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Constructability: Owners, Designers, and Contractors Practices in Industrial Projects

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Abstract: The constructability theory is built on the premise that designated experts review and analyse a plan collectively to iron out obstacles that may cause failure to the plan and make the execution efficient and cost-effective. This paper aims to reveal constructability practices among stakeholders (owners, designers, and contractors) who are executing industrial projects in Saudi Arabia. The research commenced with an intensive review of related literature. The literature review enabled the researchers to develop a questionnaire (data collection tool) which was distributed among the stakeholders via E-mail. The received data were analysed using simple statistical tools such as means, frequency, etc. The Relative Importance Index (RII) was used to measure the level of benefits from the constructability implementation. The stakeholders were found to implement constructability at the project and, to some extent, at corporate levels. Besides, they use many Construction Industry Institute (CII) concepts emerging from well-constructability CII principles in industrial projects. They form teams consisting of personnel from their organizations and facilitators either from their organization or from constructability consulting organizations. They use effective constructability review techniques such as the log/file, brainstorming, and the design review checklist. The constructability implementation yields considerable benefits, including "Reduce engineering cost," "Reduce construction cost," "Reduce the amount of rework," "Improve project safety," "Reduce schedule duration," and several others. The study contributes to the book of knowledge and provides practitioners with guidance in implementing constructability. Designers and contractors are advised to implement constructability at the corporate level.

Keywords: Benefits, constructability, Saudi Arabia, techniques, team formation.

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1. Introduction

Constructability simply means the ability to construct. Commonly, every construction project, like other human-made articles, e.g., vehicles, airplanes, doorknobs, pens, is designed first then built. Until the industrial revolution, one profession designated as the master builder was the architect, engineer, and job superintendent for each project. The master-builder was replaced with the design-bid-build system and separated the design and construction teams apart. Since then, projects have been failing to achieve their set objectives, and many researchers have attributed those failures to the occurred separation. The constructability theory is built on the premise that designated experts review and analyze a plan collectively to iron out obstacles that may cause failure to the plan and make the execution efficient and cost-effective. Constructability has become an indispensable tool for enhancing project performance. Many researchers have acknowledged that the implementation of constructability leads to enormous quantitative and qualitative benefits for stakeholders.

The Saudi construction industry is considered one of the largest construction industries in the middle east, contributing about 4.6% to its gross domestic product (GDP) (El-Malki, 2013). This industry is proliferating and is expected to grow even further with the government initiatives to re-build the Kingdom's infrastructure and private owners' significant investments in new projects (Al-Otaibi and Price, 2010). A total of $575 billion was spent in the Saudi construction industry between 2008 and 2013 (Al-Gahtany et al., 2016), $610 billion between 2015 and 2020 (Al-Rashed et al., 2014). According to Mordor Intelligence, the ongoing construction projects, mostly associated with re-building the Kingdom infrastructure, are at a value of $819 billion. The government has identified in its 2030 vision five industrial sectors, including automotive, minerals and metals processing, chemicals and polymers, energy and desalination industry, and pharmaceutical and biotech in its pursuit to diversify the economy and increase the manufacturing share to the GDP. Many energy and petrochemical projects have been built in the Kingdom over the last several decades and will continue to the future, especially as subscribed under the 2030 vision. Choi and Song (2014) assert that industrial plant construction projects become more extensive in their physical scale and complexity.

There are two significant owners, very few engineering offices, and many contractors in the Kingdom who can develop and erect industrial projects. Unfortunately, the Saudi construction industry has an unfortunate history of successful projects. Many researchers have attributed project failures to managing projects and poorness in implementing developed and available management tools such as risk management and constructability (Al-Bogamy and Dawood, 2015). In Saudi Arabia, stakeholders collectively attribute poor project performance to the low quality of project documents, including designs, specifications, and contract conditions. Also, stakeholders have not entirely implemented constructability. A reasonable number of private and few government owners utilize the concept of constructability in the construction industry and are implemented in some selected projects without corporate-level support (Almussad, 2018). The upcoming influx of industrial projects, the increased owners' desire for project improvement, and the increased control of funds make constructability implementation essential for those stakeholders to rape qualitative and quantitative benefits. Unfortunately, there has been no study investigating the implementation of constructability in the energy and petrochemical projects up to the authors' best knowledge. Thus, several questions are raised concerning the constructability concepts, principles, practices, techniques, and gained benefits. This study is an attempt to provide reasonable answers to the research questions mentioned above. Although the answers to the research questions could be found from any construction industry globally, the Saudi construction industry was available and accessible to the authors. Hence, stakeholders around the globe can benefit from the findings and recommendations of this study. This study aims to investigate how stakeholders (owners, designers, and contractors) implement constructability as a project management tool in the development of energy and petrochemical industrial projects in Saudi Arabia. The following goals were set to achieve the study's aim:

- Measure the level of constructability implementation;
- Define the dimensions factors of the constructability concept;
- Define the dimensions factors of constructability principles;
- Define the techniques that are used for implementing constructability;
- Determine the realized benefits from the constructability implementation in industrial projects.

