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CONSTRUCTABILITY: CAPABILITIES, IMPLEMENTATION, AND BARRIERS

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Abstract: Constructability means finding ways to construct effectively. It minimises disputes, cost overrun, and schedule delays. However, constructability program adoption in construction projects differs from one corporation to another, and the level of implementation (measured in two levels: corporate and project level) extends from highly sophisticated to none at all. Despite its benefits, many construction companies are reluctant to fully implement it due to many barriers (e.g. complacency with status quo and lack of expertise for design firms). In order to improve the effectiveness of constructability programs in construction projects, identification and mitigation of constructability program barriers using gap analysis techniques should be done. This paper illustrates research done with a partner company to measure degree of implementation of constructability in the company. We used CII constructability evaluation matrix to evaluate the degree of implementation of constructability program in both corporate and project levels. ASCE survey and two case studies of existing projects were also used to provide a clear picture of current practices of constructability in the company. The analysis showed that the company constructability program ranged from informal to formal and the percentages of implementation of the program in planning and execution phases were 63% and 67%, respectively. We introduced recommendations for the six missing concepts in the partner company practice.

1 INTRODUCTION

Construction projects are unique in terms of their goals and values, and different projects with different natures normally encumber systematically applying the same construction, communication, procurement or contracting methods. Defining projects major elements such as overall project plan, planning and design, construction schedule, cost estimate, and major construction method is a normal procedure applied by any construction company. The integration and optimization of project major elements enhance project objectives for achieving owner's expectations in terms of schedule, cost and quality of the final product, and normally it is done by including expert knowledge in the project. Implementing constructability concepts is one way to achieve maximum inclusion of construction expert knowledge in any construction project.

Construction Industry Institute (1986) defined constructability as "the optimum use of construction knowledge and experience in planning, design, procurement, and field operation to achieve overall project objective," and in 1991, presented by the Construction Management Committee, ASCE divided constructability into two terminologies: constructability and constructability program. The ASCE defined constructability as “the capability of being constructed” and defined constructability program as “the application of a disciplined, systematic optimization of construction related aspects of a project during the planning, design, procurement, construction, test, and start up phases by knowledgeable, experienced construction personnel who are part of a project team. The program’s purpose is to enhance the project’s overall objectives.”

Constructability programs are not fully implemented in projects due to many reasons (e.g. lack of communication between project participants starting from the conceptual design stage). Type of project, contract type, availability of experienced construction personnel and many other barriers affect the implementation of constructability programs in construction projects. For example, in public services projects, design bid built type of contracts are used. This type of project limits the involvement of contractors in the conceptual design phase of any project and normally it is mitigated by adding design services as part of the contract. Lack of understanding of the benefits of applying constructability programs is another example of barriers. Understanding benefits of applying constructability concepts on construction projects can motivate project parties on applying formal, explicit constructability knowledge bases. For example, it was found that the owner saving on project cost and schedule when applying constructability was 4.3% and 7.5%, respectively (Russell, et al., 1992b). Delivering these research outputs to project participants or stakeholders can enhance the adoption of constructability programs in construction projects.

The level of implementation of constructability programs varies from highly sophisticated program to none at all. These levels of implementation of constructability programs are controlled by barriers which limit the effectiveness of constructability concepts in the construction industry. The existence of constructability barriers extends from corporate to project levels and its mitigating process involves a three-phase cycle: identification, mitigation and review (O'Connor & Miller, 1995). Conducting surveys administered to projects parties is one way to show the gap between the formal constructability program and what is actually implemented in reality. For example, ASCE, represented by Construction Institute’s Constructability Committee, conducted a survey to address the current state of constructability best practices in the architecture, engineering and construction industry (Pocock, et al., 2006).
This paper will illustrate the gap analysis of constructability program implementation in a construction company located in Alberta. We used two approaches to study the gap: reviewing historical projects and surveys. These two approaches complement each other as the first method focuses on project level, the later focuses on corporate level. The paper also proposes a recommendation for the partner company to further enhance their constructability program implementation.

2 LITERATURE REVIEW

Based on the definition of constructability program by ASCE, the optimum use of construction program concepts in any project can be achieved by the involvement of construction personnel in the project team starting from the conceptual design stage. This point depends on the understanding of constructability program capabilities by all project parties, which can result in a corporate commitment for applying such a program. The level of implementation of constructability is controlled by many barriers such as complacency with the status quo and lack of expertise for design firms, and overcoming such barriers is important to create a solid constructability program structure. The following section discusses capabilities, implementation and barriers of constructability program.

