation, accessibility, and installation requirements of the modularized or preassembled commodity.
- Design considers jobsite accessibility: accessibility of people, material, and equipment has a major impact on the project's productivity, safety, cost, and schedule. In order to prevent the negative influence of construction site accessibility, design should consider every ease of access aspect such as the work package consequences, delivery time of major equipment, planning of material laydown area, and internal and external routes of transportation.
- Design considers severe weather conditions during construction: the conditions of severe weather might have substantial effects on achieving project objectives. These affects can potentially be prevented if design takes them into consideration, i.e., selecting construction materials that are non-sensitive to weather conditions, adopting preassembly, planning construction site accessibility and lighting, and other preventable actions.
- Planning considers jobsite security: it is very important to secure projects in order to operate construction activities in an efficient and safe manners. Site security

alternatives, i.e., control of access, security of documents, security of material and equipment, and the fencing system should be examined in the design stage.

Construction Operations

- Innovations are applied on construction methods: construction contractors must become organizations that stimulate innovations in order to excellently achieve this concept. Applying innovative construction methodologies will lead to improving the efficiency of field operations activities. These innovations might include the use of temporary systems, the use of tools and equipment, and the use of preassembly. (O'Connor and Miller 1993).

2.2.2.2 Implementation at Corporate Level

In general, it is desired to have a corporate level constructability program. This practice assures that the implementation at project level has full support from executives or top management of the organization, whether the organization is a project owner, designer or even a construction contractor. Corporate level constructability implementation also has the energy to align and link the project objectives to the corporate objectives and strategies. This type of implementation can be encountered through:

- sympathetic constructability objectives, concepts, and barriers;
- assessing constructability abilities;
- recognizing constructability benefits;
- developing a policy of constructability implementation;
- assigning a constructability sponsor;
- establishing constructability procedures; and

- developing lessons learned knowledge base (O'Connor 2006).

2.2.2.3 Implementation at Project Level

The process of project level implementation should be commenced after the initiation and continue throughout the project's lifecycle. The earlier constructability implementation starts, the higher savings can be accomplished. In order to achieve project level constructability implementation, the following steps shall be performed:

- Assigning constructability owner;
- Defining the objectives of constructability implementation;
- Selecting the most appropriate contracting type;
- Securing project contractors and sub-contractors;
- Developing the constructability team;
- Exploring the lessons learned system;
- Conducting constructability planning workshop;
- Finalizing implementation plans;
- Acting on implementation plans;
- Monitoring implementation; and
- Updating lessons learned knowledge base (O'Connor 2006).

2.2.2.4 Constructability Implementation Maturity

The maturity of implementing constructability either at corporate or project levels is classified into five levels:

1. No Program: the organization has a lack of consciousness and support of constructability and there is no adoption effort.

2. Limited Application: the organization has limited consciousness and support of constructability with lack of understanding the importance of constructability adoption proactivity. In this level of implementation, constructability is implemented on some selected projects without corporate level support.
3. Informal Program: the organization has an acceptable consciousness and support of constructability but implementation efforts have limited support within the organization.
4. Formal Program: the organization has made a comprehensive effort toward implementing constructability with full support at corporate level but some barriers exist. At this level of implementation, tracking of constructability benefits exists.
5. Comprehensive Formal Program: constructability is a culture in the organization's corporate and project levels. Organization has a comprehensive and efficient constructability implementation on all projects, ultimately realizing its benefits from proactive implementation efforts, and implementation tracking of constructability benefits is highly valued (O'Connor 2006).

2.2.3 Constructability Knowledge Transfer

Massive knowledge exchange between design and construction personnel is required for optimal constructability. In addition, it is very important to provide the required information at the right time. A Conceptual Product/Process Matrix, which is organized by detail level and project phase, was developed in order to allow the constructability team to identify issues related to constructability at the appropriate time (Pulaski and Horman 2005).

2.2.4 Constructability in Engineering Firms

While the main role of engineering firms is to design facilities, they may do additional works required by clients such as schedule development, studies, and cost estimates. In order to assure that the delivered design is practical and constructible, constructability should be carried out (Nima, Abdul-Kadir and Jafar 1999). However, constructability implementation adds extra costs onto the engineering firm that might reduce their opportunity to do business, but long-term relations with clients and contractors could result from the reputation they built by delivering constructible facilities (Arditi, Elhassan and Toklu 2002).

2.2.5 Barriers to Constructability Implementation

A constructability barrier could be any substantial obstacle that inhibits the program implementation. A study on 62 companies was conducted to identify the most common constructability barriers. it was found that barriers were classified into four categories: cultural, procedural, awareness, and incentive. The study recommended identifying constructability barriers as early as possible for successful implementation (O'Connor 2006).

2.3 CONSTRUCTABILITY IN SAUDI CONSTRUCTION INDUSTRY

A study was conducted in 2003 to examine the barriers of constructability implementation in Saudi Arabia during planning, design and construction phases. The study summarized that there is a good level of constructability awareness among general contractors but extra effort should be performed to break existing barriers (Assaf, Jannadi and Al-Yousif 2003).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter explains the procedures that were followed and methodologies that were applied to achieve this study's objectives. In addition, it outlines the data that were required and the processes by which they were collected.

3.2 REQUIRED DATA

The study used the *Constructability Implementation Guide*, Second Edition 2006, CII as a key reference document by following its proposed research roadmap and questionnaire templates. The following terminologies and definitions were sent along with the developed questionnaire to the participants to ensure common understanding of each term:

Comprehensive Formal Program: constructability is a culture in the organization that has comprehensive and efficient implementation of all projects. The organization realizes its benefits with proactive implementation efforts and the benefits are highly valued;

Conceptual Planning: the early phase of the project which is conducted by the owner using in-house knowledge and resources, or by a planning consultant to develop the scope;

Constructability: the optimum use of construction knowledge and experience in planning, design/engineering, procurement, and field operations to achieve overall project objectives;

Constructability Reports: record kept which lists constructability issues;

Construction: the phase consists of the necessary activities to convert the engineering plans and specifications into physical structures;

Construction Sensitive Schedule: the practice of backward pass scheduling technique that establishes the construction completion date first and then proceeds backward to determine the remaining scheduled activities' durations, including design;

Contracting Strategy: the combination of contract arrangement and contract type selected by the project's owner;

Contractor: the organization that is generally responsible for executing construction activities of the facility in a contractual manner;

Cost: the cost of the construction completion by the end of the project;

Design: the phase consists of both preliminary engineering and detailed engineering;

Engineering Firm: the organization that generally has responsibility for a project's detailed design/engineering;

Formal Program: the organization makes a comprehensive effort to implement constructability with full support at corporate level but some barriers exist;

Informal Program: the organization has an acceptable consciousness and support of constructability but implementation efforts have limited support within the organization;

Lessons Learned: an organized collection of design and construction knowledge and experience gained from past projects that is kept current and readily accessible for incorporation into the constructability program;

Limited Application: the organization has limited consciousness and support of constructability with failure to understand the importance of its adoption. Constructability is implemented on some selected projects without corporate level support;

No Program: the organization has a lack of consciousness and support of constructability and there is no adoption effort;

Owner: the organization providing the project's funding, and final approval and acceptance; and

Project Manager: the person from the owner organization having the authority and responsibility for overall project execution.

3.3 DATA COLLECTION

3.3.1 Source of Data

The required data for this research were requested from project department heads or equivalent working in government and private construction project owner organizations that currently operate in the three major cities of Dammam, Dhahran, and Khobar in Eastern Province, Saudi Arabia, and who expressed an interest in participating in the study. The study used the databases of Eastern Province Emirate for identifying government agencies and Chamber of Commerce – Eastern Province for identifying companies to determine eligible project owner organizations operating in the selected study area. In addition to this, two construction projects that recently completed and implemented constructability were selected and analyzed as case studies.

3.3.2 Tools to Collect Data

The required information was collected by a questionnaire. A sole questionnaire consisting of closed-ended questions with the privilege of allowing more elaboration or specifying other answers was developed to achieve the project objectives and sent to both study samples, the government project owner organizations and the private sector project owner organizations. A cover letter was also prepared to brief recipients about the objectives of the study. Each of both identical questionnaires included the following sections:

1- General information of the organization: seeking general data about the organization itself including years in business, total headcount, type and volume of executed projects, type of contracts, and delivery methods utilized.

2- General information of the respondent: seeking general data about the informant himself including experience, type and level of education, certifications and professional memberships, and their familiarity with constructability concepts.

3- Level of utilization of constructability concepts in the conceptual phase of projects: seeking the actual level of utilization of the eight concepts of constructability developed by CII that were recommended to be practiced during early conceptual planning where the project owner plays a key role in this phase; multiple choice answers were provided as a five-point value scale.

4- Evaluation of corporate level constructability implementation: seeking the actual level of implementation of CII constructability procedure at corporate level to examine which procedures are being applied in terms of corporate culture, personnel and documentation. Similarly, multiple choice answers were provided as a five-point value scale.

5- Evaluation of constructability implementation benefits from owner perspective: seeking data about the actual benefits gained from implementing constructability in terms of innovations, change orders, cost, schedule, safety, quality, and the applicability of incentives. Answering options provided were either numbers or a Yes/No dichotomous scale.

6- Assessment of owner constructability barriers: seeking informants' opinion about project owner constructability barriers developed by CII. The answering option provided was a five-point likelihood scale measuring the level of significance of each barrier.

3.3.3 Methods to Collect Data

The questionnaire was designed in electronic format and sent via email. The sample of participants was selected randomly by using randomizer.org. In addition, case studies were provided by a project manager of one of the participating organizations.

3.4 POPULATION AND SAMPLE SIZE

Kish formula, $n = \frac{s/v^2}{1+\frac{s/v^2}{N}}$ was used to calculate the sample size, where:

n: is the sample size, representing the set of engineering firms / government agencies selected from the population;

s: is the maximum standard deviation as proportion of estimation representing the degree of variability of attributes and is equal to p*q (p = 0.5) which means the population has maximum variability, and q = 1–p;

v: is the level of precision, representing the estimated range of true values of the population (assumed e = ± 10 %); and

N: is the population size, representing the full set of government agencies covered by the study.

N for government project owners = 58, and N for private project owners = 26, after applying the formula on each case, n for government project owners = 17 and n for private project owners = 13 (Kish 1995). Nevertheless, 25 questionnaires were sent for both samples as per the mentioned random selection criteria.

3.5 DATA ANALYSIS

The collected data and responses were analyzed by using qualitative data analysis and simple statistical procedures. Additionally, two different case studies implementing constructability were selected and analyzed explanatorily in depth to identify practical constructability levels in the local industry and allow for further elaboration in the field of the research.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the analyzed information that was obtained from construction project owners in private and governments sectors in the three major cities of Dammam, Khobar, and Dhahran, Saudi Arabia. This chapter also demonstrates the research outcomes in regards to the constructability implementation level of practice among these organizations. The sample sizes of government and private sector project owners are 17 and 13 organizations respectively. However, 25 questionnaires were sent to both samples, 17 organizations from government owners as well as 17 organizations from private sector owners successfully participated and returned their fully answered questionnaires. The outcomes are presented in the same order as the questionnaire for ease of reading and understanding. Participating organizations will be identified by sample instead of their official registration names for confidentiality purposes.

4.2 CHARACTERISTICS OF PARTICIPATING ORGANIZATIONS

This section presents the size, business nature, and work capability of participating organizations that might have a major impact on understanding and implementing constructability concepts.

Table 1 Participating organizations

Owner Type	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Private sector	17	50	17	50
Government sector	17	50	34	100

4.2.1 Experience of Project Owners

The number of years of participating private project owners and government project owners being in construction projects business are distributed in Table 2 and Table 3 respectively. The experience of private owners ranges from 5 years to over 30 years with an average of 23 years, which indicates a high level of experience; while the experience of participating government owners ranges from less than 5 years to over 30 years with an average of 15 years, which indicates a moderate level of experience. This level of experience can ensure the reliability of the provided information.

Table 2 Number of years in business of private organizations

Years in Business	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Less than 5 years	0	0	0	0
5 years to less than 10 years	3	17.6	3	17.6
10 years to less than 20 years	3	17.6	6	35.2
20 years to less than 30 years	0	0	6	35.2
Over 30 years	11	64.7	17	100

Table 3 Number of years in business of government organizations

Years in Business	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Less than 5 years	6	35.3	6	35.3
5 years to less than 10 years	2	11.8	8	47.1
10 years to less than 20 years	2	11.8	10	58.9
20 years to less than 30 years	1	5.9	11	64.8
Over 30 years	6	35.3	17	100

4.2.2 Number of Employees in Project Owner Organizations

The number of employees working in the private project owner organizations is distributed in Table 4. It ranges from fewer than 50 employees to more than 500 employees with an average of 392 employees. The number of employees working in the government project owner organizations is distributed in Table 5. It ranges from fewer than 50 employees to more than 500 employees with an average of 203 employees. This indicates that the participating organizations are large in terms of total headcount and human resources.

Table 4 Total headcount of private organizations

Number of Employees	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Less than 50 employees	1	5.9	1	5.9
50 employees to less than 100 employees	0	0	1	5.9
100 employees to less than 250 employees	3	17.6	4	23.5
250 employees to less than 500 employees	3	17.6	7	41.1
Over 500 employees	10	58.8	17	100

Table 5 Total headcount of government organizations

Number of Employees	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Less than 50 employees	6	35.3	6	35.3
50 employees to less than 100 employees	4	23.5	10	58.8
100 employees to less than 250 employees	0	0	10	58.8
250 employees to less than 500 employees	4	23.5	14	82.3
Over 500 employees	3	17.6	17	100

4.2.3 Number of Projects Executed Annually

The number of construction projects executed annually by private project owner organizations is distributed in Table 6. It ranges from less than 1 project per year to more than 50 projects per year with an annual average of 26 projects. The number of construction projects executed annually by government project owner organizations is distributed in Table 7. It ranges from less than 1 project per year to more than 50 projects per year with an annual average of 23 projects. This indicates that most participating organizations are executing a large number of construction projects annually.

Table 6 Number of projects executed by private project owners

Number of Projects	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Less than 1 project	1	5.9	1	5.9
1 project to less than 5 projects	2	11.8	3	17.7
5 projects to less than 15 projects	4	23.5	7	41.2
15 projects to less than 50 projects	6	35.3	13	76.5
Over 50 projects	4	23.5	17	100

Table 7 Number of projects executed by government project owners

Number of Projects	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Less than 1 project	2	11.8	2	11.8
1 project to less than 5 projects	4	23.5	6	35.3
5 projects to less than 15 projects	3	17.6	9	52.9
15 projects to less than 50 projects	3	17.6	12	70.5
Over 50 projects	5	29.4	17	100

4.2.4 Type of Projects Executed

The participating organizations demonstrated that they execute all types of construction projects such as buildings (commercial, educational, etc.), infrastructures (highways, water network, etc.), and industrials (power plants, sewage treatment plants, etc.). Table 8 illustrates that more than 50% of private sector projects are industrial type. Table 9 illustrates hat more than 50% of government sector projects are buildings type.

Table 8 Type of projects executed by private project owners

Type of Project	Percent per Respondent																	Total	Percent
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Buildings	30	70	30	10	90	30	10	20	5	4	40	100	5	10	33	10	0	497	29.2
Infrastructure	20	15	10	20	10	30	10	0	95	0	40	0	5	10	34	20	20	339	20
Industrial	50	15	60	70	0	40	80	80	0	96	20	0	90	80	33	70	80	864	50.8
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1700	100

Table 9 Type of projects executed by government project owners

Type of Project	Percent per Respondent																	Total	Percent
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Buildings	30	35	40	100	20	100	20	10	75	55	30	80	100	100	0	100	80	975	57.4
Infrastructure	70	35	40	0	0	0	80	80	25	35	40	20	0	0	100	0	20	545	32.1
Industrial	0	30	20	0	80	0	0	10	0	10	30	0	0	0	0	0	0	180	10.6
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1700	100

4.2.5 Type of Contracts Utilized

The participating private project owners indicated that they execute all common types of construction contracts such as fixed price, unit rate, and cost plus. Table 10 exemplifies that around 60% of private sector contracts are fixed price type which might be more suitable for local industrial type projects that represent the major segment among private projects as mentioned earlier. Table 11 shows that around 60% of private sector contracts are unit rate type which might be more suitable for the local building type projects as they represent the majority percentage among government projects.

Table 10 Type of contracts utilized by private project owners

Type of Contract	Percent per Respondent																	Total	Percent
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Fixed Price	0	0	80	80	95	100	100	60	80	80	70	75	80	15	80	10	10	1015	59.7
Unit Rate	100	100	15	10	5	0	0	20	20	20	20	15	10	80	0	90	80	585	34.4
Cost Plus	0	0	5	10	0	0	0	20	0	0	10	10	10	5	20	0	10	100	5.9
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1700	100

Table 11 Type of contracts utilized by government project owners

Type of Contract	Percent per Respondent																	Total	Percent
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Fixed Price	100	0	50	0	40	100	0	80	60	90	0	20	0	10	0	0	20	570	33.5
Unit Rate	0	100	50	70	0	0	100	20	25	10	100	80	100	90	100	100	75	1020	60
Cost Plus	0	0	0	30	60	0	0	0	15	0	0	0	0	0	0	0	5	110	6.5
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1700	100

4.2.6 Type of Delivery Methods Pursued

Private sector participants pointed out that they execute all common types of project delivery methods such as traditional method, turnkey, and build-operate-transfer. Table 12 shows that around 48% of private sector owners prefer turnkey project delivery method where a sole main contractor develops the detailed design and executes the construction. Seymour has claimed that turnkey type delivery method is used the most in private projects, particularly those involving capital investment (Greenfield 1982). This might be the case in local private industrial projects. Similarly, government sector participants have demonstrated that they perform all common types of project delivery methods also. Nevertheless, Table 13 shows that around 80% of government sector owners usually execute the traditional delivery method where the engineering phase is performed separately by a standalone engineering firm that then hands it over to a construction contractor for execution through a bidding process. This roadmap resulted from a government policy that empowers the separation between design and construction.

Table 12 Type of delivery methods pursued by private project owners

Type of Delivery Method	Percent per Respondent																	Total	Percent
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Traditional	100	50	0	80	0	100	0	30	100	20	20	100	20	15	70	0	50	755	44.4
Turnkey	0	50	100	0	90	0	100	30	0	80	80	0	70	80	0	100	40	820	48.2
BOT	0	0	0	20	10	0	0	40	0	0	0	0	10	5	30	0	10	125	7.4
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1700	100

Table 13 Type of delivery methods pursued by government project owners

Type of Delivery Method	Percent per Respondent																	Total	Percent
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Traditional	95	95	90	100	100	0	0	85	70	100	100	100	100	90	50	100	80	1355	79.7
Turnkey	5	5	10	0	0	100	100	10	25	0	0	0	0	10	50	0	20	335	19.7
BOT	0	0	0	0	0	0	0	5	5	0	0	0	0	0	0	0	0	10	0.6
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1700	100

4.2.7 Size of Projects Executed

Figure 1 shows that most private sector projects are large, costing more than SR100MM, which reflects the scope complexity and the high technology involvement of industrial type projects, and the cost of risk contingency associated with fixed price contracts that contractors usually add to mitigate unforeseen conditions. Figure 2 shows that most of the government sector projects are small size, costing less than SR25MM, which reflects the scope simplicity of buildings and infrastructure type projects and the low risk contingencies involved in unit rate type contracts.