This study contributes to the construction body of knowledge and practices by synthesizing essential issues and recommendations in constructability implementation across industrial projects. The study results are anticipated to be sources of knowledge and reference concerning the constructability that can be practical to stakeholders in improving construction work.

2. Literature Review

Despite the introduction of project management as a practical tool to develop construction projects, many projects in the 1960s, and most probably until today, failed to achieve their set objectives. Many researchers in the United Kingdom, such as Emmerson and Banwell, attributed those apparent project failures to the lack of communication between the construction and design teams (Kifokeris and Xenidis, 2017). Consequently, many researchers studied this phenomenon extensively. Eventually, the buildability or more prominently the constructability emerged in the 1970s. The Construction Industry Research and Information Association (1983) defines constructability as the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building. However, under this definition, constructability is constrained to the design issues that can successfully affect project completion (Wong et al., 2007). The Institution of Professional Engineers New Zealand Incorporated (2008) defines constructability "Constructability (or buildability) is a project management technique to review construction processes from start to finish during the pre-construction phase. It is to identify obstacles before a project is actually built to reduce or prevent errors, delays, and cost overruns." In 1986, the CII, for the first time, defined constructability as the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives. This CII's constructability definition is the most comprehensive today (Kifokeris and Xenidis, 2017). Therefore, constructability defines the ease and efficiency with which structures can be built. The more constructible a structure is, the more economical it will be (Clifford and Schwinger, 2011). Constructability is in part a reflection of the quality of the design documents; that is, if the design documents are difficult to understand and interpret, the project will be difficult to build (Gambatese et al., 2005).

In 1991, the ASCE Construction Management Committee defined the 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 constructability definition directed many researchers to extend the concept to a broader scope combining all the project lifecycles to achieve the project objectives; time, budget, quality, and overall owner satisfaction (Kifokeris and Xenidis, 2017). In 1992, CII Australia supplemented the constructability concept by introducing the constructability principle file. Later in 1996, CII Australia improved the constructability concept by developing a constructability implementation guideline (Wong et al., 2007). The CII-USA developed a total of 17 constructability concepts to enhance a project's constructability. Nima (2001) developed 23 constructability concepts for a project conceptual, design, and construction phases. These constructability concepts were developed to be practiced in the project's significant phases. Constructability concepts are implemented throughout the project's lifecycle. First, the feasibility study and the conceptual planning are performed in the project initiation phase, and the design and construction contractual procurements are defined. The constructability program can be a useful approach to identifying and tackling all the causes of not satisfying the project's objectives at the early stage of its lifecycle (Gambatese et al., 2007). Second, in the project execution phase, the detailed design is conducted, and the project's actual implementation in the field. Finally, in the project delivery phase, the project is delivered to its owner (Nawi et al., 2009). Implementing these constructability concepts, with proper adjustment for each project, prevents many problems in construction projects. Hence, the project's team will achieve the project's fundamental objectives, such as; time, cost, quality, and the overall owner's satisfaction (Kifokeris and Xenidis, 2017).

Furthermore, in the early 1990s, the CII in the United States of America and the CII of Australia collaboratively developed the Constructability Principles File tailored to the Australian construction industry (CII of Australia, 1993). The Constructability Principles File highlights 12 principles, which are considered the general fundamentals for implementing the constructability concepts and program (Adams, 1989; CII of Australia, 1993; Griffith and Sidwell, 1997). The 12 principles are integration, construction knowledge, team skills, corporate objectives, available resources, external factors, programmer, construction methodology, accessibility, specifications, construction innovation, and feedback. The constructability team may find some of these constructability principles not applicable to their project. Nevertheless, these constructability principles' primary objective is to facilitate constructability implementation throughout the project's lifecycle (Griffith and Sidwell, 1997).

Various tools and approaches have been introduced and developed by practitioners and professionals in the construction industry to achieve the fundamental objectives of any project (time, cost, quality, and the overall owner's satisfaction). These tools and approaches are planning & operations performance evaluation, value engineering, knowledge management, cost/benefits analysis, total quality management, hybrid value engineering, object-oriented analysis, and the total buildability performance framework. The previously mentioned tools and approaches provide input to the constructability practices (Kifokeris and Xenidis, 2017). Various tools have been developed during the past years to facilitate the constructability implementation and support construction projects' development throughout its lifecycle (the initiation, execution, and delivery phases). Also, these tools can be utilized for the evaluation and assessment activities of the project delivery.