2.1 Capabilities

Implementing constructability leads to more owner satisfaction and contractor profit. Jergeas and Put (2001) introduced an example of implementing constructability profit: Trans Canada saved 40% in building a compressor station compared to historical similar projects when they applied constructability concepts. Another example on constructability program capability was presented by Russell, et al. (1992b). He found that the owner saving in project cost and schedule when applying constructability was 4.3% and 7.5%, respectively.

2.2 Implementations

The implementation of constructability programs varies from one corporation to another. The level of implementation or existence of constructability program extends from extremely sophisticated, excellent programs to none at all (Construction Management Committee of ASCE Construc, 1991). CII also concluded that constructability program implementation in the construction industry lacks structure and is progressing slowly (1993). This section provides description of the implementation of constructability programs in the construction industry.

2.2.1 Constructability methods

According to Raviv, et al. (2012), constructability methods can be grouped under seven family categories according to different approaches or methods of implementation:

- Formal corporate policy statement
- Checklists covering corporate procedures, lessons learned, and technical issues
- Organization measures
- Contractual measures
- System modeling and analysis methods
- Reviews
- Advanced technology methods like building information technology (BIM)

Raviv, et al. (2012) found that a construction engineer with full authority and responsibility for constructability is the best, most effective way to achieve constructability, while contract incentive clauses, brain storming, owner's involvement, and formal company constructability procedures are the least effective methods. Criticising this point, the author disagrees with Raviv. The effectiveness of mentioned factors is almost of the same weight. Indeed, the integration of all these factors can produce a solid constructability program structure.

2.2.2 Constructability knowledge transfer

Typically, contractors have more expertise in constructability than engineers; therefore, transferring contractors' expertise to engineers during the design process will increase efficiency. However, the right information must be available for engineers at the right time. Unfortunately, transferring expertise is done on an ad hoc basis. O'Connor and Miller (1994) introduced the Conceptual Product/Process Matrix Model (CPPMM) which can be used to organize constructability knowledge based on appropriate timing and level of details (Pulaski & Horman, 2005). CPPMM is a kind of matrix, where the vertical axis represents level of details and the horizontal axis represents project phase. According to the current project phase, the relevant information will be introduced. For example, during steel structure design, the model might suggest using shop welding instead of bolting in site. Pulaski and Horman (2005) introduced a case study on using CPPMM in a Pentagon renovation project.

2.2.3 Constructability in design firms

Constructability starts from the design stage; engineers must bear in mind how the contractors will execute the job, otherwise schedule delays and claims are inevitable. A new contracting systems like design-build push design companies to implement constructability as a procedure in the design process. According to Arditi, et al. (2002), many design firms have a formal (explicit) constructability program that is launched as early as the conceptual planning stage of the project. They reviewed constructability implementation during the design phase in a construction project. They focused on existence of constructability programs, timing implementation, and factors that improve or hinder constructability implementation. Arditi, et al. (2002) showed that peer reviews and feedback systems are the most prevalent tools used to achieve high levels of constructability.

2.3 Constructability Implementation Barriers

Constructability tries to improve construction companies' performance; however, implementing it faces many barriers. A barrier to constructability can be defined as any significant inhibitor that prevents effective implementation of the constructability program (O'Connor & Miller, 1994). O'Connor and Miller (1994) categorized barriers into general, owner, designer, constructor, organized labor, vendor, code authority, and researcher barriers. These barriers affect corporate and project level.
Jergeas and Put (2001) designed a survey to identify constructability barriers in Alberta; they found a large gap in the following constructability concepts:

- Up-front involvement of construction personnel during design stage. This is mainly due to using the traditional contract (design-bid-build), especially in the public sector.
- Construction efficiency, which can be achieved by modularization and pre-fabrication. However, modularization is specific to certain projects.
- Using innovative construction methods.

Goodrum, et al. (2003) discussed the implementation of constructability on highway construction projects. They surveyed 19 state transportation agencies to identify implementation barriers. Lack of time, lack of available manpower, lack of available experience, and contractor reluctance were the main stated barriers.