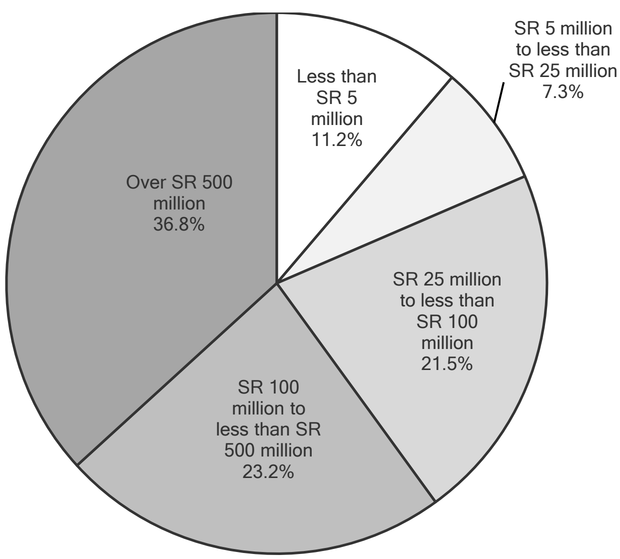

Figure 1 Average size of projects executed in private sector

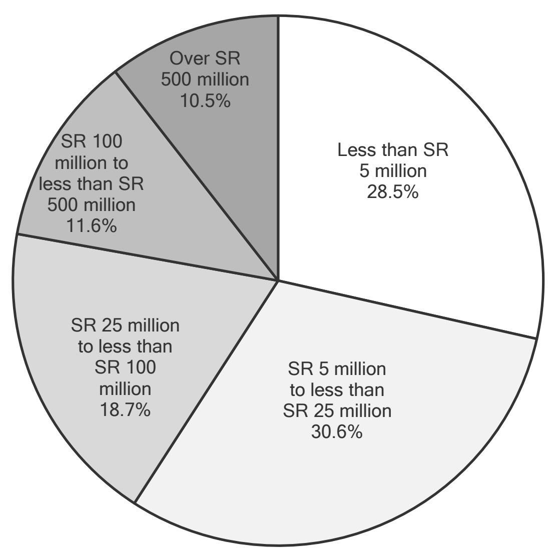

Figure 2 Average size of projects executed in government sector

4.2.8 Inclusion of Constructability in Construction Bidding Documents

The participating private project owners have indicated that around 71% of their project bidding documents often provide a section exclusively addressing constructability issues. Nevertheless, only 18% of government projects include constructability in bidding deliverables. Obviously, one cannot tell yet whether a constructability effort might be implemented among government projects, but implementation is definitely not empowered contractually.

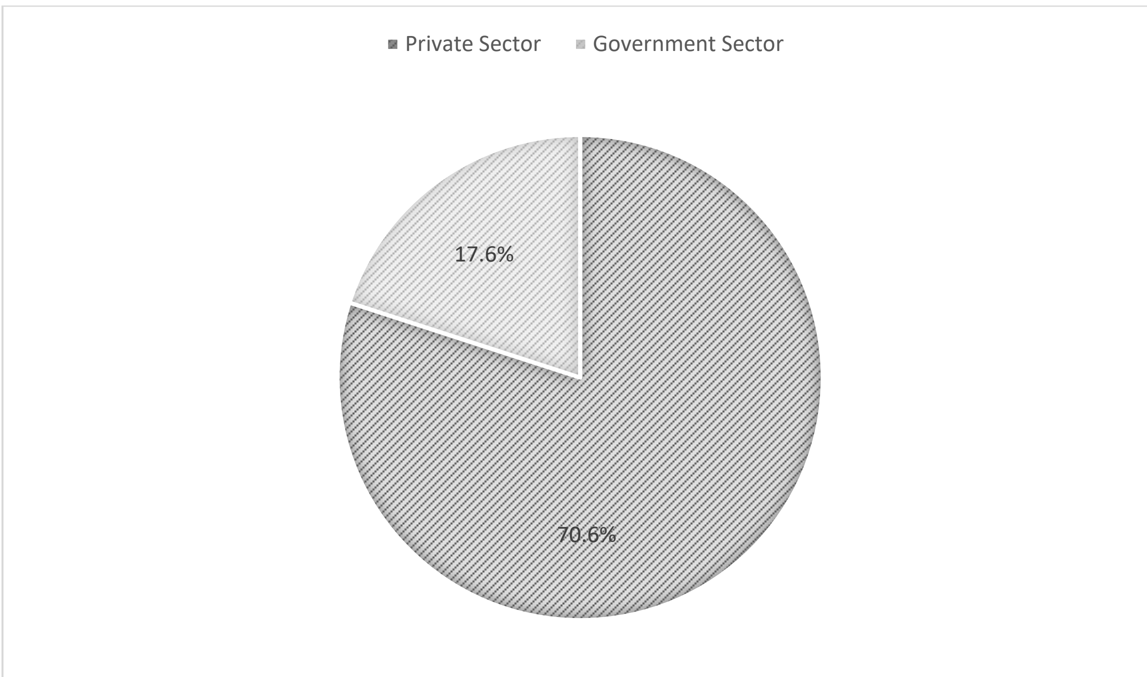

Figure 3 Organizations offer a specific section in design bid documents addressing constructability

4.3 CHARACTERISTICS OF KEY INFORMANTS

This section presents the experience, education, and the level of familiarity with constructability implementation of the participating informants which might have a major impact on the quality of the provided information.

4.3.1 Experience of Informants

The number of years of key participating informants from the private and government project owners operating in the construction industry are distributed in Table 16 and Table 17 respectively. In the private sector, experience ranges from 5 years to more than 30 years with an average of 22 years, which indicates a high level of construction experience. On the other hand, the number of years of participating key informants from government ranges from less than 5 years to more than 30 years with an average of 14 years. This level might indicate moderate experience which also gives an acceptable mark in their understanding and familiarity of constructability.

Table 14 Experience of private project owner informants

Years of Experience	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Less than 5 years	0	0	0	0
5 years to less than 10 years	2	11.8	2	11.8
10 years to less than 20 years	2	11.8	4	23.6
20 years to less than 30 years	12	70.6	16	94.2
Over 30 years	1	5.9	17	100

Table 15 Experience of government project owner informants

Years of Experience	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Less than 5 years	5	29.4	5	29.4
5 years to less than 10 years	2	11.8	7	41.2
10 years to less than 20 years	5	29.4	12	70.6
20 years to less than 30 years	4	23.5	16	94.1
Over 30 years	1	5.9	17	100

4.3.2 Positions of Informants

The positions of key participating informants from private project owners are listed in Table 18. They range from site engineer up to general manager position; 70% of the informants at the time of study execution were in key positions which can ensure the reliability of the information provided. Key positions from government participants were fewer; they ranked 59% which can ensure the quality of provided information too. The positions, as shown in Table 20, range from field engineer up to project department head.

Table 16 Positions of informants from private project owners

Position	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Project Manager	9	52.9	9	52.9
Head of Department	2	11.8	11	64.7
Field Engineer	1	5.9	12	70.6
Planning Manager	1	5.9	13	76.5
Discipline Lead	1	5.9	14	82.3
Head Architect	1	5.9	15	88.2
Site Engineer	1	5.9	16	94.1
General Manager	1	5.9	17	100

Table 17 Positions of informants from government project owners

Position	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Project Engineer	3	17.6	3	17.6
Resident Engineer	2	11.8	5	29.4
Project Manager	6	35.3	11	64.7
Construction Manager	1	5.9	12	70.6
Head of Department	2	11.8	14	82.4
PMO Manger	1	5.9	15	88.3
Engineer Officer	1	5.9	16	94.2
Field Engineer	1	5.9	17	100

4.3.3 Education of Informants

As shown in Table 20, 94% of the informants hold a bachelor’s degree or higher which is important for ensuring they have the necessary education to understand and contribute toward the study. They expressed that 47% of the informants are civil engineers, 18% are mechanical engineers, and 13% are industrial engineers. They expressed also that 77% of them hold well recognized certificates such as Project Management Professional (PMP) and Professional Engineering (PE); also, 71% are members of professional associations such as ASCE, PMI and ACI. This indicates an excellent level of proficiency and capability in project management and engineering specializations. Government project owners’ education is listed in Table 21. They all hold either an MSc. or BSc.; 77% of the informants are civil engineers, 12% are electrical engineers and 6% are mechanical engineers, while 47% of the informants hold a PMP, PE or both. In addition, 41% are members of professional associations such as ASCE, PMI and ACI which also indicates a good level of proficiency.

Table 18 Education of informants from private project owners

Degree	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Diploma	1	5.9	1	5.9
BSc.	13	76.5	14	82.4
MSc.	3	17.6	17	100

Table 19 Education of informants from government project owners

Degree	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Diploma	0	0	0	0
BSc.	14	82.4	14	82.4
MSc.	3	17.6	17	100

4.3.4 Level of Familiarity in Constructability Concepts

The level of familiarity in constructability concepts for the participating key informants from private and government project owner organizations is shown in figure 4. In fact, 88% of private sector informants have a moderate familiarity level or higher, 60% among government informants have that level of familiarity. Both groups of participants have the minimum requirement of understanding to respond to this questionnaire. The variance in constructability understanding might be affected by the variance in experience as stated in 4.3.1.

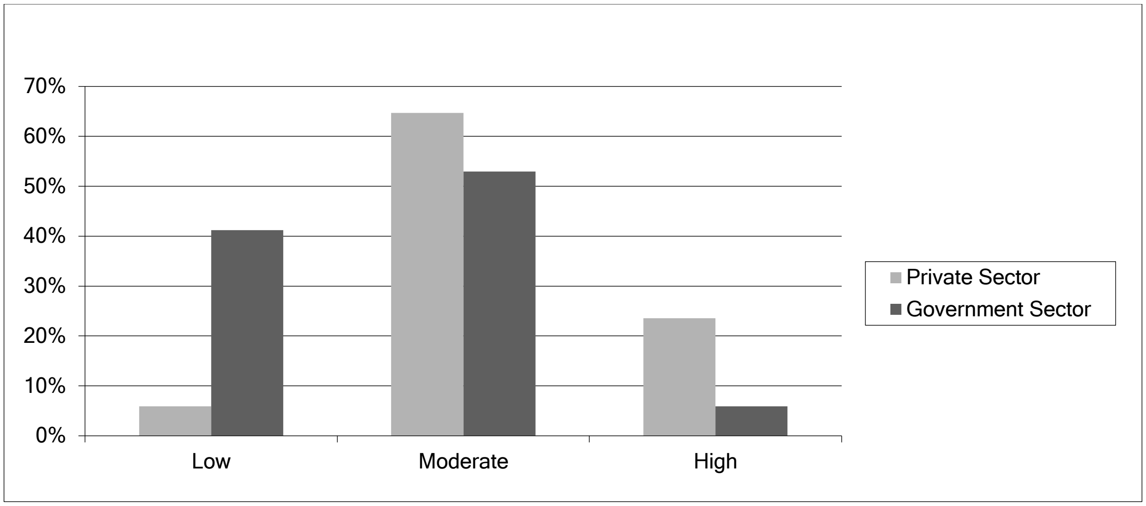

Figure 4 level of familiarity in constructability concepts and constructability implementation

4.4 CONSTRUCTABILITY CONCEPTS DURING THE CONCEPTUAL PLANNING PHASE

This section demonstrates the level of utilization of the following potential constructability concepts developed by CII that project owners usually apply during the conceptual planning phase of construction projects:

- Constructability is a section of official project execution plan document.
- Early planning phase involves personnel who have construction experience.
- Constructability is considered in the contracting strategy development.
- Schedule of the project is sensitive to the requirements of construction.
- Major design approaches consider the methodology of construction, i.e., pre-assembly.
- Construction site layout provides an efficient construction.
- Formation of a constructability team occurs as early as the project is initiated.
- The use of advanced IT applications throughout project phases.

The questionnaire used a five-point rating scale for constructability concepts evaluation in order to allow the respondents to answer naturally. Each option has a weight that varies from 1 to 5 as follows:

- Very High = 5 points
- High = 4 points
- Moderate = 3 points
- Low = 2 points
- Very Low = 1 point

Answers were analyzed to provide the results as mean and standard deviation for each concept utilization level.

4.4.1 Analysis of Data Variance

ANOVA is a statistical tool that is solely used to estimate the variation between different groups of data. As this study relies on a single common factor in each group, either private and government, one-way ANOVA was applied (Ellison, Farrant and Barwick 2009). First, the null hypothesis H_0 was set to be tested: the population means of all groups are equal or $\mu 1 = \mu 2$. Following is an explanation of ANOVA compositions:

Sum of Squares (SS): is a variation from the mean measure or the summation of the squares of these differences;

Degree of Freedom (df): If the total number of independent items of data equals N, then df equals N–1;

Mean Square (MS): is the division of the summation of between and within-group squares by df;

F Ratio (F): is the variance of the group means over the mean of the within-group variances;

P Value: is the tail area of a probability distribution diagram;

F Critical Value (F crit): is a critical value of the ANOVA test, given by the provided df and the significance level α;

Significance Level (α): is the probability of rejecting the hypothesis if it is true, confidence interval of 95% is commonly used, hence α= 100%-95% = 5% 0.05; and

Correlation: measures the degree of movement relation of two variables, +1 correlation means variables increase together, –1 correlation means the opposite, and Zero means that there is no correlation.

The first ANOVA and correlation analysis were conducted to evaluate the variance between two sets of data, the utilization of constructability concepts during the conceptual planning phase in private projects and in government projects. The output is tabulated in Table 20.

Table 20 Data variance of constructability concepts utilization

Source of Variation	SS	Df	MS	F	P-value	F crit	Correlation
Between Groups	5.748006	1	5.748006	48.89431	6.32311E-06	4.60011	0.377096

Since F is greater than F crit, the null hypothesis is rejected which means the means of the two populations are not equal. A correlation of 0.38 indicates that there is a random correlation between the two sets of data. This resulted in a second hypothesis H_1: H1: one of the means is different.

4.4.2 Level of Utilization of Constructability Concepts by Project Owners

Table 21 and 22 show the responses mean, standard deviation, and the ranking of each constructability concept utilized by project personnel in the private sector and government sectors respectively during conceptual planning stage. In private sector organizations, the answers were located between 3.00 and 4.00 with an average of 3.40 which demonstrates a moderate level of utilization of constructability concepts. They indicated the importance of construction activities consideration during the development of the overall project schedule, the capitalization on the significance of site layouts, and the intensive involvement of technology solutions. However, they abstemiously did not consider constructability in official project documents in addition to the lack of a dedicated constructability team which might negatively impact the expected implementation from contractors. Probably, the very high score realized in concept 4 is due to the nature of the operating business model of profitable companies; if the facility does not meet its on-stream milestone, no products will be developed and hence no revenues will be generated. In contrast, devoting a constructability team possibly requires more human capital, which might result in higher overheads. Project organizations in companies usually use matrix hierarchy where personnel can work laterally in manifold tasks under different managers, so companies receive optimum efficiency of their employees (Griffin 2007); (Harrison and Lock 2004). Understaffing might be another reason. Scoring high in the concept of the schedule of the project is sensitive to the requirements of construction which might be due to the importance of having projects on-stream as early as possible, to support sales and generate revenues.

Table 21 Level of utilization of constructability concepts by private project owners

S.N.	Concept	Mean	Standard Deviation	Rank
1	Constructability is a section of official project execution plan document.	3.06	1.20	7
2	Early planning phase involves personnel who have construction experience.	3.35	1.06	5
3	Constructability is considered in the contracting strategy development.	3.18	0.81	6
4	Schedule of the project is sensitive to the requirements of construction.	4.00	1.13	1
5	Major design approaches consider the methodology of construction i.e. pre-assembly.	3.41	0.94	4
6	Construction site layout provides efficient construction.	3.65	1.00	2

7	Formation of constructability team occurs as early as the project is initiated.	3.00	0.79	8
8	The use of advanced IT applications throughout project phases.	3.53	1.33	3

As shown in Table 22, government sector respondents indicated that the answers are located between 1.76 and 2.88 with an average of 2.20 which demonstrates a low level of utilization of constructability concepts. Despite the low scores they ranked, they give the highest attention toward the importance of an efficient construction site layout and the early consideration of a construction method which might be considered as common engineering sense and part of the proactive project planning. However, they do not enforce the implementation in official project documents and contracts due to the utilization of standard government contracts that do not provide an exhibit for constructability implementation as described in 4.2.8.

Table 22 Level of utilization of constructability concepts by government project owners

S.N.	Concept	Mean	Standard Deviation	Rank
1	Constructability is a section of an official project execution plan document.	1.76	0.90	8
2	Early planning phase involves personnel who have construction experience.	2.18	1.27	5
3	Constructability is considered in the contracting strategy development.	1.77	1.03	7
4	Schedule of the project is sensitive to the requirements of construction.	2.24	1.25	4
5	Major design approaches consider the methodology of construction i.e. pre-assembly.	2.35	1.32	2
6	Construction site layout provides an efficient construction.	2.88	1.27	1
7	Formation of constructability team occurs as early as the project is initiated.	2.12	1.26	6
8	The use of advanced IT applications throughout project phases.	2.29	1.05	3

4.5 CONSTRUCTABILITY IMPLEMENTATION EFFECTIVENESS AT CORPORATE LEVEL

This section presents the maturity of the permanent program of constructability implementation at corporate level in terms of corporate culture, personnel, and documentation which is significant in streamlining the implementation throughout the project lifecycles for successful constructability. The selected classification criteria are based on CII and a five-point rating scale as follow:

- Comprehensive Formal Program = 5 points, where the implementation is comprehensive and operative, real with confidence, and proactive efforts are shown; it is part of the organizational culture, and there is the presence of a widespread tracking system.
- Formal Program = 4 points, where the implementation is almost comprehensive with availability of corporate support, resistance is minimum and some barriers exist, and the tracking system emphasizes quantitative results only.
- Informal Program = 3 points, where constructability awareness exists but there is the presence of constructability constraints and barriers, and lack of a benefit tracking system.
- Limited Application = 2 points, where limited understanding of constructability exists, limited management support, poor constructability implementation proactivity, constructability is not understood among personnel, efforts are on a project-by-project basis in case of constructability adoption with no corporate support, and lack of constructability knowledge sharing.

- No Program = 1 point, where there is a lack of constructability understanding, lack of corporate support and no constructability efforts are performed.

Three points or above represents diverse levels of successful constructability results. Comprehensive Formal Program is the most preferred and recommended level of implementation while No Program is the least.

4.5.1 Analysis of Data Variance

As shown in Table 23, the null hypothesis H_0: $\mu 1 = \mu 2$ is rejected too as F is greater than F crit. In addition, both sets of data are not correlated.

Table 23 Data variance of constructability in corporate culture

Source of Variation	SS	Df	MS	F	P-value	F crit	Correlation
Between Groups	0.585938	1	0.585938	6.865998	0.015626	4.30095	0.385203

4.5.2 Constructability Implementation in Corporate Culture

Constructability in corporate culture measures the cross-organizational level of appreciation towards constructability efforts, the presence of a decidedly pervasive written constructability policy that ensures corporate commitments, and a level of support from top management for the total constructability program, including its barriers resolution.

Table 24 and Table 25 illustrate the mean response, standard deviation and ranking of each parameter of constructability culture at corporate level in private and government project owner organizations.

In private organizations, it is indicated that the answers are located between 2.82 and 3.29 with an average of 3.03 which demonstrates an informal implementation program in constructability culture among private organizations. This indicates that organizations have an acceptable consciousness and support of constructability but implementation efforts are limited (O'Connor 2006). They claimed that their management provides the required support and they recognized them for their individual efforts toward constructability implementation.

Table 24 Constructability culture in private project owners

S.N.	Parameters	Mean	Standard Deviation	Rank
1	Recognition and designation of constructability efforts.	3.06	1.29	2
2	Presence of a known and written constructability policy stating the organization's commitment.	2.94	1.19	3
3	Management are aware about and support constructability.	3.29	1.05	1
4	Recognition of efforts that break constructability implementation barriers and problems.	2.82	1.07	4

In government organizations, it is indicated that the answers are located between 2.59 and 3.06 with an average of 2.83 which demonstrates limited application in constructability culture among government organizations. This means a limited understanding of constructability exists, limited management support is provided, and poor constructability implementation proactivity is being implemented on a case by case basis (O'Connor 2006). They argued that their management supports constructability, however incentives are not provided most probably due to the complicated and centralized government awarding system.

Table 25 Constructability culture in government project owners

S.N.	Parameters	Mean	Standard Deviation	Rank
1	Recognition and designation of constructability efforts.	2.59	1.33	4
2	Presence of a known and written constructability policy stating the organization's commitment.	3.00	1.32	2
3	Management are aware about and support constructability.	3.06	1.59	1
4	Recognition of efforts that break constructability implementation barriers and problems.	2.65	1.37	3

4.5.3 Constructability Implementation in Personnel

Constructability in personnel measures the total constructability commitment toward constructability teams in terms of designating an executive level employee as a constructability sponsor accountable for the implementation program, the presence of a cross-functional constructability organization in the corporate hierarchy, the availability of a responsibility matrix among implementation stakeholders and how frequent constructability training is offered for personnel.