On the other hand, these tools could also improve the assessment and evaluation outcomes or prototype studies (Kifokeris and Xenidis, 2017). Kifokeris and Xenidis (2017) did an extensive literature review of the tools that implement constructability concepts. These constructability tools have been categorized and distinguished in two different ways: type-wise (cognitive, mathematical, methodological, programming, and software) and nature-wise (quantitative project features' & indices' assessment tools, qualitative project features' & indices' assessment tools, schedule-cost quality management & decision-making tools, program review tools, information & knowledge feedback tools, and acquired knowledge recording, management & dissemination tools).

Researchers have employed questionnaire surveys, content analysis, and/or case studies to appraise the implementation of constructability in the development process of construction projects. Yitmen and Akyel (2004) investigated, through a questionnaire survey, the constructability implementation practices in north Cyprus. They found that most stakeholders use constructability informally, few use it formally. Those who use it formally consider concepts, including "Advanced Information Technologies are applied throughout the project," "Project planning involves construction knowledge and experience," and "Project team participants responsible for constructability are identified early on." Farooqui and Ahmed (2008) asserted that many general contractors in Pakistan have been implementing part of the constructability concept mostly during the construction phase. Windapo and Ogunsanmi (2014) found that contractors in Nigeria perform informal constructability processes to check mechanical and electrical drawings for interfaces and mistakes, site layout planning, and schedule/construction program preparation. Akpan et al. (2014) declare that Nigeria's stakeholders have neither corporate constructability implementation manuals nor formal constructability implementation programs. In Indonesia, stakeholders have no corporate constructability implementation manual, formal constructability implementation programs, and techniques (Ansyorie, 2019). Unfortunately, constructability implementation is neither systematic nor comprehensive in developing countries despite its effectiveness in improving project performance.

Many researchers have acknowledged that the stakeholders realize enormous quantitative and qualitative benefits from the implementation of constructability in construction projects. Stamatiadis et al. (2019) evaluated the constructability review process for the Kentucky Transportation Cabinet at the project level by comparing change order percentages on projects reviewed versus those not being reviewed. They found actual monetary savings, about 1.25 percent of the project budget, and additional inherent savings in time, lessons learned, or other aspects intangible benefits associated with constructability reviews. Mosley and Bubshait (2019) claim that the Design-Build delivery system outperforms the Design-Bid-Build in terms of time, cost, and quality because of contractor knowledge in the design phase. Russell et al. (1994), Gil (2001), Arditi et al. (2002), Motsa et al. (2008), and Khan (2015) asserted that owners appreciate monetary savings resulting from reduced engineering cost, reduced schedule duration and reduced construction cost in terms of labor, materials, and equipment. They also asserted that owners enjoy qualitative benefits, including improved site accessibility, improved safety, reduced rework, increased communication, reduced maintenance cost, increased focus on a common goal, and increased construction flexibility. They also indicated that contractors appreciate ongoing construction, and designers appreciate better relationships with clients and contractors, fewer lawsuits, good reputation, professional satisfaction, and efficient designs.

3. Research Methodology

Achieving the research objective mandates the execution of several activities, including reviewing related literature, developing a data collection tool, collecting necessary data, and statistically analyzing the collected data. The literature was reviewed to grasp constructability's theoretical perspective and assess the data collection tool's development. A questionnaire was developed to collect the necessary data from stakeholders involved in industrial projects' development processes. The questionnaire consists of three sections. The first section comprises questions in search of data on the respondents, e.g., education, experience in the construction industry, familiarity with constructability concept, and implementation. The second section contains questions in the quest of data on the organization, e.g., age, implementation of constructability in projects. The third section contains questions seeking information on constructability concepts, principles, techniques, benefits. An intensive investigation of the construction market in the Eastern Province of Saudi Arabia revealed that there are only two owners, five designers, and forty contractors that develop energy and petrochemical industrial projects. The questionnaire was sent to all the stakeholders via e-mail. Finally, the collected data were analyzed using simple statistical tools such as frequency, mean, and standard deviation. Also, the RII of several designated variables were calculated in Eq. (1):

$$RII = \frac{\sum SR}{W \times N} \qquad (1)$$

Where SR is the scale of each factor collected from the survey; W is the highest value of the weight, which equals 5; and N is the number of the participants. The RII values range from 0 (not inclusive) to 1, with higher values indicate great importance.

Moreover, the following two hypotheses were tested:

Hypothesis 1: the stakeholders have similar perspectives in selecting key personnel for constructability teams.

Hypothesis 2: the stakeholders have similar perspectives toward constructability benefits.