2.3.1 Barrier mitigation

O'Connor and Miller (1995) suggested identifying barriers then mitigating or overcoming these barriers using barrier breaker tactics. Construction Industry Institute (CII) introduced a list of barrier breakers (O'Connor & Miller, 1995); this includes seven steps to mitigate complacency with status quo:

- Designate a strong program champion
- Report constructability program benefits regularly
- Make constructability the responsibility of younger, more energetic individuals, who more frequently confront the status quo
- Establish funded programs that promote creativity and intelligent risk-taking
- Establish monetary awards for rewarding innovation and intelligent risk-taking
- Conduct training programs in shifting paradigms, promoting creativity, and promoting critical thinking
- Screen out personnel who regularly support the status quo

3 GAP ANALYSIS

We performed a gap analysis of constructability program implementation in a construction company located in Alberta. Identifying the constructability gap is a crucial step to reaching a full constructability implementation. We used two approaches to study the gap: reviewing historical projects and surveys. These two approaches complement each other as the first method focuses on project level, the later focuses on corporate level.

3.1 Methodology

The data used in this study were obtained by two means: 1) reviewing historical projects and 2) surveying a construction manager working with the partner company (a construction company in Alberta). The survey covers two project case studies, which have been built by the partner company. The survey contains two parts: constructability program evaluation matrix, provided by CII, and a survey questionnaire prepared by ASCE Construction Institute's Constructability Committee (1991). The constructability program evaluation matrix is further divided into two sections: corporate constructability evaluation matrix and project constructability evaluation matrix, as shown in Figure 1. The corporate constructability evaluation matrix shows 13 parameters identified by CII for assessing the level of implementation of the constructability program at the corporate level. The level of implementation is

classified into five levels; level 1 represents no program implementation and level 5 represents comprehensive formal program. In project constructability evaluation matrix, 10 parameters were identified to assess the implementation of the constructability program at the project level and the classifications of implementation levels are the same as for the corporate level. This survey allows the determination of areas where improvement of constructability program is required and also identifies areas where the constructability program is successful.
The second part of the survey is used to provide a clear picture of current practices of constructability in the construction company, which is achieved by describing the following points (ASCE, 1991):

- Project phases at which constructability efforts usually begin.
- Constructability methods used during design and construction.
- Who requires constructability and who performs it.
- The major benefits of constructability and problems it could prevent.
- The major obstacles to implementing constructability.
- Progress in constructability practice and where improvement is needed.

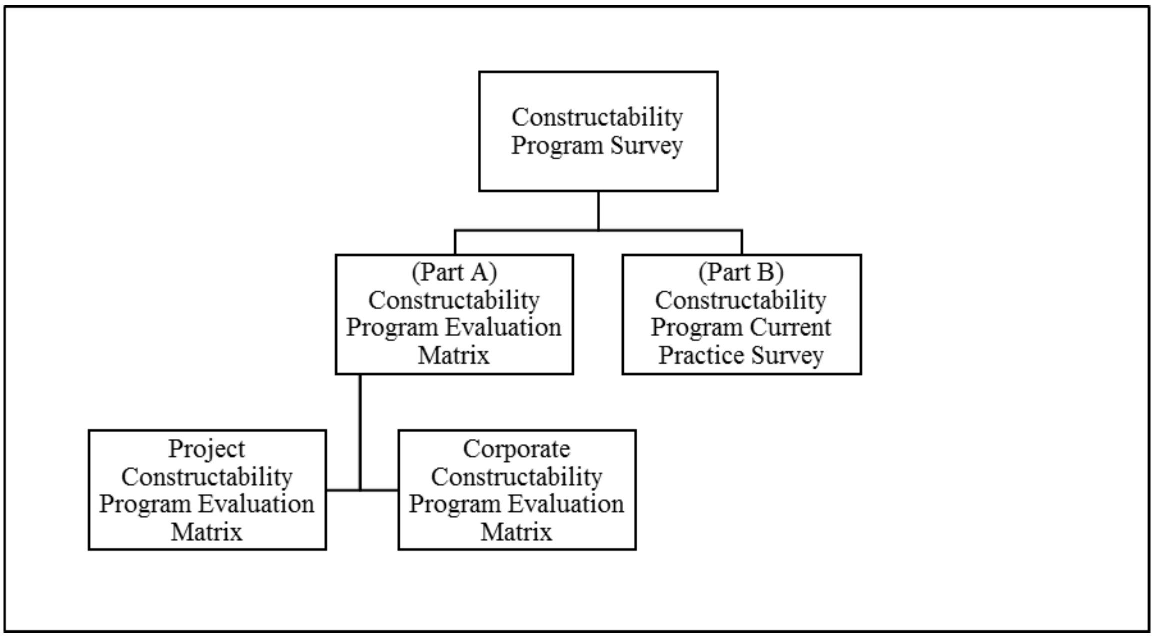

Figure 1 Constructability Survey Structure

3.2 Case Study

The gap analysis is done on two projects that have been built recently by the partner company. The first project (Project A) involves replacing four existing cyclones and associated ancillary equipment in the Raw Meal Preparation Area with two larger cyclones. The scope of the project included civil, structural, and mechanical works. The partner company tried to include constructability concepts in the project, especially in the early design phase. These attempts included:

- Brainstorming to identify stakeholders' expectation and opportunities.
- Inspecting "lessons learned" from previous projects.
- Assessing safety considerations like site congestion and critical rigging and lifting.

The Generator Replacement – Evaporator Modernization Project (Project B) for Pulp and Paper Companies is the second case study we considered in the constructability gap analysis. In this project, the partner company applied constructability concepts in different project phases, as follows:

- Conceptual design phase:
  - Optimize layout and routing by assessing equipment locations to minimize handling and reduce crane requirements.
  - Set up an effective communication plan to minimize the impact of delays for all project stakeholders.
- Design and procurement phases:
  - Assess severe winter conditions in the design phase (e.g. use domed tents).
  - Consider three different design options to see which one is better from the constructability prospective.
  - Discuss vessels' design with constructability personnel.

3.3 Result

By reviewing constructability concepts in the company's historical projects and surveying, we were able to assess how constructability concepts have been implemented in the partner company. Analysis of Part A of the survey shows that constructability implementation in the company lies between informal and formal program. Table 1 summarizes the results of constructability implementation in the partner company. We included 13 CII constructability principles (Jergeas & Put, 2001) with the corresponding degree of implementation. We used a scale from 1 to 5 for degree of implementation, where 5 means fully implemented and 1 means missing concept, in the partner company practice.
These 13 concepts can be grouped into two general categories: 1) planning phase and 2) executing phase. Figure 2 and Figure 3 show percentage of implementation for each group separately. These figures show that the partner company used concepts like constructability in early project planning and considering adverse weather; however, they are behind in using modularization, preassembly and standardized elements.

Table 1 Constructability concepts and degree of implementation (5 means fully implemented and 1 means missing concept).

Concept	Value	Concept	Value
Constructability program integration	4	Design and procurement schedules are construction sensitive	3
Constructability in early project planning	5	Designs consider constructability issues	4
Constructability in contracting strategy	2	Standardized design elements	4
Modularization and preassembly	1	Considering adverse weather	4
Site layouts promote efficient construction	5	Design facilities turnover and start-up	3
Constructability team	1	Innovative construction methods	4
Advanced information technologies (3D modeling)	4		

4 RECOMMENDATION

This section discusses the missing constructability concepts in the partner company and tries to fully implement them.