Table 26 and Table 27 illustrate the mean response, the standard deviation and the ranking of each parameter of constructability personnel at corporate level in private and government project owner organizations.

It is indicated that the private organizations' answers are located between 2.41 and 2.88 with an average of 2.63 which demonstrates a limited implementation program in constructability personnel among private organizations where constructability awareness exists; nevertheless, there is a presence of constructability constraints (O'Connor 2006). They argued that they require additional training and development in contractibility.

Table 26 Constructability personnel in private project owners

S.N.	Parameters	Mean	Standard Deviation	Rank
1	Frequent personnel training in constructability.	2.41	1.33	3
2	Designation and support from constructability sponsor.	2.59	1.28	2
3	Presence of an effective constructability organization.	2.88	1.11	1

In government project owner organizations, it is indicated that the answers are located between 2.35 and 2.71 with an average of 2.49 which demonstrates a limited application implementation program in constructability personnel also (O'Connor 2006).

Table 27 Constructability personnel in government project owners

S.N.	Parameters	Mean	Standard Deviation	Rank
1	Frequent personnel training in constructability.	2.35	1.37	3
2	Designation and support from constructability sponsor.	2.41	1.50	2
3	Presence of an effective constructability organization.	2.71	1.61	1

4.5.4 Constructability Implementation in Documentation and Tracking

Constructability in documentation measures the maturity of constructability procedures and method statements, the availability of an easily accessible lesson learned system, the effectiveness of constructability knowledge sharing, the formality of arbitrating to constructability in contracts and the efficacy of constructability implementation benefit tracking.

Table 28 and Table 29 illustrate the mean response, the standard deviation and the ranking of each parameter of constructability documentation and benefit tracking at corporate level in private and government project owner organizations.

It is indicated that the answers are located between 2.82 and 3.53 with an average of 3.16 which demonstrates an informal implementation program in documenting and tracking constructability benefits and efforts among private organizations. This indicates a lack of the presence of any reliable constructability benefit tracking system (O'Connor 2006). They argued that even though they have a corporate documentation system, the use of modern IT applications for ease of tracking is limited, companies perhaps capitalizing on cost–benefit analysis, and they might not invest in expensive IT solutions if no proven benefits would be realized.

Table 28 Constructability documentation and tracking in private project owners

S.N.	Parameters	Mean	Standard Deviation	Rank
1	Documentation of constructability procedures on the corporate level.	3.53	1.18	1

2	Presence of lessons learned system to communicate constructability.	3.47	1.12	2
3	Use of knowledge of advanced technologies of construction.	2.94	1.25	4
4	Contract documents refer to constructability.	3.06	1.09	3
5	Efforts to track the savings or other optimizations of constructability.	2.82	1.01	5

On the other hand, government organizations indicated that the answers are located between 2.35 and 2.94 with an average of 2.66 which demonstrates a limited implementation program. It means these organizations have a lack of constructability knowledge sharing due to the absence of a lesson learned system as well as the benefit of a tracking system (O'Connor 2006).

Table 29 Constructability documentation and tracking in government project owners

S.N.	Parameters	Mean	Standard Deviation	Rank
1	Documentation of constructability procedures on the corporate level.	2.88	1.54	2
2	Presence of lessons learned system to communicate constructability.	2.35	1.27	5
3	Use of knowledge of advanced technologies of construction.	2.94	1.52	1
4	Contract documents refer to constructability.	2.59	1.58	3
5	Efforts to track the savings or other optimizations of constructability.	2.53	1.50	4

4.6 CONSTRUCTABILITY IMPLEMENTATION BENEFITS AT PROJECT LEVEL

This section presents the tangible benefits and process improvements positively triggered by implementing a constructability program on construction projects during the conceptual planning, design, procurement, and construction phases.

4.6.1 Analysis of Data Variance

As shown in Table 30, the null hypothesis H_0: $\mu 1 = \mu 2$ is accepted as F is smaller than F crit. Means of both sets of data are correlated.

Table 30 Data variance of constructability benefits at project level

Source of Variation	SS	df	MS	F	P-value	F crit	Correlation
Between Groups	6.780663	1	6.780663	0.370436	0.552514	4.60011	0.940858

4.6.2 Improvements in Change Order Values

Participants have demonstrated that there is a decrease by around 40% in change order values if constructability program is efficiently applied on projects. In private sector projects, the baseline percentage of change orders value to the total projects value is 24.94% for projects that do not implement constructability; this is reduced to 15.24% after adopting constructability. Moreover, in government projects constructability has reduced the ratio from 17.47% to 10.06%.

4.6.3 Improvements in Project Schedule

Participants demonstrated that a significant schedule optimization resulted from constructability implementation. They proved that the key player in the efficiency of the results is the stage of implementation. The major schedule optimization happens when implementing the constructability program as early as when the project is initiated. In private sector projects, owners claimed that when constructability practices are adopted at the conceptual planning phase, this would result in 18.53% schedule optimization, at detailed design phase it would result in around 12.41% optimization; however, if applied during construction, it would optimize the schedule by only 7.94%. Similarly, government project owners showed that if constructability is implemented during conceptual planning, this would result in 14.59% schedule optimization and if implemented during detailed design or construction, it would result in 12.06% or 6.06% schedule optimization respectively.

4.6.4 Improvements in Project Cost

Analogously to schedule improvement, the results have showed a substantial capital cost savings associated with constructability implementation. The highest cost optimization resulted from implementing constructability during the conceptual planning phase where the majority of unforeseen conditions can be tackled and corrected effortlessly. Participating construction project owners showed that constructability implementation in the conceptual planning phase has saved 13.24% of the cost of private sector projects and 14.95% of the cost of government sector projects. In the design and construction phases, constructability saved project costs on average by 10.29% and 4.35% respectively in private sector projects and 11.47% and 5.76% respectively in government sector projects.

4.6.5 Improvements in Total Quality

Respondents provided the percentage of improvement in quality indexes for projects that applied constructability. In private sector projects, the average for quality improvement is around 16.88% and in government projects around 13.29%.

4.6.6 Improvements in Total Safety

Respondents also provided the percentage of improvement in safety indexes for projects that applied constructability. In private sector projects, the average of safety improvement is around 17.06% and in government projects around 14.94%.

4.6.7 Innovative Methods and Incentives for Design and Construction

Participants from private project owner originations demonstrated that 82.4% of them give the designer consultant or the construction contractor the privilege of incentives if they effectively achieved cost or schedule optimizations and 58.8% having the inventiveness of innovating construction methods that are more suitable for their construction operation needs; this encourages their contractors to take the initiative of implementing value improvement practices, i.e. constructability, and do construction in an innovative manner. Nevertheless, government project owners indicated that only 23.5% of them are exploiting incentives and only 17.6% have practiced innovation in construction methods.

4.7 CONSTRUCTABILITY IMPLEMENTATION BARRIERS

This section presents the level of significance of constructability implementation barriers in construction project owner organizations in terms of the total complacency with the status quo, lack of documentation, lack of understanding constructability, perception of constructability being done through other value improvement practices and design coordination, as well as constructability having no benefits, unwillingness to expend additional cost, effort, and time in early project stages, and lack of commitment toward the constructability program. The barriers were classified by root and described in indications of their existence by utilizing Constructability Barrier Assessment Checklists developed solely by CII for construction project owner organizations. The questionnaire used a five-point rating scale for constructability barriers evaluation in order to allow respondents to provide their opinions naturally. Each option has a weight that varies from 1 to 5 as follows:

- Very High = 5 points
- High = 4 points
- Moderate = 3 points
- Low = 2 points

- Very Low = 1 point

4.7.1 Analysis of Data Variance

As shown in Table 31, the null hypothesis H_0: $\mu1 = \mu2$ is rejected as F is greater than F crit. In addition, both sets of data are not correlated.

Table 31 Data variance of constructability barriers

Source of Variation	SS	df	MS	F	P-value	F crit	Correlation
Between Groups	1.790817	1	1.790817	10.3386	0.002285	4.03431	0.260186

4.7.2 Complacency with the Status Quo

Table 32 and Table 33 illustrate the mean response, the standard deviation, and the ranking of each constructability barrier of the complacency with the status quo, in private and government project owners, respectively. In the private sector, it is indicated that the answers are located between 3.12 and 4.17 with an average of 3.51 which demonstrates this barrier has a moderate level of significance in their organization. As we requested them to particularly score the total complacency with the status quo as a standalone barrier, the score of 3.29 they ranked was comparable to the overall average.

Table 32 Complacency with the status quo in private owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total complacency with the status quo	3.29	0.85	4
2	Resistance to change.	4.17	0.81	1
3	Non-innovative approaches are being utilized.	3.40	1.18	3
4	Risk unfavorable attitude toward trying something new.	3.59	0.62	2
5	No rewards for intelligent risk taking.	3.12	0.86	5

Also, government representatives indicated answers between 3.35 and 4.18 with an average of 3.76 which demonstrates this barrier has a moderate level of significance also. The calculated mean and their input on the total complacency with the status quo are almost the same.

Table 33 Complacency with the status quo in government owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total complacency with the status quo	3.82	1.20	3
2	Resistance to change.	4.18	1.17	1
3	Non-innovative approaches are being utilized.	3.35	1.22	5
4	Risk unfavorable attitude towards trying something new.	3.88	1.27	2
5	No rewards for intelligent risk taking.	3.59	1.23	4

Both samples argued that resistance to change and risk unfavorable attitude towards trying something new have the highest significance toward constructability implementation. Change resistance is an organization culture that might be driven by several factors including: an incorrect initial observation about trying something new, low motivation, and lack of creativeness (Pardo del Val and Martínez Fuentes 2003).

4.7.3 Lack of Documentation

Table 34 and Table 35 illustrate the mean response, the standard deviation, and the ranking of each constructability barrier of the lack of documentation in private and government project owners, respectively. In the private sector, it is indicated that the answers are located between 3.06 and 3.29 with an average of 3.18 which demonstrates this barrier has a moderate level of significance. Their input ranking and calculated mean are almost similar.

Table 34 Lack of documentation in private owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total lack of documentation.	3.06	1.20	2
2	No formal system for documenting lessons learned.	3.29	1.21	1

On the other hand, government project owners classified it as a highly significant barrier. They indicated answers between 4.41 and 4.65 with an average of 4.53 which demonstrates this barrier has a high level of significance. Both their input and the calculated means have a high score, so it seems they have concerns about the practice of the current documentation process and the lack of a lessoned learned system.

Table 35 Lack of documentation in government owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total lack of documentation.	4.41	0.94	2
2	No formal system for documenting lessons learned.	4.65	0.49	1

4.7.4 Lack of Understanding Constructability Concepts

Table 36 and Table 37 illustrate the mean response, the standard deviation, and the ranking of each constructability barrier of the lack of understanding constructability concepts in private and government project owners, respectively. Private project owners indicated answers between 3.24 and 4.00 with an average of 3.53 which demonstrates this barrier has a moderate level of significance. The calculated mean and their input on the total lack of understanding constructability concepts are almost the same. They see ineffective design coordination as a highly significant barrier having negative implications toward the implementation. However, constructability implementation itself can overcome this barrier; if constructability is a process that must be implemented, effective coordination and the integration of design teams will occur (Robert, et al. 2010).

Table 36 Lack of understanding constructability concepts private owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total lack of understanding constructability concepts.	3.41	1.06	3
2	Constructability roadmap is not available.	3.47	1.12	2
3	Constructability definition is not known.	3.24	1.30	4
4	Ineffective coordination through design.	4.00	1.12	1

Government project owners indicated between 2.88 and 4.06 with an average of 3.44 which demonstrates this barrier has a moderate level of significance also. The calculated mean and their input on the total lack of understanding constructability concepts are almost the same. They highlight the unavailability of a constructability roadmap as a highly significant barrier. This might have resulted from the low contractibility implementation at corporate level in government organizations.

Table 37 Lack of understanding constructability concepts in government owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total lack of understanding constructability concepts.	3.65	1.00	2
2	Constructability roadmap is not available.	4.06	1.03	1
3	Constructability definition is not known.	3.17	1.33	3
4	Ineffective coordination through design.	2.88	1.36	4

4.7.5 Perception of We Are Doing Constructability

Table 38 and Table 39 illustrate the mean response, the standard deviation, and the ranking of each constructability barrier of the perception of we are doing constructability in private and government project owners respectively. It is indicated that the answers are located between 2.71 and 3.03 with an average of 2.87 which demonstrates this barrier has a low level of significance. The calculated mean and their input are almost the same.

Table 38 Perception of we are doing constructability in private owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total perception of we are doing constructability.	2.71	0.78	3
2	Routine design practices can achieve constructability.	2.88	0.75	2
3	Value engineering equals constructability.	3.03	0.99	1

In government project owners, it is indicated that the answers are located between 3.47 and 3.82 with an average of 3.67 which demonstrates this barrier has a moderate level of significance.

Table 39 Perception of we are doing constructability in government owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total perception of we are doing constructability.	3.71	0.99	2
2	Routine design practices can achieve constructability.	3.82	0.88	1
3	Value engineering equals constructability.	3.47	1.07	3

4.7.6 No Proven Benefits of Constructability

Table 40 and Table 41 illustrate the mean response, the standard deviation, and the ranking of each constructability barrier of the perception of no proven benefits of constructability in private and government project owners. It is indicated that the answers in the private sector are located between 2.12 and 2.71 with an average of 2.43 which demonstrates this barrier has a low level of significance.

Table 40 No proven benefits of constructability in private owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Totally, there are no proven benefits of constructability.	2.12	0.78	3
2	It is too expensive to conduct constructability.	2.47	0.80	2
3	Senior management is not convinced of the cost benefits of constructability.	2.71	1.16	1

In government project owners, it is indicated that the answers are located between 3.00 and 3.41 with an average of 3.22 which demonstrates this barrier has a moderate level of significance.

Table 41 No proven benefits of constructability in government owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Totally, there are no proven benefits of constructability.	3.00	1.12	3
2	It is too expensive to conduct constructability.	3.24	1.09	2
3	Senior management is not convinced of the cost benefits of constructability.	3.41	1.06	1

4.7.7 Unwillingness to Expend Additional Cost, Effort, and Time in Early Project Stages

Table 42 and Table 43 illustrate the mean response, the standard deviation, and the ranking of each constructability barrier of the unwillingness to expend additional cost, effort, and time in early project stages in private and government project owners, respectively. In the private sector, it is indicated that the answers are located between 3.24 and 3.53 with an average of 3.36 which demonstrates this barrier has a moderate level of significance.

Table 42 Unwillingness to expend additional cost, effort, and time in early project stages in private owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total unwillingness to expend additional cost, effort, and time in early project stages.	3.53	0.87	1
2	Failure to obtain additional front end funding.	3.24	0.83	5
3	Strict design fee.	3.41	0.87	2
4	Unbending scope of design services.	3.35	0.93	3
5	Expectation of free advice from contractors.	3.29	0.99	4

In government project owners, it is indicated that the answers are located between 3.53 and 4.65 with an average of 4.00 which demonstrates this barrier has a high level of significance which might be due to the failure to obtain additional front funding and the fixed scope of design services.

Table 43 Unwillingness to expend additional cost, effort, and time in early project stages in government owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total unwillingness to expend additional cost, effort, and time in early project stages.	4.06	0.88	3
2	Failure to obtain additional front-end funding.	4.65	1.06	1
3	Strict design fee.	3.65	1.17	1
4	Unbending scope of design services.	4.06	0.87	3
5	Expectation of free advice from contractors.	3.53	1.01	5

4.7.8 Lack of Commitment toward Constructability

Table 44 and Table 45 illustrate the mean response, the standard deviation, and the ranking of each constructability barrier of the lack of commitment toward constructability in private and government project owners, respectively. It is indicated that the answers are located between 2.82 and 3.53 with an average of 3.19 which demonstrates this barrier has a moderate level of significance.

Table 44 Lack of commitment toward constructability in private owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total lack of commitment toward constructability.	3.24	0.83	2
2	Constructability is a low priority.	2.82	0.88	4
3	No constructability policy statement exists.	3.18	1.01	3
4	No constructability champion is assigned.	3.53	0.87	1

In government project owners, it is indicated that the answers are located between 3.12 and 3.53 with an average of 3.35 which demonstrates this barrier has a moderate level of significance.

Table 45 Lack of commitment toward constructability in government owner organizations

S.N.	Barrier	Mean	Standard Deviation	Rank
1	Total lack of commitment toward constructability.	3.12	0.99	4
2	Constructability is a low priority.	3.41	1.12	2
3	No constructability policy statement exists.	3.53	1.07	1
4	No constructability champion is assigned.	3.35	1.11	3

A study has been conducted to measure barriers to deploy constructability in Saudi construction industry. It has identified some of the above-mentioned constructability barriers such as: designing without construction experts review due to traditional contracting method, owners do not give attention to constructability in the contracting strategy, believing in no proven benefits from implementing constructability, and designers lack of construction experience (Assaf, Jannadi and Al-Yousif 2003).

CHAPTER 5

CASE STUDIES

5.1 INTRODUCTION

Two case studies were selected to examine the constructability implementation in a professional private project owner organization operating in the Eastern Province, Saudi Arabia. The first case study is a building commercial type project, Case Study-1 and the second case study is an industrial type project, Case Study-2. Both cases comprise a qualitative examination of the accomplished benefits and the constructability efforts performed throughout each project lifecycle.

5.2 CONSTRUCTABILITY AT CORPORATE LEVEL

The owner has had a very high level of commitment toward constructability at corporate level and has full understating of constructability objectives. Their effort in regards of constructability implementation was proven by:

1- Adopting the Construction Industry Institute (CII) constructability business model and performing a long-term collaboration with CII resulted in a continuous process of improvement in the constructability implementation roadmap.

2- Having a firm commitment to perform constructability by developing a constructability method statement that clearly explain how and when it shall be implemented.

3- Offering a full-time job constructability sponsor under project management office organization who oversees cross-functional constructability program implementation. In, addition, appointing a project engineer in every project as a constructability champion who is accountable in coordinating constructability review workshops and implementation efforts across all disciplines. He also ensures that those who are involved in the constructability exercises fully understand it and have the experience to implement it.

4- Establishing a user friendly accessible lessons learned knowledge base system that provides pitfalls mitigation recommendations to project teams and is being updated frequently.

5- Including constructability recommendations in the clause of terms and conditions in all contracts.

6- Certifying constructability awareness courses and recognizing saving efforts.

7- Collecting and documenting/tracking all constructability findings in an issue log with narrative, approximate cost, and schedule effect.

8- Mandating the inclusion of a constructability log in project close-out documentation to be assessed for incorporation into the Lessons Learned database to assist future projects.

9- Having frequent brainstorming sessions to assess complex constructability issues and conducting problem solving workshops for the most complicated ones.