4. Results Analysis

Because the populations are small, the structured questionnaire was distributed in the first quarter of 2019 via e-mail to the two owners, five designers, and 40 contractors. The questionnaire was followed-up with e-mails and telephone calls to invite constructability experts to participate in the study. Twenty-five experts from contracting organizations, two from owner organizations, and five from designer organizations completed and returned the questionnaires. Improving the reliability of the collected data mandated restoring questionnaires that had at least 80% of their contents duly completed, and the data were provided by constructability experienced experts. Two returned questionnaires, mainly from contractors, failed the 80% questionnaire contents completion and, therefore, were eliminated. The questionnaire included a question on the level of the respondent's familiarity with constructability. Ten participating contractors were eliminated from the sample because they had slightly and average familiarity with constructability. Therefore, all owners, designers, and 32.5% of the contractors participated in the study, which is considered above the typical norm of 20-30% response rate in most postal questionnaire surveying of the construction industry (Akintoye and Fitzgerald, 2000). Thus, the 20 participants form a reliable, acceptable, and representative sample.

4.1 Characteristics of the Participants

The participating experts are college-educated with civil, mechanical, electrical, chemical, and industrial engineering degrees, of which about (55%) of them hold Masters or Doctorate of Philosophy degrees. Moreover, the participants are also certified by one or more professional organizations: 60% are Project Management Professional (PMP) certified, 20% are Professional Engineers certified, 25% are Risk Management Professionals (PMI-RMP) certified, 5% are Program Management Professional (PgMP) certified, and other organizations certify 25%. Furthermore, the participants are active members of one or more professional associations: 60% are members in the PMI, 5% are in ASCE, 5% are in ASME, 10% are in SPE, and 35% are other members in other professional association. The majority (90%) of the participants have ten or more years of experience in the construction industry, and the majority (80%) have participated in the development and construction of more than six construction projects. The participants occupy different positions in their organizations. The participants from the owner organizations are senior project engineers, from the designer organizations are project managers and constructability specialists/facilitators, and from the contractor organizations are mostly project managers and constructability specialists/facilitators.

The participants are well cognizant of the constructability concept and practices which were acquired through different sources. About 65% gained through job training, 40% through self-training, and 30% through their organizations' courses. Moreover, the participants have involved in a different number of constructability practices. The majority of the participants (75%) have participated in more than four constructability practices, and the remaining have participated in at least two.

The results indicate that the participants are employed in well-established organizations that have been in existence for a long time. The owner organizations have been in business for more than 25 years and annually build more than 40 complexes, mostly industrial projects worth between \$50 to less than \$500 million, which are awarded ether under design-bid-build or design-build delivery systems. The designer organizations have been in business for different years, four have been for less than 15 years and one for more than 25 years, and annually design at least four complex projects, mostly industrial, worth between \$50 to less than \$500 million. The majority (85%) of the contractors also have been in business for more than ten years and construct annually more than two complexes, mostly industrial projects worth between \$50 to less than \$500 million. The lump-sum and unit price contracts are the dominant mechanisms for the legal binding between owners and contractors. The owners, the designers, and the contractors indicated that they always, sometimes, and often, respectively, address constructability issues in the bid documents of complex industrial projects.

In summary, the participants are well informed in complex industrial projects and constructability practices. Therefore, the participants and their organizations are considered qualified and trustworthy sources of information related to complex industrial projects and constructability. Hence, obtaining information from such calibers increases the reliability of the obtained results.

4.2 Constructability Implementation

The results indicate that the owners, 60% of the designers, and 57% of the contractors, have constructability programs at their corporate level. It is worth mentioning that the results indicate that (26%) of the contractor's participants did not know if their organizations have a corporate constructability program. On the other hand, the results indicate that all three parties implement constructability at the project level, including industrial projects. It is believed that the owners, as repetitive builders, are very active in continuously enhancing their project management capabilities through structured and effective educational training for their project management employees and in the adaptation of proven tools such as constructability. The owners are known for their passions to enhance local designers and contractors' managerial and engineering capabilities. Therefore, it is assumed that the owners have influenced the local designers and contractors to adopt constructability in their practices through structured workshops and contract requirements.