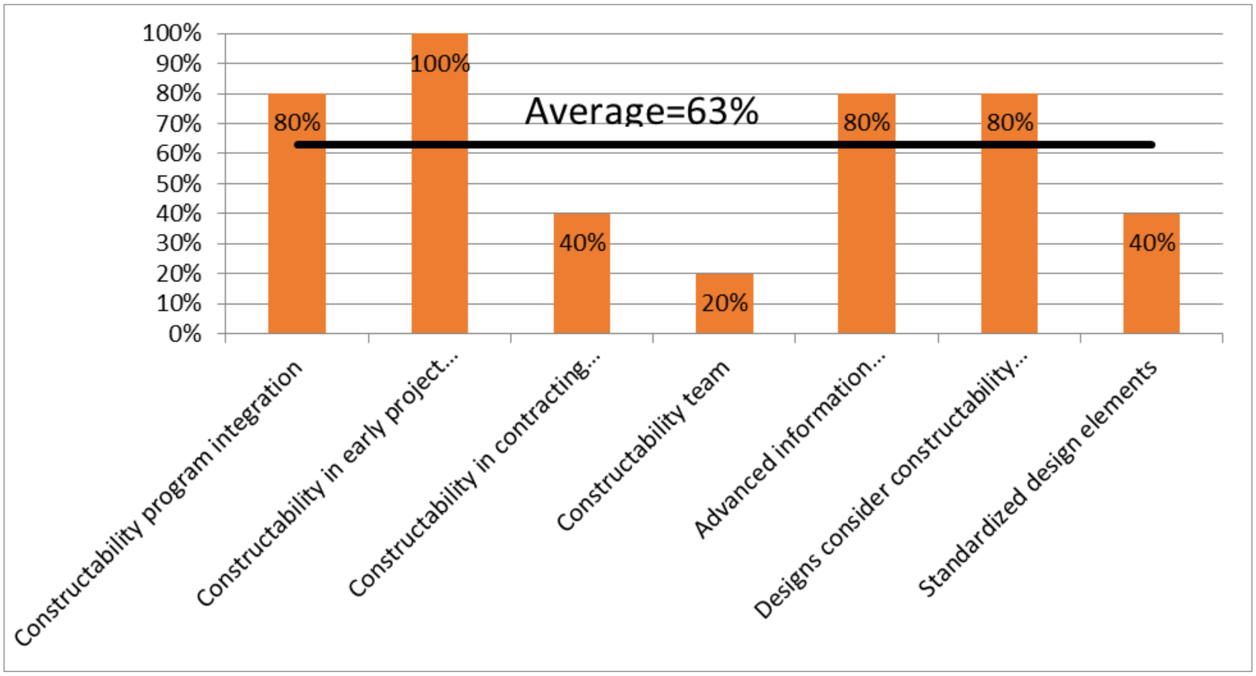

Figure 2 Degree of constructability implementation concepts in planning phase

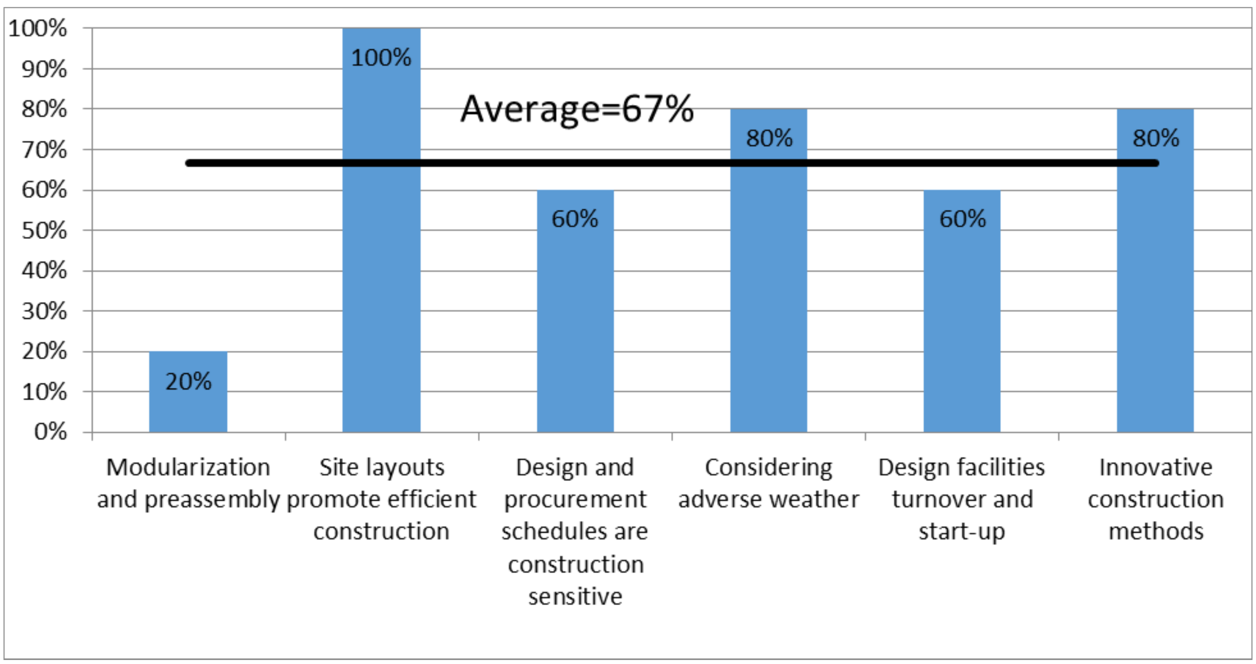

Figure 3 Degree of constructability implementation concepts in execution phase

4.1 onstructability in Contracting Strategy

The ultimate use of constructability program concepts in construction is affected by the selection of the type of contract. For example, in design-build and cost reimbursable contracts, the owner and contractor teams work together, while in design-bid-built contracts, the owner and contractor teams work individually, which results in less integration of construction experience in the design stage. The construction management committee of ASCE summarized the factors affecting the selection of the type contract as the following (1991):

- Owner's corporate policy on contracting.
- Availability of in-house experienced personnel.
- Time available to get the project designed and constructed.
- Desire of owner to control elements of project.
- Importance of cost to owner.
- Amount of risk owner wants to contract out.
- Availability of contractors.
- Local construction climate.
- Experience or confidence in contractor or design builder.