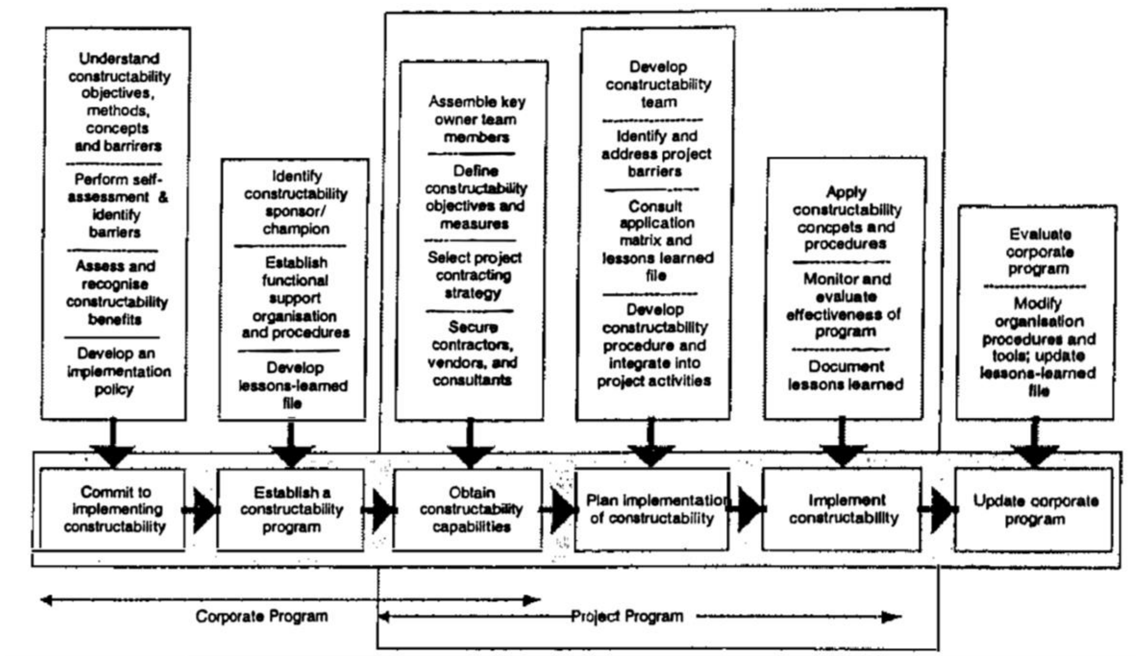

Figure 5 CII constructability implementation model

5.3 CONSTRUCTABILITY AT PROJECT LEVEL

As the use of constructability can significantly improve the cost, schedule, and operability, constructability is being applied in all construction projects. Lessons learned, which is defined by Senge as “the continuous testing of experience, and the transformation of that experience into knowledge – accessible to the whole organization, and relevant to its core purpose,” is jointly adopted along with constructability in several phases for several objectives to capture, analyze, and implement these lessons (Senge 1994).

5.3.1 Business Case Development

Lessons Learned Implementation (LLI) is where a structured approach workshop is conducted at the early stage of this phase (around 0–10%) to recommend and examine applicable lessons learned from previous projects that are already captured and registered in the lessons learned system and might benefit this phase or upcoming phases. Afterward, a mitigation strategy will be developed along with selected lessons for implementation follow-up that is required to ensure they are not repeated. A report will be generated containing each lesson's title, the accountable champion, and estimated date of completion. At 90–100% completion of the phase, a Lessons Learned Collection (LLC) workshop is conducted. The objective of LLC is to collectively collect and document unique lessons learned in this phase of the project, and register them in the system if they pass the lesson evaluation criteria. The report of LLC consists of the title of each proposed lesson, background of the lesson, root cause, and recommendations.

5.3.2 Study Phase

The second LLI workshop is conducted at 0–10% completion of the study phase. During this workshop, the team go over the action items appointed in the report developed during the previous phase and propose additional lessons to be included if any. There is no LLC workshop in this phase.

5.3.3 Scoping Phase

The third LLI is conducted at the early stage of this phase as well as the second LLC workshop which is conducted at the end. However, at 60% scoping completion, a formal constructability review workshop is conducted by inviting planning, design, and construction subject matter experts together to analyze the design, to reduce cost, save time, or improve reliability. In the constructability review workshop attendees go over numerous disciplines including: general engineering, HSSE, material management, site layout, project schedule, and civil works, as well as the structural, equipment, piping, electrical, and mechanical aspects. Also, they might propose other items specifically related to the review project. By the end of the workshop, the champion develops a constructability report consisting of a list of attendees, constructability review checklist, and constructability issue sheet reflecting the status update of each item and who is assigned for each one.

5.3.4 Preliminary Engineering

The fourth LLI is conducted at the early stage of preliminary engineering, as well as the third LLC workshop which is conducted at the end. In addition, at 30% completion, the second formal constructability review workshop is conducted to follow up on the previous actions and ensure mitigations are captured in the drawings.

5.3.5 Detailed Design

The fifth LLI is conducted at the early stage as well as the fourth LLC workshop which is conducted at the end. At 20% completion, the third formal constructability review workshop is conducted.

5.3.6 Construction

The sixth LLI is conducted at the early stage as well as the fifth LLC workshop which is conducted at the end. At construction, there is no constructability review workshop because all constructability recommendations were embedded in contract documents.

5.3.7 Participants

A wide range of expertise with various disciplines are involved during each review workshop. The minimum required of participants is that they are working for project management organizations, facility operators, planners, quality inspectors, safety personnel, contractor representatives, and discipline engineers from design consultant firms.

5.4 CASE STUDY-1

Case study-1 is a commercial residential type project consisting of five identical buildings, each one including 38 units with the required amenities and infrastructure. Constructability reviews were implemented by the project owner in the early conceptual planning and kept conducted until the detailed engineering phase just prior to the commencement of construction activities as per the roadmap described in section 5.3. This project was being initiated in 2011 in order to provide residential buildings for the private sector owner to allow housing its bachelor employees close to their work location. The company does not own any housing units and has been leasing 140 bachelor housing units to accommodate these employees. It was proposed to design and construct five identical furnished residential buildings, 3-story each, for male bachelor employees on a long-term leased land parcel. The buildings have a total area of 8,350 square meters and include a total of 190 bachelor housing units. The scope also includes a 2,500 SM open parking lot, walkways, and landscaping. A constructability champion was assigned to the project as early as the scoping was initiated to manage constructability implementation action items. The first constructability review meeting was held at 60% scoping after finalizing the site layout, major equipment selection, and contracting strategy development. The second and third reviews were held at 30% preliminary engineering and 20% detailed engineering to prevent major design changes and constructability deficiencies. Site expert personnel were heavily involved in the review workshops. Lesson Learned implementation and collection workshops were also conducted.

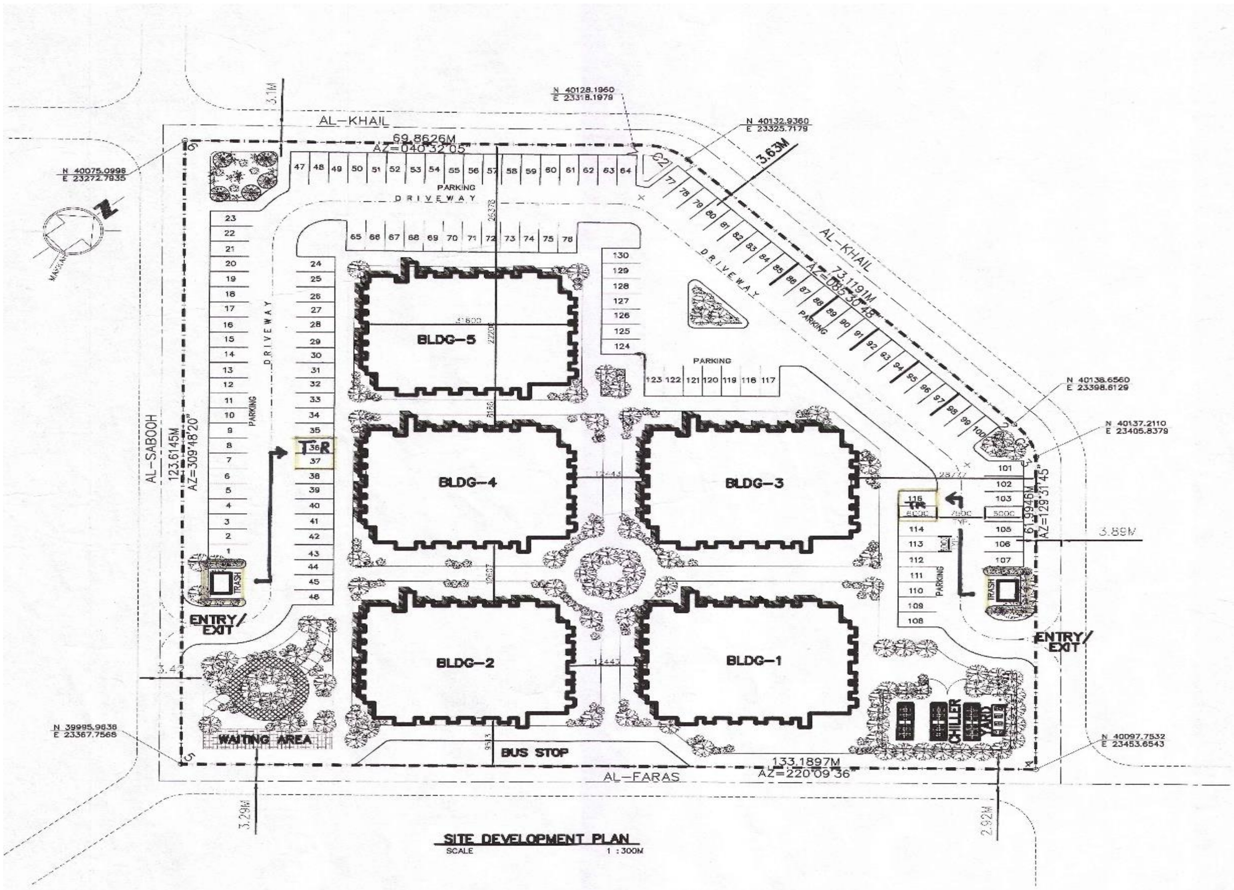

Figure 6 Masterplan of case study-1

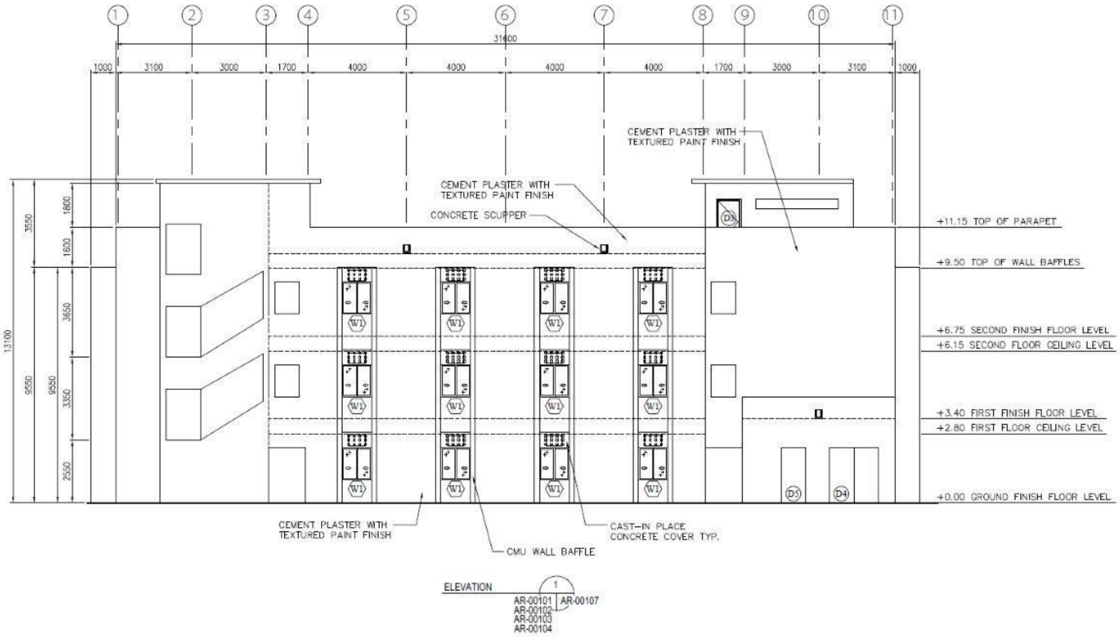

Figure 7 Elevation of case study-1

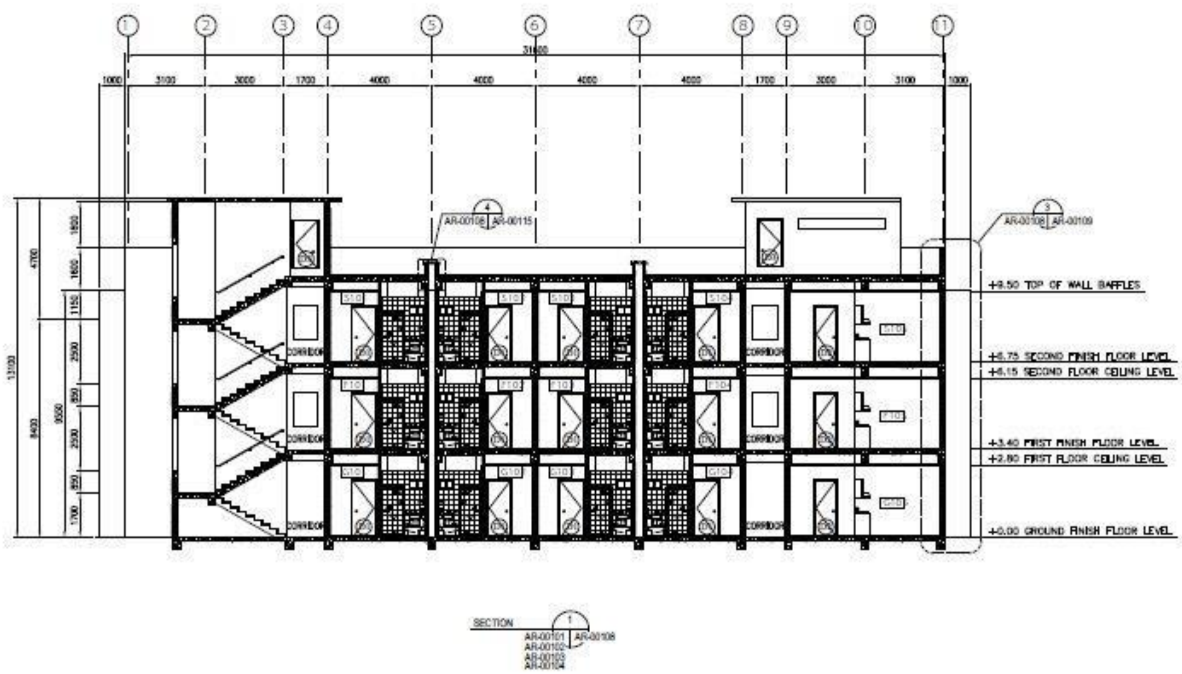

Figure 8 Section of case study-1

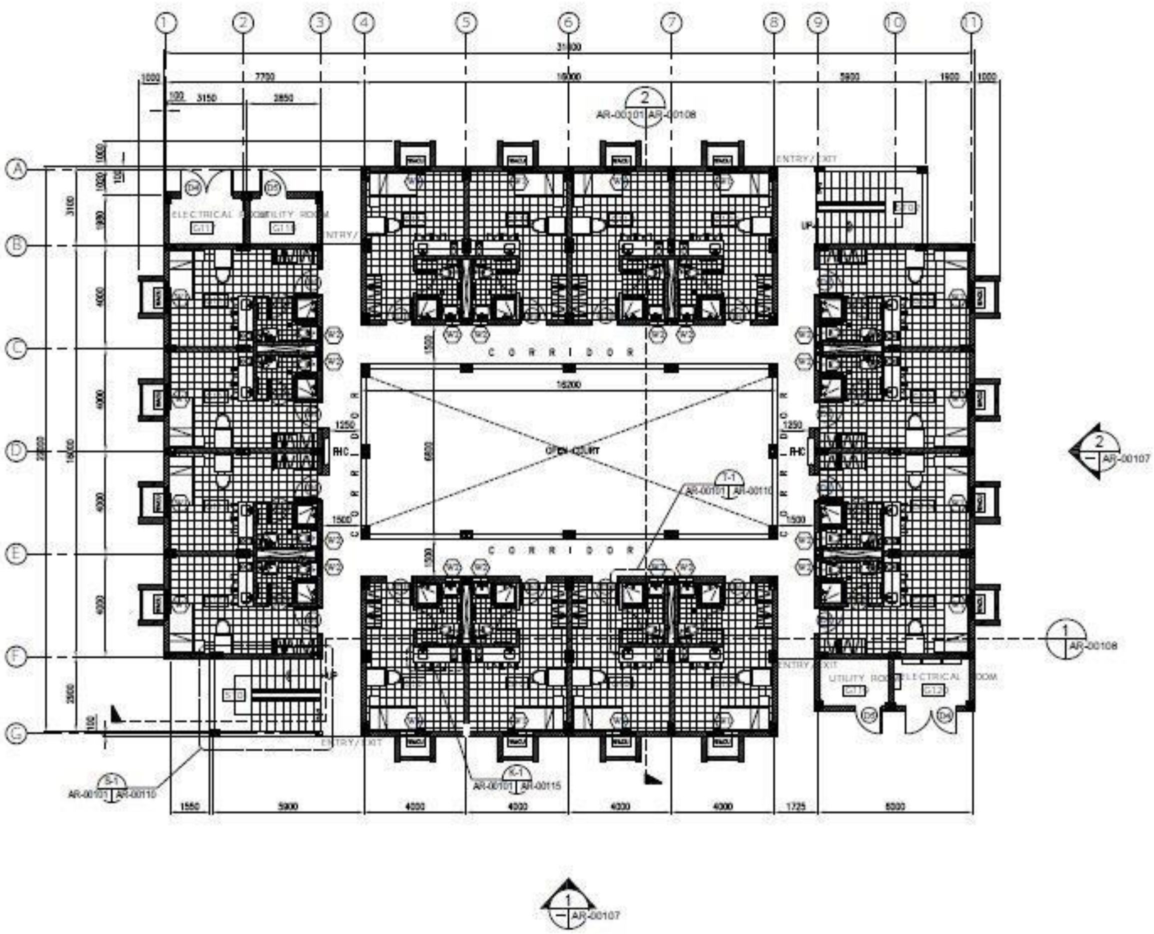

Figure 9 Floor layout of case study-1

5.5 CASE STUDY-2

Case study-2 is an industrial type project to provide 60 MBD truck loading facility to directly load refined products through pipelines from the nearest refining facility. The project scope includes 8 multi product loading bays spilt between two racks, with each rack consisting of eight diesel loading arms, six P91 loading arms and two P95 loading arms, a fire water system, 20 km long pipeline, industrial support buildings, parking, and a physical security system. Constructability reviews were implemented by the project owner at 60% completion of the scoping phase, 30% preliminary engineering phase, and 20% detailed design. Sixteen subject matter experts from different experiences participated in review workshops and were involved in reviewing the preliminary engineering design phase constructability review checklist and the development of project specific constructability issues and challenges. A constructability champion was assigned before the first workshop to manage constructability action items implementation and tracking.