4.2.1 Constructability concepts

The constructability concepts delineate guidelines and strategies to enhance the entire project constructability (Kifokeris and Xenidis, 2017). The participants were asked to select from the CII constructability concepts they usually implement to develop their industrial construction projects. The stakeholders identified the constructability concepts in determining the establishment, planning, implementing, and updating the constructability program and presenting the critical strategic issues targeted for continuous improvement within industrial projects. Table 1 presents the frequency of the implemented constructability concepts. Studying the table indicates that the stakeholders implement many constructability concepts but with variance frequency. The results indicate that one owner implements 13 of the given 16 CII constructability concepts, while the other owner implements only six concepts. The owners implement the following six concepts: the "Constructability implementation plans are an integral part of the Project Execution Plan," the "Important, early design decisions consider modularization/preassembly, construction automation, and other major construction method options," the "Procurement, construction, and start-up efficiency are considered in the development of contract documents," the "Module/preassembly designs facilitate fabrication, transport, and field installation," the "Designs promote construction accessibility of personnel, material, and equipment," and the "Innovative construction management and field methods are applied to increase construction efficiency." In observing the six considered constructability concepts, it can be noted that all these concepts belong to front-end planning, design, procurement, and planning. It seems that industrial projects' nature dictates the development of guidelines and strategies to improve modularization, procurement, module designs, design, and innovation in construction management. Both owners do not consider "Permanent and temporary site layouts promote efficient construction," "Design elements are standardized," and "Designs facilitate construction and field productivity under adverse weather conditions." It seems that both owners do not have policies to standardize industrial projects, so they do not have concepts dealing with standardization. There might be bundle suitable construction sites either under their possession and/or in the market for their industrial projects. Therefore, there are no site layout constraints on construction sites and, hence, they do not need to develop a concept dealing with site layouts. Seemingly, they do not have issues with harsh weather conditions to develop a concept to consider such an issue. The majority (80%) of the designers consider the first and the last concepts mentioned above, which are both design-related. Besides, the majority (80%) of the designers consider numeral concepts, which coincide with some of the owners' considered concepts. The coincided concepts are "Constructability implementation plans are an integral part of the Project Execution Plan," "Important, early design decisions consider modularization/preassembly, construction automation, and other major construction method options," and "Module/preassembly designs facilitate fabrication, transport, and field installation." Also, the majority of the designers consider "Early project feasibility planning takes advantage of construction knowledge and experience," "Project schedules are construction - and start-up sensitive," "Design and procurement schedules are construction-sensitive," and "Designs are configured to enable efficient construction and use of efficient technologies." Inspecting the above concepts reveals that they are all design related.

The majority of the contractors also establish several concepts in their constructability implementation. These concepts are "Constructability implementation plans are an integral part of the Project Execution Plan," "Project schedules are construction - and start-up sensitive," "Design and procurement schedules are construction-sensitive," "Procurement, construction, and start-up efficiency are considered in the development of contract documents," and "Designs promote construction accessibility of personnel, material, and equipment." Observing the concepts mentioned above reveals that they are mostly construction related.

4.2.2 Constructability principles

The above constructability concepts emerge from constructability principles. The participants were asked to indicate the constructability principles from which concepts are drawn. Table 2 presents the participants' selected principles. The results indicate the owners' six implemented constructability concepts emerge from five constructability principles. These principles are the "Project integration: the constructability must be part of the developed project plan," "Construction knowledge: the construction expertise must be involved in the project planning phase," "Team skills: the project team must be selected based on experience, knowledge, and skills required for the project," "Accessibility: the construction accessibility need to be considered to enhance the project's constructability," and "Feedback: the lesson-learned databases and best-practices utilization can enhance constructability." The other owner indicated that the 12 constructability principles are the source of the constructability concepts. Similarly, the designers draw constructability concepts from "Project integration," "Program," and "Feedback" principles.

4.2.3 Constructability review techniques

The formal implementation process, the corporate constructability log/file, the design review checklist, the peer review, and the brainstorming are the prevalent available techniques for constructability reviews. The participants were asked to select from the constructability mentioned above techniques the ones that they adopt in constructability reviews. The results indicate that the participants use single or multiples techniques, as shown in Table 3, for constructability reviews of industrial projects. One owner asserted that they only use the "Corporate constructability log/file" technique.

Table 1. Constructability concepts utilization frequency

Constructability Concept	Owner		Designer		Contractor	
	Frequency	%	Frequency	%	Frequency	%
CC1: Constructability implementation plans are an integral part of the Project Execution Plan	2	100	4	80	11	84.6
CC2: Early project feasibility planning takes advantage of construction knowledge and experience	1	50	4	80	8	61.5
CC3: Development of the project contracting strategy involves construction knowledge and experience	1	50	2	40	8	61.5
CC4: Project schedules are construction - and start-up sensitive	1	50	4	80	10	76.9
CC5: Important, early design decisions consider modularization/preassembly, construction automation, and other major construction method options	2	100	4	80	9	69.2
CC6: Permanent and temporary site layouts promote efficient construction	0	0	4	80	5	38.5
CC7: Advanced information technologies are applied to facilitate efficient construction	1	50	2	40	5	38.5
CC8: Design and procurement schedules are construction-sensitive	1	50	5	100	10	76.9
CC9: Designs are configured to enable efficient construction and use of efficient technologies	1	50	4	80	7	53.8
CC10: Design elements are standardized	0	0	2	40	8	61.5
CC11: Procurement, construction and start-up efficiency are considered in the development of contract documents	2	100	3	60	11	84.6
CC12: Module/preassembly designs facilitate fabrication, transport, and field installation	2	100	4	80	9	69.2
CC13: Designs promote construction accessibility of personnel, material, and equipment	2	100	3	60	10	76.9
CC14: Designs facilitate construction and field productivity under adverse weather conditions	0	0	3	60	4	30.8
CC15: Project plans enhance security during construction	1	50	3	60	7	53.8
CC16: Innovative construction management and field methods are applied to increase construction efficiency	2	100	3	60	6	46.2