Constructability concepts can be formulated in the contracting strategy by the following points:

1. Including the help of experienced construction personnel in choosing the right contract for the right project for the owner.

2. Adding design services as part of fixed price contracts.

3. Achieving mutual trust with the owner to maintain the use of cost reimbursable type of contracts in the future.

4. Documenting success stories when using constructability programs and delivering them to owners.

4.2 Constructability Team

Constructability process involves the integration of construction knowledge and experience prior to the beginning of the actual design. This process is achieved by the formation of a constructability team that includes construction experts. The application of constructability team in the construction industry differs based on the motivation and the attitude of project participants on applying constructability programs in their projects. For example, the owner is required to expand his front-end planning and invest more time and money in forming a constructability team to better address the interrelationship between construction method, material, equipment, and construction trades. In the contractors' point of view, constructability teams are always formed while tendering and prior to construction to break down the project to allocate required labor, equipment, materials, etc. for the project. The maximum effectiveness of constructability programs in terms of forming constructability teams can be achieved when constructability teams of the owner and the contractor work together in harmony. This concept can be achieved by considering the following points:

1. Consider forming constructability teams as part of the project roadmap.

2. Establish formal commitment to the idea of constructability.

3. Highlight the importance of early involvement of constructability.

4. Establish constructability specialist's position in the company.

4.3 Standardized Design Elements

Projects are unique and different projects have different design elements. It is difficult to standardize design elements that can work in any project because the design is controlled by the design firm. However, it is possible to standardize the design elements for big projects with repetitive features such as high rise buildings and residential compounds; therefore, constructability in the form of standardized design elements can be applied in only certain types of projects. Maximizing the use of standardized design elements can be achieved by the following points:

1. Deliver the fact of saving time and money by using standardized design elements to the owner.

2. Enforce the use of standardized design elements in projects of repetitive nature.

3. Provide in-house training in BIM technology.

4.4 Modularization and Preassembly

Prefabrication and preassembly have doubled in the last 15 years (Haas, et al., 2000). However, some companies fail to implement this concept due to barriers like “it is specific for certain projects” (Jergeas & Put, 2001). However, modularization and preassembly are very effective to overcome severe weather and uncontrolled quality on site. It improves productivity and reduces project duration. The following guidelines will help in implementing this concept:

1. Form constructability team early and make sure they are involved in design stage.
2. Use BIM technology.
3. Realize that using modularization and preassembly will be very useful for schedule-driven projects.
4. Perform further analysis for modularization and preassembly cost benefit.

4.5 Design and Procurement Schedules are Construction Sensitive

Construction sensitive schedules are defined by CII as ones that consider project completion date and the requirements of the construction phase to optimize the project cost and schedule (Rusell, et al., 2004). This concept tries to balance the time allocation for each activity in the schedule. To avoid this concept’s barriers:

1. Develop a detailed schedule in the design phase.
2. From the early start, assign considerable time allocation for planning, design, procurement, and construction (Rusell, et al., 2004).
3. Avoid unnecessary changes to the main schedule.
4. Make sure late procurement will not affect the schedule.

4.6 Design Facilities Turnover and Start-up

This concept ensures integrating facilities turnover and start-up in the design stage. This is an important concept to avoid facilities start-up problems and design/construction changes. In order to utilize this concept:

1. Contractors should be involved in the design stage with owners and designers.
2. Prefer new contracts (e.g. design-build) over traditional ones (design-bid-build).

5 CONCLUSION

This paper discusses constructability concepts implementation in the partner company, starting from the gap analysis. The study concluded that use of constructability concepts by the company lies between informal and formal constructability program classification. The degree of implementation of constructability concepts was further divided into two phases: planning and execution phases. It was found that the degree of implementation of constructability concepts in both phases were 63% and 67%, respectively. We found that there are six concepts that need more work within the partner company. Three of them are related to planning phase while the other three are related to execution phase. This paper states specific recommendations for each concept in order to mitigate their barriers and implement them smoothly.

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