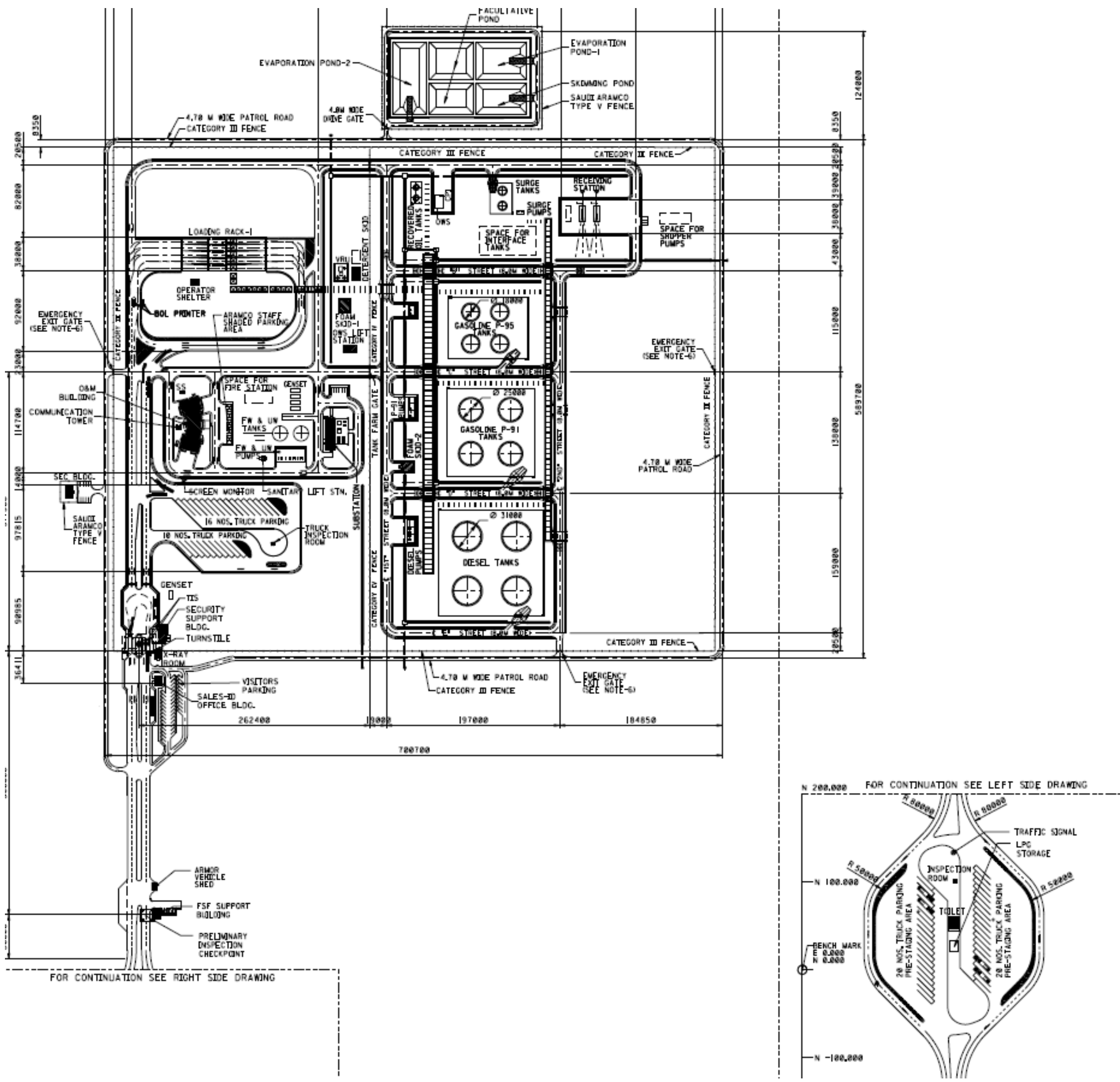

Figure 10 Masterplan of case study-2

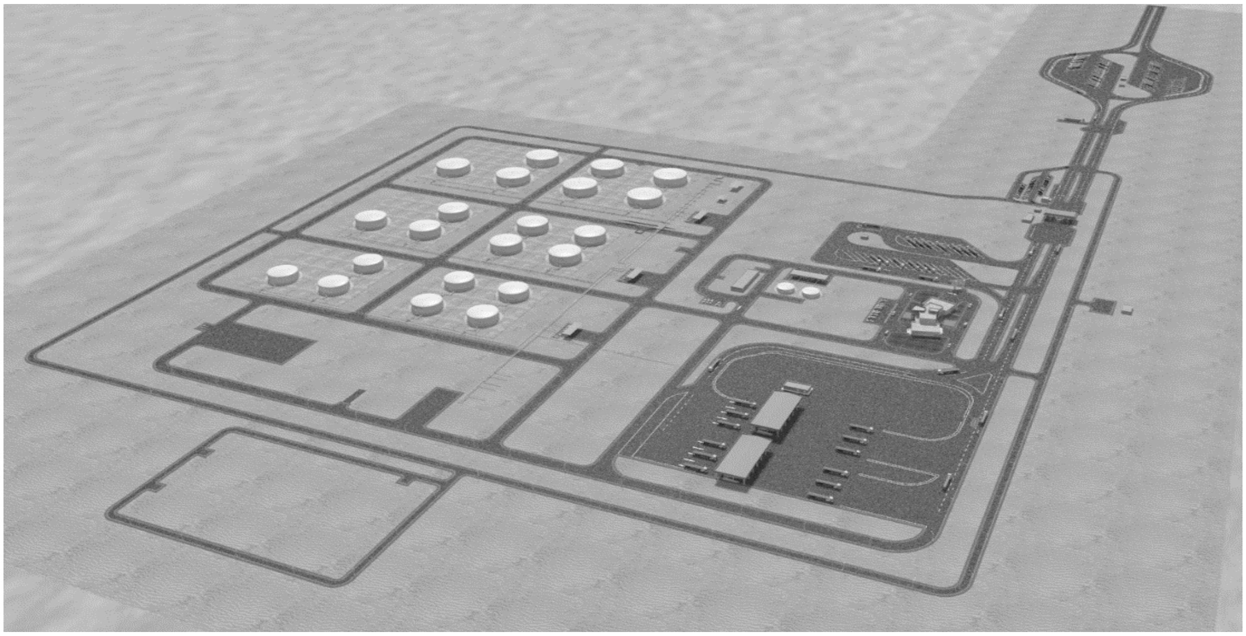

Figure 11 Prototype of case study-2

5.6 CONSTRUCTABILITY IMPLEMENTATION CHARACTERISTICS

Table 46 Constructability implementation characteristics in case study 1 & 2

	Case Study-1	Case Study-2
Phase of constructability start	Conceptual Planning	Conceptual Planning
Review conducted by	Owner	Owner
Lesson Learned Implementation workshop conducted	Yes	No
Construction personnel participated	Yes	Yes

*The requirement of having Lessons Learned Implementation workshop was waived due to schedule constraints.

5.7 IMPLEMENTATION OF CONSTRUCTABILITY

This section outlines CII constructability concepts implemented in each phase of the two case studies, as per the CII implementation roadmap.

5.7.1 Implementation of Constructability in Conceptual Planning

Table 47 Constructability in Conceptual Planning

	Case Study-1	Case Study-2
Project execution plan considers constructability implementation	Yes	Yes
Construction experienced personnel involved	Yes	Yes
Construction knowledge is considered in the contracting strategy development	Yes	Yes
Overall project schedule is construction/startup sensitive	Yes	Yes
Early design considers principle construction methodologies	Yes	Yes
Permanent and temporary facility layouts should be integrated	Yes	Yes
Taking advantage of promoting advanced information technology	Yes	Yes
Early establishment of constructability team	Yes	Yes

5.7.2 Implementation of Constructability in Detailed Engineering

Table 48 Constructability in Detailed Engineering

	Case Study-1	Case Study-2
Schedules of design and procurement are construction sensitive	Yes	Yes
Design is configurable	No*	Yes
Standardizing the design of construction elements and material	Yes	Yes
Development of contract documents considers procurement, construction, and startup	Yes	Yes

Design considers assembling, transportation, and installation	Yes	Yes
Design considers jobsite accessibility	Yes	Yes
Design considers severe weather conditions during construction	Yes	Yes
Design considers jobsite security	Yes	Yes

*Pre-cast concrete with bearing walls was chosen due to a binding agreement with local government agency who has the jurisdiction on the leased land.

5.7.3 Implementation of Constructability in Construction

Table 49 Constructability in Construction

	Case Study-1	Case Study-2
Innovations are applied on construction methods	Yes	Yes

5.8 BENEFITS OF CONSTRUCTABILITY IMPLEMENTATION

This section presents the benefits achieved in each case resulting from a comprehensive constructability implementation.

Table 50 Benefits of Constructability Implementation realized in case study 1 & 2

	Case Study-1	Case Study-2
Capital Cost Avoidance %	18.75	4.20
Schedule Optimization %	14	8.3

The average accomplished savings in cost and schedule in both case studies are below the averages achieved by implementing constructability in the private sector which are 13% and 19% for cost and schedule respectively. This is due to the long-term experience in project execution; most of constructability issues were captured in other projects and made a part of the lessons learned database that can be accessible by all project teams. This resulted in more accurate conceptual planning and scoping where constructability is still valid and can afford some savings; however, not as much as anticipated in projects belonging to owners having much less constructability experience.

5.9 LESSONS LEARNED REVIEWED IN CASE STUDY-1

1. **<u>Conduct Site Survey and Geotechnical Investigation During Preliminary Engineering</u>**

   - **Date: 3/21/2006**
   - **Number: 033**
   - **Background/Experience:**

   <u>Case 1 – Soils Testing for Piles</u>

   670 piles were needed to provide support for vessels, pipe racks, foundations, etc. During preliminary engineering; a soil test consisting of 3 bore holes was done. All holes matched the results of an older geotechnical survey on file. Based on this information, the LSTK bid package assumed a 12-meter pile length. Actual conditions in the field differed from the soils investigation. Approximately 220 of the piles failed the load test, and pile extensions were required, resulting in a 2-month schedule impact on this portion of the work and a change order over SR1MM.

   <u>Case 2 – Assumed Soil Bearing Capacity for Foundations</u>

Per standards, if soil investigation reports are not available for an area, you should assume a minimum soil bearing capacity of 100 kilo-Newtons per square meter to design foundations. During the preliminary engineering, the soil bearing capacity was assumed as 100 kilo-Newtons per square meter and the foundations were designed accordingly. During the estimate review, it has been noted that the foundations seemed large. It was resolved that during detailed engineering a geotechnical investigation would be done to ascertain the exact soil bearing capacity and soil characteristics. Then the foundation design would be reviewed and modified if necessary. Note that it is expected that the geotechnical investigation will be difficult because there are no existing survey details, especially with regards to existing underground piping and electrical facilities.

- **Root Cause/Benefit:**

  Case 1 – Soils Testing for Piles

  1- Geotechnical report was not comprehensive. It did not contain enough specific information covering the pile driving area.
  2- LSTK contractor did not verify conditions during detailed design.

  Case 2 – Assumed Soil Bearing Capacity for Foundations

  1- Geotechnical investigation was postponed from preliminary engineering to detailed engineering due to short schedule for preliminary engineering.

- **Recommendation:**

  Case 1 – Soils Testing for Piles

1- Should perform a more comprehensive soils investigation during preliminary engineering. Don't rely on old surveys.

2- Reconfirm soil conditions in critical areas. LSTK contractor to work more closely during detailed engineering phase to identify critical areas.

3- Assume worst case when designing pile lengths.

Case 2 – Assumed Soil Bearing Capacity for Foundations

Conduct site survey and geotechnical investigation during the preliminary engineering to generate plan and profile for the existing aboveground facilities and include markers for underground facilities. After the site survey, perform geotechnical investigation for the soil properties. This will allow more accurate design of foundations and a more accurate estimate.

2. Common Civil-Electrical Design Interface Problem - Electrical Manhole Design

- **Date: 6/22/2008**
- **Number: 130**
- **Background/Experience:**

Project design included 800 electrical manholes throughout the plant. The majority were for low voltage cable, for which there is no specific standard. Designer used a stringent design with cast walls, like manholes used for medium voltage cable. During construction, the contractor requested a change from the cast wall design to a draw pit constructed of blocks. There was a concrete shortage, and it was thought that converting to the block design would save time. After construction of the block draw pits, cracks and shifting walls were discovered. The team requested the contractor revert to the concrete wall design to correct the situation. The contractor refused due to the late discovery of this problem and because the electrical and control cables were already pulled through the subject draw pits.

- **Root Cause/Benefit:**

1- Civil designers normally look to civil, not electrical, standards when designing civil structures. The requirement for special design for an electrical manhole is only mentioned in electrical standards. There is no reference whatsoever to this issue in any civil standard. This is usually missed because the manhole design is done by a civil designer who is not familiar with the electrical requirements.

2- There is often poor coordination between various disciplines during design.

3- In the overall sequence of design activities, civil design is done at an earlier phase than electrical design, which hampers efforts at coordination between civil and electrical designers.

4- In construction, there was a concrete shortage, and it was thought that converting to the block design manhole would save time.

- **Recommendations:**
  1- Improve commentary in civil standards to alert designers to the need to interface with non-civil standards.
  2- Civil-related standard drawings that are referenced in electrical standards should also be referenced clearly in civil standards.
  3- During detailed design, minimize the number of electrical manholes; the more manholes you have, the more construction time you need.
  4- The construction team should verify that design and construction managers establish working systems to promote regular, effective coordination among all different disciplines.

3. <u>Anchor Bolt Design and Installation Problems</u>

- **Date: 1/22/2008**
- **Number: 111**
- **Background/Experience:**

Anchor bolt installation is one of the most frequent sources of construction problems. These preventable problems can be difficult, time consuming, and expensive to fix, resulting in schedule delays and change orders. This lesson describes several typical anchor bolt problems encountered by projects and provides recommended strategies to avoid these pitfalls.

Case 1 - Too Much Anchor Bolt Projection on Pipe Support Foundations

Case 2 - Too Little Anchor Bolt Projection on Rotating Equipment Foundations

Case 3 - Severe Damage to Concrete Pedestals and Anchor Bolt Threads after Forcing Base Plate onto Tilted, Misaligned Anchor Bolts

Case 4 - Example Method for Holding Anchor Bolts in Fixed Position to Prevent Tilting

Case 5 - Lack of Anchor Bolt Corrosion Allowance in Corrosive Environment

Case 6 - Euthanizer Column Base Plate Anchor Bolts Mismatch Problem

- **Root Cause/Benefit:**

Following are common root causes that may apply to multiple cases above:

1- Not using best practices of anchor bolt design & installation

2- Not using standard drawings of anchor bolt details

3- Inadequate coordination between civil and mechanical disciplines, especially when there are late changes affecting anchor bolt design

4- Not providing equipment manufacturer vendor data about anchor bolt design requirements to civil designers

5- Failure to consider corrosion allowance in corrosive environment

6- Inadequate anchor bolt template

7- Not securing lower part of anchor bolt to prevent moving or tilting during concrete placement

8- Inadequate field checking of anchor bolt position, alignment, projection, etc. prior to concrete placement

9- The lift plan produced by the manufacturer did not consider the displaced center of gravity due to offset weight distribution, which therefore prevented the column from hanging vertically under the hook position. This offset could and should have been calculated and corrected by a strategically placed counter weight.

10- The extreme tight tolerances advised by the manufacturer between the anchor bolt holes and anchor bolts made it virtually impossible to allow the column to pass over the anchor bolts without causing damage to the bolts.

11- There are conformed mismatch discrepancies between the upper and lower bolt holes in the compression and base rings at three locations.

- **Recommendation:**

1- During the detailed engineering phase, when designing anchor bolt installation, designers should refer to best practices of anchor bolt design & installation and standard drawings of anchor bolt details.

2- Anchor bolt projection above the top of concrete is computed as follows:

  - Thickness of grout + thickness of base plate (or height of anchor bolt chair above the top of grout) + 1.5 x the diameter of anchor bolt
  - Thickness of grout + thickness of base plate (or height of anchor bolt chair above the top of grout) + 2.5 x the diameter of anchor bolt

3- The thread length required at the top of the anchor bolt must be sufficient to accommodate two nuts and about half of the anchor bolt diameter projecting above the top nut. Normally a thread length of about 3 bolt diameters will be sufficient to provide some tolerance for errors in the elevation of the anchor bolt placement in the field. During design review, make sure that IFC drawings include foundation details, including anchor bolt type, layout, and projection. Especially, check anchor bolt layout to ensure correct match with the equipment or structure to be installed into the anchor bolts and make sure that final vendor data from equipment manufacturers regarding anchor bolts is provided to the civil designers. Make sure that civil and mechanical design groups coordinate with each other on anchor bolt design details, especially if there are late changes that will affect anchor bolt design. It is essential to verify anchor bolt projection length calculations to ensure that nuts will properly engage per the standards.

4- During the detailed engineering phase, make sure to consider corrosion allowance. Recognize that corrosive conditions may vary within the project, especially if the project has multiple locations.

5- During design, identify any need for post-installed anchor bolts. Post-installed anchor bolts are any type of anchor bolt that is installed after the foundation concrete has hardened. This includes expansion anchors, bolts set in pockets, adhesive anchors, etc.

6- During construction, when fixing anchor bolts into the rebar/formwork, check to avoid four common problems:

- Misalignment – Recheck bolt layout to ensure alignment with base plate holes in equipment or structure.
- Tilting – Verify that bolt is aligned vertically. Make sure that the bottom part of anchor bolts is secured to prevent movement or tilting of the anchor bolts during concrete placement.
- Too much projection or too little projection – Verify bolt projection length to ensure that nut(s) will properly engage with bolt thread, considering thickness of grout, base plate, washer, nut(s), etc.

7- Consider establishing an inspection hold point before pouring concrete to check anchor bolt layout and projection length, especially in cases involving large foundations or multiple foundations.

8- Consider the offset weight distribution when preparing the column lift plan to ensure column will be hooked vertically during installation.

9- Consider tolerances between the anchor bolt holes and anchor bolts at the design phase to ensure adequate clearance to avoid potential problems during installation.

4. Common Scope Definition Pitfalls when Project Interfaces with Existing Utility Systems

- **Date: 7/1/2008**
- **Number: 267**
- **Background/Experience:**

Experience has shown that problems frequently arise when the project scope involves additions or modifications to existing utilities systems such as cooling water, wastewater, power, etc. Typical examples of such problems include:

- Late addition to main project scope without evaluating the impact on utilities. This may lead to unexpected major cost increases and delays.
- Incomplete documentation of existing utility networks and loads. This may lead to delays in gathering information, invalid assumptions, and performance deficiencies.

- **Root Cause/Benefit:**

1- Unrealistic expectations about the amount of time and money required to analyze complete existing network for the sake of a relatively minor upgrade

2- Incomplete awareness or consideration of other project impacts on utility loads

3- Incomplete documentation of existing utility systems after original project and upgrades

4- Tendency to rush incorporation of late scope changes without full evaluation of secondary impacts, especially on utility systems

- **Recommendation:**

1- Projects that interface with existing facility utilities must be particularly vigilant to recognize these issues early and prevent them from becoming major problems.

2- Scope should clearly define limits of any utility load studies to be conducted in the preliminary engineering phase.

3- Preliminary engineering should include time and money to conduct such studies as defined in Scope.

4- When conducting existing utility load analysis, ensure that the end user provides complete, accurate, and timely input of existing utility capacities and loads. The end user should also fully communicate his knowledge about other ongoing and forthcoming projects that may affect common utilities in the existing plant.

5- Do not rush late scope changes. Ensure thorough analysis of all proposed scope changes, including impact on utilities systems such as cooling water, wastewater, power, etc.

6- Facilitate early recognition of invalid assumptions and promote project team alignment by holding a Project Execution Planning Workshop.

5. Considerations When Expanding Existing Circuit Breaker Panels or Motor Control Centers

- **Date: 3/20/2007**
- **Number: crwr-038**
- **Background/Experience:**

Case 1 - Existing Breakers Obsolete, Had to Buy New Panel

The design called for buying and installing new breakers into an existing circuit breaker panel, with the intention that the new breakers would be purchased to match the existing ones. However, during construction it was determined that the existing breakers were obsolete and that it would be cheaper and faster to buy a whole new panel and breakers. This required a change order.

Case 2 - Panel Space Available & Reserved, But New Breaker Not Compatible with Existing Cubicle

When the contractor was ready to install a power breaker in the existing cubicle assigned at the substation, the contractor found that the cubicle did not have the draw-out mechanism to install the breaker for the new feeder to the gatehouse. The project team arranged with the plant operation for an alternative cubicle assigned for the new feeder. The project could have been delayed if the alternative cubicle had not been available and a new mechanism needed to be ordered.

Case 3 - Cheaper to Buy Whole New Panel than to Custom Make New Breaker to Interface with Existing Panel

The project scope included replacement of 34.5KV breakers in existing switchgear that was scheduled to be replaced three years after completion of this project. When the LSTK contractor evaluated the costs of procuring/testing/guaranteeing a custom-made breaker to interface with the obsolescent switchgear panel, it was concluded that buying a whole new panel would be cheaper.

Case 4 - Rework Due to Interconnection Incompatibility between New and Existing Electrical Control Gear in Mechanical Control Center

On arrival on site of a new additional 480 V MCC to the existing 480 V MCC (R84-P-753, R84-P-754, R-84-P-755 & R84-P-756), it was found that the new equipment (manufactured by a manufacturer different from the existing control center) did not have the same width as the existing control gear. The difference in dimension did not allow for proper direct connection of the bus bars and violated the equipment clearance space of 900 mm, depending on the distance condition as required as specified in NEC.110.26, table 110.26 (A) (1).

To correct this discrepancy, the new additional control gear was returned to the manufacturer for rectification to comply with the requirement of the Scope of Work, Section 3.5.3.4, which requires that new added MCC sections shall be supplied with the same dimensions as the existing. The equipment had to be re-worked and modified, which contributed to delays in project completion and construction progress.