The other owner declared that he adopts the “Corporate constructability log/file” technique combined with either the “Formal implementation process,” the “Design review checklist,” the “Peer review,” and/or the “Brainstorming” techniques. The results indicate that the “Formal implementation process” is the most popular technique for the designers, where 80% of them use it. One designer uses only the above technique, another designer uses it with the “Brainstorming” technique, and the remaining designer uses it with the “Corporate constructability log/file,” the “Design review checklist,” and/or the “Brainstorming” techniques. The results show that no designer uses the “Peer review” technique for constructability reviews. About 85% of the contractors use the “Design review checklist” technique combined with one or more of the other constructability techniques: about 36% combine it with one or more of the other four constructability techniques; about 27 % combine it only with the “Brainstorming” technique; about 9% combine it with the “Corporate constructability log/file” and/or the “Formal implementation process”; about 9% combine it with the “Corporate constructability log/file” and/or the “Peer review” technique; about 9% combine it with the “Formal implementation process” and the “Brainstorming” techniques. Only two designers reported that they use only one technique for constructability reviews. One uses the “Formal implementation process” technique, and the other uses the “Corporate constructability log/file” technique.

4.2.4 Constructability team

The participants provided numerical scoring expressing their opinions on the importance of the involvement of certain key personnel in the constructability process during the early stages of industrial project development. The weighted average for each key personnel was calculated, then it was divided by the upper scale of the measurements resulting in what is referred to as "important index" therefore, the level of importance of the key personnel was calculated and presented in Table 4. The results indicate that the stakeholders form a constructability team for each industrial project. The team usually consists of personnel selected from the stakeholders' organizations. One-Way ANOVA was used to test the hypothesis that the stakeholders consider similar importance to key personnel for the constructability team. The output of the One-Way ANOVA test is tabulated in Table 5. Since P is greater than 0.05, the nil hypothesis is rejected. That is, the stakeholders differ in the importance of the selection of key personnel for the constructability team.

It is known that both owners create as early as a project conceptualization stage a project management team (PMT) to oversee and manage the development of the designated project. The PMT usually consists of a project manager, lead project engineer, project engineer, end-user representative, and many others. The results indicate that the owners consider the participation of the PMT project manager, the lead project engineer, the project engineer, and the end-user representative as extremely important. The designers similarly consider the participation of the PMT project manager and the lead project engineer in the constructability team extremely important and the project manager and the end-user representative are very important. The contractors also agree with owners and designers and consider the owners' personnel involvement in the constructability team very important. The designers indicated that their lead engineer and the discipline engineer in the constructability team were extremely important, while the discipline manager's participation was very important. The owners agree with the designers' selection of the personnel and their importance to the constructability team. The contractors agree with the designers' selected personnel and consider the lead engineer and the discipline engineer's participation in the constructability team very important. However, the discipline manager's participation is somewhat important. The contractors consider the involvement of their project managers and site project engineers in the constructability team extremely important, and their site superintendents' involvement is very important.

Table 2. Constructability principles utilization

Constructability Principles	Owner		Designer		Contractor	
	Frequency	%	Frequency	%	Frequency	%
CP1: Project Integration: The constructability must be part of the developed project plan	2	100	5	100	10	76.9
CP2: Construction knowledge: The construction expertise must be involved in the project planning phase	2	100	4	80	10	76.9
CP3: Team skills: The project team must be selected based on their experience, knowledge and skills requirement for the project	2	100	3	60	9	69.2
CP4: Corporate objectives: The project team need to understand the project objectives as well as the client's objectives so that the constructability can be enhanced	1	50	3	60	7	53.8
CP5: Available resources: In the project's design phase, the available resources (manpower skills, equipment and technologies) must be considered	1	50	1	20	8	61.5
CP6: External factors: External factors such as; unforeseen bad weather, political issues ...etc. could affect the project cost and/or schedule	1	50	3	60	7	53.8
CP7: Program: The project program must be construction-sensitive, realistic and have the commitment of the project team	1	50	5	100	9	69.2
CP8: Construction methodology: In the project's design phase, the construction methodology must be considered	1	50	4	80	12	92.3
CP9: Accessibility: In the project's design and construction phase, the construction accessibility need to be considered to enhance the project's constructability	2	100	4	80	12	92.3
CP10: Specifications: The projects constructability can be enhanced by developing transparent specifications	1	50	3	60	7	53.8
CP11: Construction innovation: The projects constructability can be enhanced using innovation ideas during the construction stage	1	50	4	80	6	46.2
CP12: Feedback: The projects constructability can be enhanced by utilizing the lesson-learned databases and best-practices for other projects	2	100	5	100	11	84.6