Case 5 - Maintaining Existing Incomers Location on New Switchgear

The two incomers of 34.5kV switchgear did not reach as far as the tie breaker. However, the old switchgear layout was included in the information provided to the supplier, but the two incomers of the new switchgear did not reach as far as the tie breaker. Each incomer ended before spare cubicles in the old switchgear. The bus ducts were run directly from the transformers to these incomers. One of the new two cable buses of the switchgear overlapped with the other switchgear cable bus. The overlap of the two new cable buses with the other switchgear cable bus impacted the cutover of the two switchgears. The cutover sequence was as follows: Bus-A of P-001, Bus-C of P-002, Bus-B of P-001, and Bus-D of P-002.

- **Root Cause/Benefit:**

  Case 1

  Inadequate investigation of existing equipment and marketplace.

  Case 2

  Although the contractor, early in the project, did check availability of the cubicle assigned for the project, they did not check whether the cubicle was operative and the new breaker compatible.

  Case 3

  Ensuring compatibility of new parts with obsolescent equipment can be more difficult and expensive than expected.

  Case 4

  Field verification of dimensions of the existing MCC was not performed prior to placing the purchase order. The order for the new equipment was placed with a different manufacturer than the existing equipment.

  Case 5

  Proper field verification was not done.

- **Recommendation:**

  1- When developing scope for replacement of breakers, consider replacing the entire panel. During scoping and Preliminary Engineering phases, determine plans to replace the existing panel.

2- Prepare justification to include new panel in project scope.

3- Ensure site investigation of all affected facilities and adequate investigation of the marketplace to determine potential obsolescence of compatible equipment. Primary considerations when researching the market should be current availability, forecast obsolescence, cost, and schedule.

4- During field verification of existing facilities, be sure to check for functionality and compatibility between existing and new equipment/materials to be installed.

5- Ensure that the supplier maintains the same layout of existing switchgear during the review of NMR-601 to ensure smooth cutover plan.

6. Constructability Issues for a Building Project

- **Date: 2/10/2004**
- **Number: 80**
- **Background/Experience:**

The construction schedule for the new Surveying Services building in Dhahran was negatively affected by site and design constraints that could have been reduced with more constructability review and planning.

Site Access

Site access was limited. The building site was in a very confined area next to existing facilities. Only one access route was provided to the work site, and the construction contractor and facility end user had to share this access throughout construction. This situation was inconvenient for the construction contractor and unsafe for all users. Access from only 1 side of site greatly limited the ability to start work on that side of the site.

Construction Sequence

The construction sequence was not fully analyzed. Temporary parking and site fencing could have been done earlier by short form contract instead of included in building contractor's scope. This could have reduced the project duration and simplified the building contractor's work.

Design Constraints

The scope included a basement for record storage. The basement required a 9-meter deep excavation, mostly rock. This prevented other work, such as building foundations, from starting. It took 3 and half months to complete the excavation and partially build a retaining wall before the building foundation work could be started. The design of a loading area ramp at basement level required more rock excavation. Also, this facility is now difficult to utilize, because the freight elevator is not at the same level as the ramp.

Conflicts between Design Disciplines

- Architectural – Structural conflicts

· Cross bracing was located at window openings

· Missing foundation details, columns, and beams for hallway

· Missing structural steel drawing for roof staircase

- Architectural – Mechanical conflicts

· Sewer line routed under building foundation and through communications room

- **Root Cause/Benefit:**

1- A constructability study was not done since the project value was under $10MM. The project was assumed to be a routine small building, and constructability difficulties were not sufficiently recognized before construction start.

2- Existing facilities needed to continue operations until completion of the new building

3- Provision of only one access route to the site was due to security concerns

4- Inadequate coordination between design disciplines

- **Recommendation:**

1- A project team to ensure construction input during preliminary engineering and detailed design. Optimum timing is at 30% preliminary engineering and 20% detailed design. A contact project management office to facilitate constructability analysis.

2- In future building designs, consider eliminating the basement and replacing with alternative storage space to suit Proponent's needs; for example, add a second story to the annex building.

3- In future building designs, consider repositioning the footprint of the new building to allow a bigger work area or temporary relocation of existing facility occupants to allow demolition of old building before construction of new one.

4- During detailed design, a project team to insist on regular coordination meetings between disciplines.

CHAPTER 6

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

This chapter presents a summary of the study and a summary of the results. Furthermore, it presents the study conclusion and its recommendations.

6.1 SUMMARY OF THE STUDY

Constructability is a very useful planning tool that integrates the engineering phase with construction expertise to achieve project objectives and mitigate unforeseen risks associated with the nature of construction activities. This study was conducted to examine the level of practice of constructability among project owner organizations of Saudi construction projects and figure out the implementation barriers. A questionnaire was emailed to 25 private project owners and another 25 government sector project owners that operate in the three major cities of Al-Khobar, Dammam and Dhahran, Eastern Province, Saudi Arabia. Seventeen private sector project owners in addition to 17 government sector project owners demonstrated their willingness and responded.

6.2 SUMMARY OF THE RESULTS

This section summarizes the results obtained from the respondents’ work for the targeted project owner organizations.

6.2.1 Constructability Concepts Utilization

It was indicated from the results that, while private project owners have a moderate level of utilization of constructability concepts during the conceptual planning phase, government project owners demonstrated a low level of utilization of constructability concepts.

6.2.2 Corporate Level Implementation

Private sector project owners demonstrated an informal implementation in corporate culture and in documentation and tracking. However, they demonstrated a limited implementation in personnel development; meaning that project owners from the private sector have an acceptable consciousness and support of constructability but implementation efforts have limited support within the organization. On the other hand project owners from the government sector demonstrated that they have a limited application in all constructability implementation aspects. They have a limited consciousness and support of constructability with a lack of understanding of the importance of constructability adoption proactivity. At this level of implementation, constructability is implemented on some selected projects without corporate level support.

6.2.3 Constructability Implementation Benefits

Results have showed a reduction of 40% in change orders values in both organizations: 18.53% schedule and 13.24% cost optimizations resulted from constructability implementation during conceptual planning in private projects, and 14.59% and 14.95% schedule and cost optimizations in government projects; the average of quality improvement in private projects is 16.88% and in government projects is around 13.29%; and the average of safety improvement in private projects is 17.06% and in government projects is 14.94%.

6.2.4 Constructability Implementation Barriers

Government project owner representatives claimed that lack of documentation and unwillingness to expend additional cost, effort, and time in the early project stages are barriers that have high significance toward constructability implementation in their organizations. Private project owners have not classified any barrier as highly significant which might be a result of having a moderate level of utilization of constructability concepts during the conceptual planning phase. However, they demonstrated some sub-barriers as highly significant ones, such as resistance to change and ineffective coordination through design.

6.3 CONCLUSION

The implementation in private sector project owners was more effective. However, both types of organizations require more effort toward promoting their constructability corporate environment and concepts utilization. At project level, both have proven that implementing constructability has positive implications toward construction projects. It prevents change orders, optimizes cost and schedule, and improves project safety and quality. Some barriers do affect its implementation especially in government sector projects.

6.4 RECOMMENDATIONS

- It is recommended that constructability should be part of project operations in all construction projects regardless of their type and volume, by utilizing the CII roadmap and corporate implementation model, which will result in more effective capital investment that benefits government as well as companies.

- Private project owners should emphasize having a dedicated project constructability team when the project is first initiated, make constructability part of the project execution plan document, and provide more capitalization on personnel recognition and development.
- Government project owners should have constructability as part of the construction execution plan, as well as construction contracts to enforce its implementation, establish constructability training and recognize personnel saving efforts, and overcome constructability barriers by introducing a lessons learned platform and tracking system such as Aconex.
- As we are witnessing the fourth industrial revolution relying on technology, modern engineering IT solutions such as Building Information Modelling (BIM) should be heavily utilized by project owners to prevent constructability issues and provide more effective documentation and tracking tools that will benefit implementation process lessons learned in projects.
- Design engineers should have construction experience at an early stage in their career life which will result in promoting the quality of their designs.
- Further study of constructability is recommended among construction contractors and engineering consultants operating in Saudi Arabia and working in government and private projects to allow for a more comprehensive image about constructability implementation in the local industry.

APPENDIX A

STUDY QUESTIONNAIRE

Dear Participant:

I would like to solicit your support by answering this questionnaire. I am a graduate student in Construction Engineering and Management at KFUPM. I am conducting a study on Constructability in Saudi Projects for my Master's Thesis. The objective of the study is to examine the level of implementation of constructability best practice in construction type projects and also to explore the possible barriers of adopting it.

The questionnaire should not take more than 20 minutes. Your answers will be kept anonymous and confidential. Only aggregate results will be presented or documented. Your help with this research is strictly voluntary. If you are interested in the results of the study, I will share the final outcomes with you. Should you need any further information, please contact me at (013) 880-4854 or via abdulrahman.mussad@gmail.com.

Abdulrahman Al-Mussad

Section 1: This section contains general questions about the organization. You are kindly requested to provide the requested information by placing a (√) in the box next to the proper answer.

1. For how many years has your organization been in construction business?
    - Less than 5 years [ ]
    - 5 years to less than 10 years [ ]
    - 10 years to less than 20 years [ ]
    - 20 years to less than 30 years [ ]
    - Over 30 years [ ]

2. How many years has your organization been in managing projects?
    - Less than 5 years [ ]
    - 5 years to less than 10 years [ ]
    - 10 years to less than 20 years [ ]
    - 20 years to less than 30 years [ ]
    - Over 30 years [ ]

3. What is the total number of employees in your organization?
    - Less than 50 employees [ ]
    - 50 employees to less than 100 employees [ ]
    - 100 employees to less than 250 employees [ ]
    - 250 employees to less than 500 employees [ ]
    - Over 500 employees [ ]

4. How many project(s) does your organization execute annually?
    - Less than 1 project [ ]
    - 1 project to less than 5 projects [ ]
    - 5 projects to less than 15 projects [ ]
    - 15 projects to less than 50 projects [ ]
    - Over 50 projects [ ]

5. What type of project(s) does your organization execute? — Approximate Percentage
   - Buildings (commercial, educational, etc.) [ ] %
   - Infrastructure (highways, water network, etc.) [ ] %
   - Industrial (power plants, sewage treatment plants, etc.) [ ] %
   - Others, please specify [ ] %

   100 %

6. What is the average size of project(s) executed? — Approximate Percentage
   - Less than SR 5 million [ ] %
   - SR 5 million to less than SR 25 million [ ] %
   - SR 25 million to less than SR 100 million [ ] %
   - SR 100 million to less than SR 500 million [ ] %
   - Over SR 500 million [ ] %

   100 %

7. What is the contract type(s) you typically use in your projects? — Approximate Percentage
   - Fixed Price [ ] %
   - Unit Rate [ ] %
   - Cost Plus [ ] %
   - Others, please specify [ ] %

   100 %

8. What is the delivery method(s) you typically use in your projects? — Approximate Percentage
   - Traditional [ ] %
   - Turnkey [ ] %
   - Build-Operate-Transfer [ ] %
   - Others, please specify [ ] %

   100 %

9. What is the average percentage of design completion when you award construction contract?
   - Less than 10% [ ]
   - 10% to less than 30% [ ]
   - 30% to less than 50% [ ]
   - 50 to less than 100% [ ]
   - 100% [ ]

10. Do you often offer a specific section in design bid documents exclusively addressing constructability issues?
    - Yes [ ]
    - No [ ]

Section 2: This section contains general questions about the respondent. You are kindly requested to provide the requested information by placing a (√) in the box next to the proper answer.

11. How many years you have been in the business of construction projects?
    - Less than 5 years [ ]
    - 5 years to less than 10 years [ ]
    - 10 years to less than 20 years [ ]
    - 20 years to less than 30 years [ ]
    - Over 30 years [ ]

12. What is your job title?
    - Project Engineer [ ]
    - Resident Engineer [ ]
    - Project Manager [ ]
    - Construction Manager [ ]
    - Projects Consultant [ ]
    - Others, please specify [ ]

13. What is your level of education?
    - Diploma [ ]
    - BSc. [ ]
    - MSc. [ ]
    - PhD [ ]
    - Others, please specify [ ]

14. What is your degree discipline?
    - Civil Engineering [ ]
    - Mechanical Engineering [ ]
    - Electrical Engineering [ ]
    - Industrial Engineering [ ]
    - Management [ ]
    - Others, please specify [ ]

15. What professional certificate(s) you have?
   - Project Management Professional (PMP) [ ]
   - Professional Engineer (PE) [ ]
   - Associate Value Specialist (AVS) [ ]
   - PMI Risk Management Professional (PMI-RMP) [ ]
   - Program Management Professional (PgMP) [ ]
   - Others, please specify [ ]

16. What professional associations you are member in?
   - American Society of Civil engineers (ASCE) [ ]
   - Project Management Institute (PMI) [ ]
   - American Concrete Institute (ACI) [ ]
   - American Society of Mechanical Engineers (ASME) [ ]
   - Construction Management Association of America (CMAA) [ ]
   - Others, please specify [ ]

17. What is your level of familiarity in constructability concepts and constructability implementation?
   - Unfamiliar [ ]
   - Low [ ]
   - Moderate [ ]
   - High [ ]

Section 3: This section contains questions about the utilization of constructability concepts in the conceptual planning phase of the project

18. The following are potential constructability concepts that owners may applied during the conceptual planning phase. You are kindly requested to indicate the level of utilization of these concepts in your projects by placing a (√) in the box next to each of them.

Constructability Concepts	Level of Utilization				
	Very	High	Moderat	Low	Very
1. Constructability is a section of official project execution plan document.	[ ]	[ ]	[ ]	[ ]	[ ]
2. Early planning phase involves personnel who have construction experience.	[ ]	[ ]	[ ]	[ ]	[ ]
3. Constructability is considered in the contracting strategy development.	[ ]	[ ]	[ ]	[ ]	[ ]
4. Schedule of the project is sensitive to the requirements of construction.	[ ]	[ ]	[ ]	[ ]	[ ]
5. Major design approaches consider the methodology of construction i.e. pre-assembly.	[ ]	[ ]	[ ]	[ ]	[ ]
6. Construction site layout provides an efficient construction.	[ ]	[ ]	[ ]	[ ]	[ ]

7. Formation of constructability team is occurred as early as the project got initiated.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
8. The use of advanced IT applications throughout project phases.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
9. Others, please specify.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**

Section 4: This section contains questions about the implementation of constructability in corporate level

19. The following questions designed to measure the constructability implementation procedures that are followed in your organization's corporate level. You are kindly requested to indicate the procedure you are implementing in your projects for each item by placing a (√) in the box next to each of them.

Implementation Item	Procedure				
	Comprehensive Formal Program	Formal Program	Informal Program	Limited	No Program
For Constructability in Corporate Culture, which procedure you are applying for:					
1. Recognition and designation of constructability efforts.	[ ]	[ ]	[ ]	[ ]	[ ]
2. Presence of a known and written constructability policy stating the organization's commitment.	[ ]	[ ]	[ ]	[ ]	[ ]
3. Management are aware about and support constructability.	[ ]	[ ]	[ ]	[ ]	[ ]
4. Recognition of efforts that break constructability implementation barriers and problems.	[ ]	[ ]	[ ]	[ ]	[ ]
5. Others, please specify.	[ ]	[ ]	[ ]	[ ]	[ ]
For Constructability in Personnel, which procedure you are applying for:					

6. Frequent personnel training in constructability.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
7. Designation and support from constructability sponsor.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
8. Presence of effective constructability organization.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
9. Others, please specify.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
For Constructability in Documentation and Tracking, which procedure you are applying for:					
10. Documentation of constructability procedures on the corporate level.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
11. Presence of lessons learned system to communicate constructability.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
12. Use of knowledge of advanced technologies of construction.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
13. Contract documents are referring to constructability.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
14. Efforts to track the savings or other optimizations of constructability.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**
15. Others, please specify.	**[ ]**	**[ ]**	**[ ]**	**[ ]**	**[ ]**

Section 5: This section contains questions about constructability benefits

20. The following questions designed to measure the constructability implementation benefits in your organization's projects. Please answer the following:

- Do you particularly innovate construction methods on your projects?
  - Yes
  - No
- What is the percentage of change order costs from total project value for projects implementing constructability? _________%
- What is the percentage of change order costs from total project value for projects not implementing constructability? _________%
- What is the average savings from implementing constructability in Conceptual Planning?

  a. _______ % of total cost b. ________ % of project schedule
- What is the average savings from implementing constructability in Design?

  a. _______ % of total cost b. ________ % of project schedule
- What is the average savings from implementing constructability in Construction?

  a. _______ % of total cost b. ________ % of project schedule
- What is the average improvement in Project Quality Index (PQI) due to constructability implementation?

  ________ %
- What is the average improvement in Project Safety Index (PSI) due to constructability implementation?

  ________ %
- Do you effectively exploit incentives with designer/contractor in order to achieve more effective cost and schedule?
  - Yes
  - No

Section 6: This section contains questions about the owner barriers of constructability

21. The following are potential constructability barriers in project owner organizations. Please provide your opinion in the level of significance of each barrier by placing a tic (√) in the box next to each of them.

Constructability Concept	Level of Significance				
	Very	High	Moderat	Low	Very
Complacency with the status quo:	[ ]	[ ]	[ ]	[ ]	[ ]
1. Resistance to change.	[ ]	[ ]	[ ]	[ ]	[ ]
2. Non-innovative approaches are being utilized.	[ ]	[ ]	[ ]	[ ]	[ ]
3. Risk unfavorable attitude towards trying something new.	[ ]	[ ]	[ ]	[ ]	[ ]
4. No rewards for intelligent risk taking.	[ ]	[ ]	[ ]	[ ]	[ ]
5. Others, please specify.	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of documentation:	[ ]	[ ]	[ ]	[ ]	[ ]
6. No formal system for documenting lessons learned.	[ ]	[ ]	[ ]	[ ]	[ ]
7. Others, please specify.	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of understanding constructability concepts:	[ ]	[ ]	[ ]	[ ]	[ ]

8. Constructability roadmap is not available.	[ ]	[ ]	[ ]	[ ]	[ ]
9. Constructability definition is not known.	[ ]	[ ]	[ ]	[ ]	[ ]
10. Ineffective coordination through design.	[ ]	[ ]	[ ]	[ ]	[ ]
11. Others, please specify.	[ ]	[ ]	[ ]	[ ]	[ ]
Perception of we are doing constructability:	[ ]	[ ]	[ ]	[ ]	[ ]
12. Routine design practices can achieve constructability.	[ ]	[ ]	[ ]	[ ]	[ ]
13. Value engineering equals to constructability.	[ ]	[ ]	[ ]	[ ]	[ ]
14. Others, please specify.	[ ]	[ ]	[ ]	[ ]	[ ]
There are no proven benefits of constructability:	[ ]	[ ]	[ ]	[ ]	[ ]
15. It is too expensive to conduct constructability.	[ ]	[ ]	[ ]	[ ]	[ ]
16. Senior management is not convinced of the cost benefits of constructability.	[ ]	[ ]	[ ]	[ ]	[ ]
17. Others, please specify.	[ ]	[ ]	[ ]	[ ]	[ ]
Unwillingness to expend additional cost, effort, and time in early project stages:	[ ]	[ ]	[ ]	[ ]	[ ]

18. Failure to obtain additional front-end funding.	[ ]	[ ]	[ ]	[ ]	[ ]
19. Strict design fee.	[ ]	[ ]	[ ]	[ ]	[ ]
20. Unbending scope of design services.	[ ]	[ ]	[ ]	[ ]	[ ]
21. Expectation of free advice from contractors.	[ ]	[ ]	[ ]	[ ]	[ ]
22. Others, please specify.	[ ]	[ ]	[ ]	[ ]	[ ]
Lack of commitment toward constructability:	[ ]	[ ]	[ ]	[ ]	[ ]
23. Constructability is a low priority.	[ ]	[ ]	[ ]	[ ]	[ ]
24. No constructability policy statement exists.	[ ]	[ ]	[ ]	[ ]	[ ]
25. No constructability champion is assigned.	[ ]	[ ]	[ ]	[ ]	[ ]
26. Others, please specify.	[ ]	[ ]	[ ]	[ ]	[ ]

APPENDIX B

PRIVATE PROJECT OWNERS OPERATING IN DAMMAM, KHOBAR AND DHAHRAN

1. Al Inma Bank, Dammam
2. Al Rajhi Bank, Dammam
3. Arab National Bank, Dammam
4. Azizia Panda, Dammam
5. Bank Al Bilad, Dammam
6. Bank Al Jazira, Dammam
7. Banque Saudi Fransi , Dammam
8. Emaar, Khobar
9. General Electric, Dammam
10. Jarir Bookstore, Dammam
11. Mobily, Dammam
12. Prince Mohammed Bin Fahd University, Khobar
13. Riyad Bank, Dammam
14. Samba Financial Group (Samba) , Dammam
15. Saudi Aramco, Dhahran
16. Saudi Electricity Company, Dammam
17. Saudi Hollandi Bank, Dammam
18. Saudi Investment Bank, Dammam
19. Saudi Railway Company, Dammam
20. Saudi Telecommunication Company, Dammam

21. Saudia Aerospace Engineering Industries, Dammam

22. Tamimi Group, Dammam

23. The National Commercial Bank, Dammam

24. The Saudi British Bank, Dammam

25. Zain Saudi Arabia, Dammam

26. Zamil Industrial, Dammam

APPENDIX C

GOVERNMENT PROJECT OWNERS OPERATING IN DAMMAM, KHOBAR AND DHAHRAN

1. Al-Khobar Governorate, Khobar
2. Board of Grievances, Dammam
3. Branch of Ministry of Culture and Information, Dammam
4. Central Department of Statistics and Information, Dammam
5. Chamber of Commerce in the Eastern Province, Dammam
6. Civil Affairs Management, Dammam
7. Control and Investigation Board, Dammam
8. Customs, Dammam
9. Dammam College of Technology, Dammam
10. Dammam Municipality, Dammam
11. Department of Narcotics Control in Eastern Province, Dammam
12. Department of Zakat and Income Tax, Dammam
13. Dhahran Municipality, Dhahran
14. Eastern Region Police Directorate, Dammam
15. Emirate of Eastern Province, Dammam
16. General Auditing Bureau, Dammam
17. General Directorate for Social Affairs, Eastern Province, Dammam
18. General Directorate of Border Guard in the Eastern Province, Dammam
19. General Directorate of Civil Defense in the Eastern Province, Dammam
20. General Directorate of Education in the Eastern Province, Dammam

21. General Directorate of Health Affairs, Eastern Province, Dammam

22. General Directorate of Prisons, Dammam

23. General Directorate of Transport in the Eastern Province, Dammam

24. General Organization for railways, Dammam

25. General Presidency of the National Guard in the Eastern Province, Dammam

26. General Presidency of the Promotion of Virtue and Prevention of Vice, Dammam

27. General Presidency of Youth Welfare, Dammam

28. GOSI Eastern Province, Dammam

29. King Abdul Aziz Port, Dammam

30. King Fahd Causeway Authority, Khobar

31. King Fahd University of Petroleum and Minerals, Dhahran

32. Meteorology and Environmental Protection Administration, Dammam

33. Ministry of Civil Service, Dammam

34. Ministry of Defense, Dhahran

35. Ministry of Electricity and Water Branch, Dammam

36. Ministry of Finance, Dammam

37. Ministry of Foreign Affairs in the Eastern Province, Dammam

38. Ministry of Housing Branch, Dammam

39. Ministry of Islamic Affairs, Endowments, Dawah, and Guidance, Dammam

40. Ministry of Justice, Dammam

41. Ministry of Labor, Khobar

42. Ministry of Petroleum and Minerals, Dhahran

43. Municipality of Khobar, Khobar

44. Passports, Dammam

45. Premises Security force in the Eastern Province, Dammam

46. Real-Estate Development Fund, Dammam

47. Road Security Force, Dammam

48. Saline Water Conversion Corporation, Khobar

49. Saudi Arabian Monetary Agency, Dammam

50. Saudi Arabian Specifications Standards, Dammam

51. Saudi Credit and Saving Bank in the Eastern Province, Dammam

52. Saudi Red Crescent Authority in the Eastern Province, Dammam

53. Special Force, Dhahran

54. The Bureau of Investigation and Public Prosecution , Dammam

55. The General Directorate of Post, Dammam

56. The Ministry of Commerce Branch, Dammam

57. Traffic Department in Eastern Province, Dammam

58. University of Dammam, Dammam

APPENDIX D
CONSTRUCTABILITY REVIEW ITEMS OF CASE STUDY-1

No.	Category	Action By	Item	Initial Review Action Sheet			
				Accepted	Rejected	Assigned to	Due Date
SECTION 1 - GENERAL ENGINEERING							
1-1	General Engineering	XXX	Designers should minimize the use of terms field will verify and field routing.	√		YYY	Jan-14
1-2	General Engineering	XXX	Complete as soon as possible the design and layout of installations that become difficult to access because of the installation of following equipment, piping, conduit, etc.		√		
1-3	General Engineering	XXX	Arrange facilities so that access required for construction will not be blocked or restricted.		√		
1-4	General Engineering	XXX	During design, emphasize and coordinate the practical constructability aspects of installation, repair and retrofit as well as for operations/maintenance. Consulting with the field and/or construction can often result in considerable savings in the field.		√		
1-5	General Engineering	XXX	Check for proper equipment location to minimize later revisions during design (and follow RC standards).	√		YYY	Jan-14
1-6	General Engineering	XXX	Rationalize standard specifications and material requirements to meet local codes, practices and available materials (RC standards).	√		YYY	Jan-14
1-7	General Engineering	XXX	Visit to the site to identify all special site conditions	√		YYY	Jan-14
1-8	General Engineering	XXX	Keep construction access in mind when planning layout for major equipment. Good access lowers rigging costs and provides future maintenance access. An open construction layout leaves work areas for future maintenance.	√		YYY	Jan-14
1-9	General Engineering	XXX	Size the width of roads and gates to accommodate the largest cranes and pieces of equipment that will be used or placed on the project.		√		
1-10	General Engineering	XXX	Plan access ways for cranes to be used in both construction and maintenance.	√		XXX	Jun-14
1-11	General Engineering	XXX	Make sure that the plot plan provides for temporary facilities and easy access to lay-down areas.	√		YYY	Jan-14

1-12	General Engineering	XXX	Plan roadways and traffic patterns to facilitate safe fast handling and to avoid having traffic interfering with earthwork activities.	√		XXX	Jun-14
1-13	General Engineering	XXX	Thoroughly review the soil study at the jobsite to establish the optimum design/construct methods.	√		YYY	Jan-14
1-14	General Engineering	XXX	When working in or adjacent to operating facilities, review access ways to and from installation areas, prefabrication shops, storage areas and parking areas with administration facilities and residents so that traffic patterns that minimize interferences and facilitate construction can be established.	√		XXX	Jun-14
1-15	General Engineering	XXX	Plan locations of temporary barricades, fences and gates to ensure the protection and security of the construction site.	√		XXX	Jun-14
1-16	General Engineering	XXX	Locate fabrication areas (rebar for example) adjacent to storage area.	√		XXX	Jun-14
1-17	General Engineering	XXX	Establish isolated storage locations for highly combustible items as cad-weld materials, painting, cleaning fluids, etc.	√		XXX	Jun-14
1-18	General Engineering	XXX	Consider the need for emergency access and evacuation in the planning process.	√		XXX	Jun-14
1-19	General Engineering	XXX	Determine whether any of the permanent plant utilities can be made available for use during construction. If they can, and if a new facility is being constructed, provide for early design.		√		
1-20	General Engineering	XXX	Preplan lay-down areas such that stored items are easy to find, maintain (if required) and remove. Provide suitable working surface (such as gravel) and adequate drainage.	√		XXX	Jun-14
1-21	General Engineering	XXX	Develop a temporary power one-line diagram showing source, requirements and points of service; show routing on the plot plan with installation details and point of service; and determine the above ground distributions system requirements.	√		XXX	Jun-14
1-22	General Engineering	XXX	Verify and confirm that there is enough temporary power at the start of construction for peak construction needs. Ensure that there is enough temporary power available for checkout and startup or that permanent power will be available when primary stages of startup begin.	√		XXX	Jun-14
1-23	General Engineering	XXX	Water management plan for hydro testing and leak testing of pressure and gravity piping.	√		XXX	Jun-14

SECTION 2 - SAFETY AND SECURITY							
2-1	Safety Security	XXX	Provide clear, direct access ways and aisles to prevent tripping and congestion hazards		√		
2-2	Safety Security	XXX	Provide for good escape routes in case of fire or other emergencies on site.	√		XXX	Jun-14
2-3	Safety Security	XXX	When developing the plot plan, group equipment foundations in a way that permits the proper drainage of mass excavations.		√		
2-4	Safety Security	XXX	Consider area drainage during construction when developing the plot plan. Temporary ditching may be appropriate. Mitigation plan for drainage of runoff to sewer or sea.	√		XXX	Jun-14
2-5	Safety Security	XXX	Consider using a single, separate contractor to provide the security services for the entire project at construction gates, at offsite lay-down, storage and parking areas and for onsite facilities.	√		XXX	Jun-14
2-6	Safety Security	XXX	If possible, erect temporary fencing for job site and/or lay-down area security during construction.	√		XXX	Jun-14
2-7	Safety Security	XXX	Fire truck access to difficult to reach locations, include in safety and traffic control plan	√		XXX	Jun-14
SECTION 3 - MATERIALS MANAGEMENT							
3-1	Mat'ls	XXX	Minimize the number of materials used on the project.	√		XXX	Jun-14
3-2	Mat'ls	XXX	Identify the computer systems required to manage the materials red line DWG and documentation, and ensure that they are adequate and compatible for tracking and auditing.	√		XXX	Jun-14
3-3	Mat'ls	XXX	Make sure that responsibilities for the supply of subcontractor materials are clearly understood and identified in the contract documents. Keep in mind that materials supply can have a substantial impact on contractor performance. The price of materials may be small compared to the cost of delays and other impacts. Tagging system shall be reinforced against all materials on site.	√		XXX	Jun-14
3-4	Mat'ls	XXX	Establish a comprehensive materials management process with which all parties associated with the project agree. Ensure that all computer tracking systems are compatible. Keep in mind	√		XXX	Jun-14

			that the objective is to get the right material item to the field at the right time.				
3-5	Mat'ls	XXX	Have construction, in conjunction with engineering and procurement, develop a well-defined field schedule for all materials and equipment. This schedule should be developed early in the project, so that the design effort can be programmed to meet construction needs.	√		XXX	Jun-14
3-6	Mat'ls	XXX	Develop materials specifications in conjunction with vendors as early as possible. These specifications must take into consideration the true availability of materials in the market place.	√		XXX	Jul-14
3-7	Mat'ls	XXX	Use additional engineering manpower or overtime to keep the procurement process on track. Consider the total impact on the project.		√		
3-8	Mat'ls	XXX	When delays occur, work with the vendor/supplier to develop a plan of action to get back on track before the next milestones. Do not limit corrective action to getting on track by the end date.	√		XXX	Jun-14
3-9	Mat'ls	XXX	Develop a plan, a tracking program and procedures for material and equipment maintenance during storage and installation prior to startup. There can be considerable cost involved in this activity.	√		XXX	Jun-14
3-10	Mat'ls	XXX	Select the suppliers for bulk materials as early as possible and obtain commitments for delivery of long lead items. Use the suppliers to assist in timing of purchase.	√		XXX	Jun-14
3-11	Mat'ls	XXX	See to it that test and temporary bulk materials, particularly erection materials are not overlooked.	√		XXX	Jun-14
3-12	Mat'ls	XXX	Establish a well-defined computer tracking system for field control of bulk materials.	√		XXX	Jun-14
SECTION 4 – SCHEDULING							
4-1	Schedule	XXX	Develop an optimum construction sequence schedule, one that is based on engineering or procurement constraints; then; schedule the engineering and procurement activities to support this best-case schedule, modifying as necessary. The project schedule should be construction driven.	√		YYY	Jan-14
4-2	Schedule	XXX	See to it that the project schedule incorporates all the pre-assembly and modularization plans for the project.	√		YYY	Jan-14

4-3	Schedule	XXX	Identify repetitive work and use the same crew to perform this work.	√		YYY / XXX	Jan-14
4-4	Schedule	XXX	On portions of the job where engineering and procurement lead-time restrictions are at a minimum, push construction operations ahead quickly.		√		
4-5	Schedule	XXX	Plan equipment and material deliveries to avoid double handling by setting the items directly in position when received and incorporating the principle of just-on-time delivery to the maximum extent feasible.		√		
4-6	Schedule	XXX	Study field manpower requirements in relation to this schedule, and work with engineering to modify the sequences of design release in ways to achieve leveling of critical labor peaks.	√		XXX	Jan-14
4-7	Schedule	XXX	Study the effect of crane and other equipment movements on the permissible density of workers in congested areas, and plan shift-work or other programs to relieve overload problems with either equipment or people.	√		XXX	Jan-14
4-8	Schedule	XXX	Time heavy lifts to optimize crane usage.		√		
4-9	Schedule	XXX	Develop a plot plan to support the delivery of all pre-assemblies, skids and modules. Consider locating underground facilities on aboveground equipment. Also consider the impact of these facilities on the movement and location of construction equipment.		√		
4-10	Schedule	XXX	Locate underground utility corridors so that underground work does not affect the construction of deep foundations.	√		YYY / XXX	Jan-14
SECTION 5 - CIVIL WORKS							
5-1	Civil Works	XXX	Design foundations in 2" or 4" increments so field has flexibility in the type of forms to use; for example, patent forming systems (rental) can be a cost savings on some jobs. Patent forming systems are most economical when dimensions are in 2" or 4" increments.	√		YYY	Jan-14
5-2	Civil Works	XXX	Standardize foundation sizes for structures and miscellaneous support foundations. Should be designed as per geotechnical report.	√		YYY	Jan-14

5-3	Civil Works	XXX	Issue standard reinforcing details (cut-sheets) early so fabrication can start prior to actual installation of foundation. In the case of offsite fabrication, issue drawing early to fabricator. "CUT SHEETS WILL BE BY FABRICATOR OR CIVIL SUBCONTRACTOR."	√		XXX	Jun-14
5-4	Civil Works	XXX	Standardize bolts where practical, i.e., keep "type," thread type, and length of bolts consistent. When possible, keep bolt sizes to ¼" increments. Try to avoid as many 5/8", 7/8" and 1-1/8" bolts as possible.		√		
5-5	Civil Works	XXX	Issue bolt list (quantity, size, etc.) early, especially if there are requirements for special alloy steel or hot dip galvanizing.		√		
5-6	Civil Works	XXX	Request change of concrete form removal time except for elevated slabs, according to ACI 318-08 code.	√		XXX	Jun-14
5-7	Civil Works	XXX	Add special concrete testing requirements to drawing vs. specification interpretation, according to ACI 318-08 code.	√		XXX	Jun-14
5-8	Civil Works	XXX	Maximize use of site materials for backfill instead of imported select materials wherever possible.	√		XXX	Jun-14
5-9	Civil Works	XXX	When referring to a code, be specific, reference code, page, paragraph, dates, section, etc.	√		YYY	Jan-14
5-10	Civil Works	XXX	Construction and Engineering must thoroughly review the soil study at the proposed jobsite to establish the optimum Design/Construct method given alternatives.	√		YYY / XXX	Jan-14
5-11	Civil Works	XXX	Roads should be designed early so that road bases can be installed and utilized during the construction phase. Compaction of grades and subgrades shall be implemented before utilities layout and installation.	√		YYY / XXX	Jan-14
5-12	Civil Works	XXX	Fence plans and details should be developed early to aid with security measures.	√		XXX	Jun-14
5-13	Civil Works	XXX	Access roads should be designed to facilitate the movement of major equipment during and after construction. This should be incorporated into permanent road design when possible.	√		XXX	Jul-14
5-14	Civil Works	XXX	Avoid construction below water table whenever possible. Need input from geotechnical report about water table.	√		YYY / XXX	Jan-14
5-15	Civil Works	XXX	Underground drawings must show existing utilities.	√		XXX	Jun-14

5-16	Civil Works	XXX	Prior to the start of the project, select and test various sources of backfill material. The initial soils investigation should cover pits in the area of the jobsite. Include quantity survey as part of the investigation.	√		XXX	Jun-14
5-17	Civil Works	XXX	Specify mill test certificate requirements from vendors for rebar, bolts and embeds.	√		XXX	Jun-14
5-18	Civil Works	XXX	Establish excavation philosophy, i.e., individual footing excavation vs. major excavations, piling requirements, etc., as part of the Construction plan.	√		XXX	Jun-14
5-19	Civil Works	XXX	Field fabrication of rebar & embeds.	√		XXX	Jun-14
5-20	Civil Works	XXX	Concrete - Engineering/Construction to specify required additives and curing compounds. Confirm compliance with specification and location what is available?. Concrete - Specify aggregates and cement that are locally available.	√		XXX	Jun-14
5-21	Civil Works	XXX	Concrete - If more than one cement type is required, develop action plan to prevent inefficiencies, QC problems, scheduling difficulties, etc. Evaluate cost to go to one type of cement. LOOK @ TYPE 2.	√		XXX	Jun-14
5-22	Civil Works	XXX	Develop concrete placing programs and rates to minimize construction joint and maximize re-use of forms while staying within the mixing and placing capacity of equipment. Review the use of concrete conveyors, pumps and cranes with Engineering.	√		XXX	Jun-14
5-23	Civil Works	XXX	Early grading and paving sub base will facilitate efficient construction, drainage, and effective housekeeping.	√		XXX	Jun-14
5-24	Civil Works	XXX	Purchase bulk rebar in 60' lengths if possible.	√		XXX	Jun-14
5-25	Civil Works	XXX	Underground electrical plan drawings should show the location and elevations of all conduits, cables, ducts, etc., and also any underground piping which cross these underground ducts. (Profile views should be provided whenever runs change direction or cross.). Installation shall be implemented after compaction of grade and subgrade.	√		YYY / XXX	Jan-14
5-26	Civil Works	XXX	Review duct bank and manhole layouts to keep sharp bends to a minimum.	√		YYY	Jan-14

5-27	Civil Works	XXX	Minimize vertical rebar splices by extending column and wall rods to full height instead of using dowels.		√		
5-28	Civil Works	XXX	Have structural designers review their reinforced concrete design from the standpoint of the difficulty in placing rebar, placing and vibrating concrete and concrete formwork. For instance, consideration must be given to the available opening between vertical and horizontal rebar for the placement of stirrups or when hooked steel must be threaded through openings and hooked around horizontals and verticals. In either case, it may be more practical from construction standpoint to detail the item in two pieces, even though the splice will require additional material. In some instances, increasing the bar size and spacing will provide the necessary clearance.	√		XXX	Jun-14
5-29	Civil Works	XXX	Ensure that concrete specifications are practical and economical with respect to curing, weather protection, tolerances, etc. according to ACI code.	√		XXX	Jun-14
5-30	Civil Works	XXX	Use concrete of a single strength as much as possible.	√		YYY	Jan-14
5-31	Civil Works	XXX	To avoid possible delays on foundation construction caused by missing dimensions and details, investigate the possibility of mounting equipment on skids, which can be easily anchored to more simple foundations using drilled anchor bolts. Serving report should confirmed.	√		XXX	Jun-14
5-32	Civil Works	XXX	Consider using an automated concrete quality monitor (CQM) to assess the quality of fresh concrete while it is being placed. This device was developed by the U.S. Army Corps of Engineers and will predict the 28-day compressive strength of concrete, based on the water and cement contents of the fresh concrete. The device is easy to operate and readily available in the marketplace. It costs under U$10,000 and can perform a test in just 14 minutes.	√		XXX	Jun-14
5-33	Civil Works	XXX	A28-day criterion for concrete strengths may be overly conservative in most cases; consider a 90-day strength criterion instead.	√		XXX	Jun-14