Table 3. Constructability review techniques

Constructability Review Techniques	Frequency	%
Owners (n=2)		
1, 2, 3, 4, 5	1	50
2	1	50
Total	2	100
Designers (n=5)		
1, 2, 3, 5	1	20
1	2	40
1, 5	1	20
2, 5	1	20
Total	5	100
Contractors (n=13)		
1, 2, 3, 4, 5	4	30.8
3, 5	3	23.1
1, 2, 3	1	7.7
2, 3, 4	1	7.7
1	1	7.7
2, 3, 5	1	7.7
2	1	7.7
1, 3, 5	1	7.7
Total	13	99.4

Legend: Constructability review techniques
1: The formal implementation process
2: The corporate constructability log/file
3: The design review checklist,
4: The peer review, and
5: The brainstorming

The owners and designers concur with the contractors' selection of personnel from their organization and the asserted level of importance. The stakeholders expressed extreme importance for a constructability facilitator's involvement in the formed constructability team. Although the three parties agree on the importance of a constructability facilitator's involvement, they differ on his origin.

The participants were asked to identify the best origin for the selection of the facilitator. The participants provided numerical scoring expressing the origins of the constructability facilitators who are involved in the constructability teams. The weighted average for each key personnel was calculated, then it was divided by the upper scale of the measurements in what is referred to as "important index" therefore, the level of importance of the key personnel was calculated and presented in Table 6.

Both owners indicated the best origin for the constructability facilitator is the designer organization and specifically the designer in-house constructability consultant. However, one owner nominates also the third-party-constructability consultants as alternative sources for constructability facilitators. This owner may select the constructability facilitator based on a qualification system. It is interesting to notice that the owners prefer to select the constructability facilitators from outside their organizations. The owners may believe that external constructability facilitators may bring with them new experiences and innovative ideas to enhance the constructability team function. The results indicate that 80% and 60%, of the designers select the facilitator from a third-party consultant and from the contractor, specifically the contractor in-house constructability consultants, respectively.

Table 4. Importance of personnel involvement in conducting constructability review for projects

Key Personnel Involvement in Constructability	RII (%)		
	Owners	Designers	Contractors
Project manager (owner)	100	80	85
Lead project engineer (owner)	100	96	85
Project engineer (owner)	100	92	85
End user representative (owner)	100	88	85
Discipline manager (designer)	90	84	78
Lead project engineer (designer)	100	92	86
Discipline engineer (designer)	100	92	85
Construction manager (contractor)	100	96	95
Site superintendent (contractor)	90	88	85
Site project engineer (contractor)	100	88	91
Constructability designer/ facilitator	100	96	94

Table 5. One-way ANOVA results on key personnel

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	10.23	10	1.02	1.3	0.23	1.86
Within Groups	252.13	319	0.79			
Total	262.36	329				

Another 40% of the designers select facilitators from either the owner, designer, contractor, or a third-party constructability consultant. The contractors have shown varieties of opinions on the origin from where the constructability facilitator to be selected. About 62% of the contractors believe that the designers in-house constructability consultants and third-party consultants are the facilitator's best origins. About 54% of contractors also recommend selecting constructability facilitators from the owners' in-house constructability consultants. Also, about 34% of the contractors believe that their constructability consultants are the best facilitator's origin. In general, the participants rank the third-party-consultant first, the designers' in-house constructability consultants second, and the owners' in-house constructability consultants third as the best origin for facilitators.

4.2.5 Realized benefits from constructability implementation

The participants provided numerical scoring expressing their level of agreement on the gained benefits from implementing constructability in industrial projects. The benefits' weighted averages were calculated and divided by the upper scale of the measurements resulting in what is referred to as RII. Therefore, the levels of importance of the benefits were calculated and presented in Table 7.

Table 6. The best facilitator for constructability reviews

Best Facilitator	Frequency	%
Owners (n=2)		
2, 4	1	50
2	1	50
Total	2	100
Designers (n=5)		
1, 2, 3, 4	2	40
4	2	40
3	1	20
Total	5	100
Contractors (n=13)		
1, 2, 3, 4	2	15.4
4	1	7.7
1	1	7.7
1, 4	2	15.4
1, 2	2	15.4
3	1	7.7
2, 3	1	7.7
2, 4	2	15.4
2, 3, 4	1	7.4
Total	13	99.7

Legend: Constructability review techniques
1: Owner in-house constructability consultant,
2: Designer in-house constructability consultant,
3: Contractor in-house constructability consultant,
4: Third party constructability consultant
n: Number of participants

One-way ANOVA was used to test the hypothesis that owners, designers, and contractors value the constructability benefits similarly. The output of the One-Way ANOVA test is tabulated in Table 8. At the 95% confidence level, the nil hypothesis is rejected, and it could be asserted that the stakeholders differ in their perspectives toward the importance of gained benefits. However, if the confidence level is relaxed to 87%, the hypothesis that there are no differences in their perspectives toward the importance of constructability benefits shall be accepted.