5-34	Civil Works	XXX	Consider specifying a pre-approved repair procedure for concrete with voids or rock pockets, allowing immediate repair without documentation. This should result in better quality repairs and reduced documentation. Most concrete repairs are standard and should be performed while the concrete is still green.	√		XXX	Jun-14
SECTION 6 - STRUCTURAL							
6-1	Structural	XXX	Construction should participate in the conceptual planning of all structures to provide input into the practicality of pre-assembly and erection techniques.	√		YYY / XXX	Jan-14
6-2	Structural	XXX	Priorities on sequence of delivery of box culvert from vendor to the field must follow erection sequence and the Engineer should concentrate efforts toward design and release of drawings in accordance with established priorities. Shop orders will parallel priorities.	√		YYY / XXX	Jan-14
6-3	Structural	XXX	All approved for construction design drawings transmitted to the field should be full size (24" x 36") sepias. The title block on these drawings should be explicit and the drawing numbers legible, and identifying name and number for each structure or pipe-rack. In addition, each revision to these drawings should be subsequently issued to the field at the time of transmittal to the fabricator.	√		YYY / XXX	Jan-14
6-4	Structural	XXX	Each shop detail drawing from the steel fabricator should have a listing of the piece marks and structural weights. Shop detail drawings must be transmitted to the field with the erection drawings.	√		XXX	Jun-14
6-5	Structural	XXX	Only IFC drawings to be issued to the field.	√		XXX	Jun-14
6-6	Structural	XXX	Tagging procedures:	√		XXX	Jun-14
		XXX	Put two (2) piece-marks on all fabricated steel all rebar.	√		XXX	Jun-14
		XXX	Both will be used to show the piece-mark number, the shop order number, and the project number (or area number on multiple unit projects). This tagging method should be used on all fabricated steel items, including ladders and platforms. Tagging procedures will be issued with the inquiry document.	√		XXX	Jun-14
SECTION 7 - EQUIPMENT							

7-1	Instrum-entation	XXX	Data sheets will be made available at jobsite for the field acceptance and inspection.	√		XXX	Jun-14
7-2	Instrum-entation	XXX	Assure IFCof all vendor drawings are published and issued to the field.	√		XXX	Jun-14
7-3	Instrum-entation	XXX	Install permanent labels on equipment at factory instead of temporary labels.	√		XXX	Jun-14
7-4	Equipment	XXX	Provide grounding lugs on all tanks and equipment for field installation of grounding cables, most particularly anything with a lining. Orient equipment and lugs for embedded grounding termination.		√		
SECTION 8 - PIPING							
8-1	Piping	XXX	Provide specifications for preventative maintenance and storage requirements of specialty items.		√		
8-2	Piping	XXX	Where pipe borings cross permanent roads, assure design incorporates structural protection to support the heaviest transportation loads expected.	√		YYY	Jan-14
SECTION 9 - ELECTRICAL							
9-1	Electrical	XXX	Standardize designs where possible.	√		YYY	Jan-14
9-2	Electrical	XXX	Underground electrical plan drawings should show the location and elevations of all conduits, cables, ducts, etc., and also any u/g piping crossing these u/g ducts. Make every effort to flag individual cases.	√		YYY	Jan-14
9-3	Electrical	XXX	Ground drawings should be issued before or in conjunction with civil drawings.	√		YYY	Jan-14
9-4	Electrical	XXX	Engineering must establish requirements for electrical testing, hi-pot, relay testing, megger inputs, etc., so that if necessary a subcontract can be let for this specialized service.	√		YYY	Jan-14
9-5	Electrical	XXX	Conduit stub-ups under raised floors or in termination rooms for instrument wiring should be located near doors when possible to make wire pulling less costly. Avoid stub ups directly under equipment if possible.	√		YYY	Jan-14
9-6	Electrical	XXX	Review drawings to eliminate multiple runs of conduit by replacement with an equivalent tray and improve sequencing.	√		YYY	Jan-14
9-7	Electrical	XXX	When possible, design high voltage electrical lines underground to minimize	√		YYY	Jan-14

			crane contact and other fatal shock hazards.				
9-8	Electrical	XXX	Portions of work which can be pushed ahead to relieve later peaking of critical crafts should be identified/scheduled.	√		YYY	Jan-14
9-9	Electrical	XXX	Close interface between client and contractor personnel will be maintained through construction.	√		YYY	Jan-14
9-10	Electrical	XXX	Follow the project to the field. Key design engineering personnel will be made available to be resident at the site to assist with questions of design intent and to help out during pre-commissioning/continuity checkout.	√		YYY	Jan-14
9-11	Electrical	XXX	Long lead-time delivery items shall be purchased as soon as possible to support the construction schedule.		√		
9-12	Electrical	XXX	The types of bulk materials shall be standardized to reduce the number of different sizes and/or materials. This will assist the construction contractor by having fewer deliverables to monitor and eventually issue to construction force.	√		YYY	Jan-14
9-13	Electrical	XXX	The use of galvanized "unistrut" rather than using structural steel supports and brackets smaller than 2 inch in section shall be maximized.	√		YYY	Jan-14
9-14	Electrical	XXX	Long run cable will be identified on the individual spools when they are shipped.	√		YYY	Jan-14
9-15	Electrical	XXX	Electrical cable pulling locations for access of equipment for banking of cable spools, for downhill pulls, etc. shall be carefully planned as cable tray drawings are developed.	√		YYY	Jan-14
9-16	Electrical	XXX	A simple and logical wire marking system which also can be used during construction for quantity control shall be developed.	√		YYY	Jan-14
9-17	Electrical	XXX	Pre-commissioning/continuity check guidelines and requirements will be developed up front so that proper documentation can be developed to support the field activities.	√		YYY	Jan-14
9-18	Electrical	XXX	Specify coding of individual conductors by different colors of insulation for control cables rather than identifying conductors with numbers or letters on the same color insulation.	√		YYY	Jan-14
9-19	Electrical	XXX	Cable number will be shown on schematic drawings.	√		YYY	Jan-14

9-20	Electrical	XXX	Electrical drawings should reference Civil drawings that detail appurtenances (supports, block outs, embeds, etc.) to accommodate electrical components.	√		YYY	Jan-14
9-21	Electrical	XXX	Do not utilize block diagrams for installation by themselves. They always require layout drawings, schematics and wiring diagrams to back them up.	√		YYY	Jan-14
9-22	Electrical	XXX	Engineering should ensure that the purchase orders include the cable reel numbers from the pull schedule so that the reels will be properly marked when received.	√		YYY	Jan-14
9-23	Electrical	XXX	All material bought for special installations should be referenced to the drawing and the drawing referenced to the correct BOM.	√		YYY	Jan-14
9-24	Electrical	XXX	All cable tray horizontal fitting installations require proper support on each side of the fitting. This is commonly left off the structural design.	√		YYY	Jan-14
9-25	Electrical	XXX	Engineering shall insure that all control system interlock information is utilized on all schematics and referenced as required.	√		YYY	Jan-14
9-26	Electrical	XXX	All special NAMEPLATE requirements should be specified up-front to eliminate rework after installation.	√		YYY	Jan-14
9-27	Electrical	XXX	Cable schedules should have to/from routing, cut length schedules for power cables, cable number, MED. VOLTAGE CABLE, reel numbers, SYSTEM TURN-OVER NUMBER and a layout reference drawing number.	√		YYY	Jan-14
9-28	Electrical	XXX	Overhead cable trays are preferred over underground raceways/conduits as they offer more flexibility for future additions.	√		YYY	Jan-14
9-29	Electrical	XXX	Avoid installing cable tray directly over the top of electrical equipment inside substation. An offset may be required for cable access and dropouts.		√		
9-30	Electrical	XXX	Design adequate support for cable tray that is hung in a substation, control room or any location where tray loading may exceed the normal.		√		
9-31	Electrical	XXX	All engineering purchased tagged equipment such as control panels, lighting/power panels and junction boxes shall be purchased with identification tags attached. This will aid in material control and field erection. Coordinate	√		YYY	Jan-14

			location of light fittings with mechanical equipment layout.				
9-32	Electrical	XXX	Vendor will comply with specifications for marking terminal blocks. This continues to be a source of excessive field rework man-hours.	√		YYY	Jan-14
9-33	Electrical	XXX	Include excavation, backfill and trenching specs in the Electrical and Instrumentation scope subcontract packages, as required.	√		YYY	Jan-14
9-34	Electrical	XXX	Investigate use of inexpensive PVC conduit for embedded runs.	√		YYY	Jan-14
9-35	Electrical	XXX	Coordinate location of power outlets with furniture layout.	√		YYY	Jan-14
9-36	Electrical	XXX	Ensure all HVAC isolators are accessible and not obstructed by mechanical equipment.	√		YYY	Jan-14
SECTION 10 - PROJECT SPECIFIC ISSUES-CHALLENGES-CONCERNS							
10-1	Project Specific	XXX	Develop a traffic control plan including ingress and egress for heavy equipment and contractor employees. Consider box drainage culvert may restrict access to portions of the site for heavy equipment or design box drainage culvert to handle heavy equipment transportation loading.	√		YYY	Jan-14
10-2	Project Specific	XXX	Construction temporary offices size, security & temporary utilities. Develop drawings to outline the areas available.	√		YYY	Jan-14
10-3	Project Specific	XXX	Construction personnel parking areas and preparation of the parking areas; engineered fill?		√		
10-4	Project Specific	XXX	Develop dust, noise and pollution control plans for use during construction. Surrounded by major development.	√		XXX	Jan-14
10-5	Project Specific	XXX	Consider making temporary utilities available to construction contractor. Requires up front coordination with municipalities.		√		
10-6	Project Specific	XXX	Dewatering and disposal of water. Coordinate with municipality regarding disposal of water.		√		
10-7	Project Specific	XXX	Long lead material availability and delivery including transformers.	√		XXX	Jul-14
10-8	Project Specific	XXX	MARAFIQ and STC approvals of electrical and non-electrical utilities and communications.	√		XXX	Jul-14
10-9	Project Specific	XXX	late delivery of doors and windows		√		
10-10	Project Specific	XXX	late delivery of ceramic tiles		√		

10-11	Project Specific	XXX	Identify location of all utilities tie-in points at the interface. Coordinate with government agencies to determine the specific locations of the tie points.	√		XXX / YYY	Dec-13
10-12	Project Specific	XXX	Consider precast box culvert segments during detail design instead of cast in place to facilitate construction. Box culvert precast fabrication work can be done while site development is in progress.	√		XXX / YYY	Dec-13

APPENDIX E

ACONSTRUCTABILITY REVIEW ITEMS OF CASE STUDY-2

No.	Category	Action By	Item	Initial Review Action Sheet			
				Accepted	Rejected	Assigned to	Due Date
SECTION 1 - GENERAL ENGINEERING							
1-6	General Engineering	XXX	Complete as soon as possible the design and layout of installations that become difficult to access because of the installation of following equipment, piping, conduit, etc.	√		YYY	May-13
1-7	General Engineering	XXX	Arrange permanent plant facilities so that access required for construction will not be blocked or restricted.	√		YYY	May-13
1-12	General Engineering	XXX	Check for proper equipment location to minimize later revisions during design. Incorporate an appropriate level of pre-assembly and include work areas for the pre-assembly activities in the site layout.	√		YYY	May-13
1-15	General Engineering	XXX	Visit to the site to identify all special site conditions	√		YYY	May-13
1-16	General Engineering	XXX	Keep construction access in mind when planning layout for major equipment. Good access lowers rigging costs and provides future maintenance access. An open construction layout leaves work area for future turnarounds/maintenance.	√		YYY	May-13
1-19	General Engineering	XXX	Size the width of roads and gates to accommodate the largest cranes and pieces of equipment that will be used or placed on the project.	√		YYY	May-13
1-20	General Engineering	XXX	Plan access ways for cranes to be used in both construction and maintenance. Provide convenient crane access to heavy equipment.	√		YYY	May-13
1-21	General Engineering	XXX	Make sure that the plot plan provides for temporary facilities and easy access to lay-down areas.	√		YYY	May-13

1-33	General Engineering	XXX	Consider the need for emergency access and evacuation in the planning process. Make part of LSTK contract	√		YYY	May-13
SECTION 2 - SAFETY AND SECURITY							
2-1	Safety Security	XXX	Provide clear, direct access ways and aisles to prevent tripping and congestion hazards	√		YYY	May-13
2-2	Safety Security	XXX	Provide for good escape routes in case of fire or other emergencies on site.	√		YYY	May-13
2-3	Safety Security	XXX	When developing the plot plan, group equipment foundations in a way that permits the proper drainage of mass excavations.	√		YYY	May-13
2-6	Safety Security	XXX	If possible, erect permanent fencing for job site and/or lay-down area security during construction.	√		YYY	May-13
2-7	Safety Security	XXX	Security Fencing Type w/ associated elements is determined by facility classification. The classification is pending conducting/completing SVA as per standard.	√		YYY	May-13
2-8	Safety Security	XXX	Construction site should be secured.	√		YYY	May-13
2-9	Safety Security	XXX	Maintaining a minimum of 60 m clearance from plant security fence for vital elements as defined by operator.	√		YYY	Mar-13
2-10	Safety Security	XXX	The need for FSF government check point.	√		YYY	May-13
2-11	Safety Security	XXX	Pipes proposed adjacent & parallel to a portion of security patrol road better to be relocated in a safer location.	√		YYY	Mar-13
2-12	Safety Security	XXX	Areas surrounding security fence (in/out) is reserved for security services. They shall be cleared from other obstructions/installations, including swale/drainage channels & ditches.	√		YYY	May-13
2-13	Safety Security	XXX	Where applicable contractors staff should arrange for their ID & Access.	√		YYY	May-13
SECTION 4 - SCHEDULING							
4-2	Schedule	XXX	See to it that the project schedule incorporates all the pre-assembly and modularization plans for the project.	√		YYY	May-13

4-7	Schedule	XXX	Study the effect of crane and other equipment movements on the permissible density of workers in congested areas, and plan shift-work or other programs to relieve overload problems with either equipment of people.	√		YYY	May-13
4-9	Schedule	XXX	Arrange equipment to facilitate construction sequencing. Develop a specific sub-schedule to ensure that the plot plan arrangement will allow equipment setting.	√		YYY	May-13
4-10	Schedule	XXX	Develop a plot plan to support the delivery of all pre-assemblies, skids and modules. Consider locating underground facilities on aboveground equipment. Also consider the impact of these facilities on the movement and location of construction equipment.	√		YYY	May-13
SECTION 5 - CIVIL WORKS							
5-51	Civil Works		Storm drainage systems should be developed as early as possible in order to facilitate usage during construction.	√		YYY	May-13
5-52	Civil Works		Roads should be designed early so that road bases can be installed and utilized during the construction phase.	√		YYY	May-13
5-53	Civil Works		Fence plans and details should be developed early to aid with security measures.	√		YYY	May-13
5-54	Civil Works		Access roads should be designed to facilitate the movement of major equipment during and after construction. This should be incorporated into permanent road design when possible.	√		YYY	May-13
5-55	Civil Works		Avoid construction below water table whenever possible.		√		
SECTION 6 - STRUCTURAL							
6-1	Structural	XXX	Construction should participate in the conceptual planning of all structures, pipe-racks, and bridges to provide input into the practicality of pre-assembly and erection techniques.		√		
SECTION 7 - EQUIPMENT							
7-1	Equipment	XXX	As early as possible, the Engineer should provide the following information to formulate a Preliminary Master Rigging Plan:		√		

		XXX	Major equipment lists complete with dimensions and estimated erection weights.		√		
7-2	Equipment	XXX	Plot Plans showing equipment arrangement, access, structures and other obstructions.		√		
SECTION 8 - PIPING							
8-2	Piping		Provide specifications for preventative maintenance and storage requirements of specialty items.		√	LSTK	
8-5	Piping		Engineering should provide specifications and criteria for nondestructive examination requirements, (radiography, Liquid Penetrant, etc.) with construction input. Specify type of fluid as per ASME B31.3	√		YYY	May-13
8-12	Piping		Where pipelines cross permanent roads and crane access-ways around buildings, assure design incorporates structural protection to support the heaviest cranes routinely used. Heavier cranes can be matted.		√		
SECTION 9 - ELECTRICAL							
9-1	electrical	XXX	preliminary cutover and energization plan for all areas. Specify requirement for detailed cutover plan to be prepared by LSTK contractor.		√		
9-2	electrical	XXX	temporary power for construction site provided by LSTK contractor. LSTK to provide their own generators and transformers for construction and pre-commissioning activities.	√		YYY	May-13
SECTION 11 - PROJECT SPECIFIC ISSUES-CHALLENGES-CONCERNS							
11-1	Project Specific	XXX	identification of solid waste, wastewater and other types of disposal area for EPC. Require EPC contractor to create and submit for approval a waste management plan. Boiler plate standard contract?	√		YYY	Apr-13
11-2	Project Specific	XXX	requirements for an emergency evacuation plan for workers. Access and egress requirements as part of the plan. Review need for temporary fence and gates.	√		YYY	Apr-13

11-3	Project Specific	XXX	identify disposal area for hydro testing water.	√		YYY	Apr-13
11-4	Project Specific	XXX	implement modularization concept for structural steel such as pipe racks. Develop methodology or criteria for designing pipe racks utilizing modularization. Require a modularization study of LSTK bidder / contractor.	√		YYY	Apr-13
11-5	Project Specific	XXX	critical lift to be identified and when and where. Review availability of schedule and accommodate the critical lift in the construction schedule.		√		
11-6	Project Specific	XXX	identify a reliable source of demineralized hydro testing water. Investigate sea water as alternate supply		√	NA	NA
11-7	Project Specific	XXX	develop facilities 3-D modeling requirements for project proposal and detail design including tanks. Define level of 3-D modeling required, systems to be used and how often model must be submitted and updated, model review frequencies and other criteria. Facilitates visualization of construction and minimizes rework.	√		XXX	Apr-13
11-8	Project Specific	XXX	define the work permits issue procedure, requirements and responsibilities.	√		XXX	Apr-13
11-9	Project Specific	XXX	identify all necessary permits from different organizations. SCECO, municipalities outside the plant and inside the plant internal organizational permits etc.	√		XXX	Apr-13
11-10	Project Specific	XXX	Verify jubail bulk plant access road construction interface with construction of tareg 8	√		YYY	Apr-13
11-11	Project Specific	XXX	Obtain approval for power line route from RC and SEC	√		YYY	May-13
11-12	Project Specific	XXX	Verify scraper location spacing from SSD fence based on the SSD standards.	√		YYY	May-13
11-13	Project Specific	XXX	provide connection for oily water sewer of future loading bays.	√		YYY	May-13
11-14	Project Specific	XXX	Shift the OWS header south of pipe rack for easy construction	√		YYY	May-13
11-15	Project Specific	XXX	Consider rerouting the pipe ways between scraper and loading bays to facilitate constructions.	√		YYY	May-13

11-16	Project Specific	XXX	develop a drainage plan to avoid ponding	√		YYY	May-13
11-17	Project Specific	XXX	provide asphalt paving around vapor recovery unit and scraper area.	√		YYY	May-13
11-18	Project Specific	XXX	OWS is provided for recovered oil tank, CPI Separator, VRU and other equipment handling hydrocarbon.	√		YYY	May-13
11-19	Project Specific	XXX	Verify that above ground product pipes are located at least 18m away from SSD fence.	√		YYY	May-13
11-20	Project Specific	XXX	Review the composite drawing to check conflict between foundations, cable routing, under pipe routing etc.	√		YYY	Apr-13
11-21	Project Specific	XXX	Include overall site development plan showing access roads.	√		YYY	Apr-13
11-22	Project Specific	XXX	Define Site office, fabrication yard and laydown yard location	√		YYY	Apr-13
11-23	Project Specific	XXX	obtain LUP for borrow pit (for site grading)	√		YYY	Apr-13
11-24	Project Specific	XXX	obtain SA hydrology dept. approval for water well	√		YYY	Apr-13
11-25	Project Specific	XXX	verify power source and control signal tie-in for sectionalizing valve for MTBE pipeline.	√		YYY	Apr-13
11-26	Project Specific	XXX	Verify entry gate cabinet location to avoid parking of trucks on the main road	√		YYY	Apr-13
11-27	Project Specific	XXX	Verify compatibility issue between Truck identification system (TIS) and preset controller.	√		YYY	Apr-13
11-28	Project Specific	XXX	Verify criteria for medical clinic requirement.	√		YYY	Apr-13

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