The results indicate that the three parties acknowledge the realization of great benefits from implementing constructability in industrial projects. The owners strongly agree that implementing constructability leads to "Reduce engineering cost," "Reduce construction cost," "Reduce the amount of rework," "Reduce disruption to production," "Improve project quality" "Improve site accessibility," "Smoothen the start-up," "Increase construction flexibility," "Improve project safety," and "Enhance team building and cooperation." Observing those benefits reveals that they are owner and construction-related and parameters to his satisfaction. The owners agree that the implementation of constructability benefits to "Reduce schedule duration," "Reduce maintenance cost," and "Improve communication." It is interesting that owners somewhat agree that constructability implementation "Increase problem avoidance," "Increase of understanding of purpose/effective of individual's involvement," and "Increase commitment of the project team." It was expected to realize higher agreement levels from owners to those benefits.

The designers strongly agree that the implementation of constructability benefits "Improve communication" and "Improve project quality." The designers also agree on several gained benefits from constructability implementation. These benefits are "Reduce construction cost," "Reduce schedule duration," "Reduce the amount of rework," "Reduce disruption to current production," "Reduce maintenance cost," "Increase problem avoidance," "Increase commitment of the project team," "Increase construction flexibility," "Improve project safety," "Improve site accessibility," and "Enhance team building and cooperation."

Table 7. Benefits of implementing constructability in complex projects

Benefits	Level of Agreement					
	Owner		Designer		Contractor	
	RII (%)	Rank	RII (%)	Rank	RII (%)	Rank
Reduce engineering cost	100	1	64	7	72	9
Reduce construction cost (labor, material and equipment)	100	1	84	4	83	5
Reduce schedule duration	80	3	88	2	86	3
Reduce amount of rework	100	1	86	3	89	1
Reduce disruption to current production	100	1	80	5	86	3
Reduce maintenance cost	80	3	80	5	78	7
Smoothen the start-up	90	2	76	6	78	7
Increase problem avoidance	70	4	88	2	83	5
Increase of understanding of purpose/ effective of individual's involvement	70	4	76	6	80	6
Increase commitment of the project team	70	4	88	2	83	5
Increase construction flexibility	90	2	84	4	78	7
Improve communication	80	3	92	1	75	8
Improve project quality	100	1	92	1	85	4
Improve project safety	90	2	88	2	88	2
Improve site accessibility	100	1	80	5	89	1
Enhance team building and cooperation	90	2	88	2	83	5

Table 8. Data variance of constructability implementation benefits

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	18.33	15	1.22	1.42	0.13	1.69
Within Groups	400.33	464	0.86			
Total	418.67	479				

The designers somewhat agree that the constructability benefits "Smoothen the start-up" and "Increase of understanding of purpose/effective of an individual's involvement." Interestingly, designers disagree that the implementation of constructability benefits to "Reduce engineering cost." They may consider the additional costs for constructability to increase engineering costs. The contractors agree that constructability implementation leads to "Reduce the amount of rework," "Reduce disruption to current production," "Reduce schedule duration," "Reduce construction cost," "Improve site accessibility," "Improve project safety," "Improve project quality," "Increase problem avoidance," "Enhance the project team commitment," "Enhance team-building and cooperation," and "Increase understanding of purpose/capable of individual's involvement." All the above benefits are construction-related.

The participants were asked to declare the percentages of schedule reduction and cost-saving realized from the constructability implementation in industrial construction projects. The owners, 60% of the designers, and 30% of the contractors reported a 7% schedule reduction from the original project completion schedule due to implementing constructability concepts in industrial construction projects. Furthermore, the remaining contractors (40%) and about 30% of the contractors acknowledged the realization of (3%- 5%) schedule reduction of the total project duration resulted from the constructability implementation. On the other hand, the owners, 40% of the designers, and about 30% of the contractors admitted to realizing (1% - 3%) cost savings from the total project budget due to implementing constructability concepts in their industrial construction projects. Furthermore, about 40% of the designers stated that they had cost savings mounted to (3% - 5%) of the total project budget. The remaining 20% of the contractors appreciated more than a 5% cost reduction in project budget resulting from the implementation of constructability in industrial projects. It is worth mentioning that the majority of the participants from the stakeholders' organizations indicated that the fee for conducting the constructability review is ranging from $15,000 to less than $20,000 for each industrial construction project.

Therefore, owners acknowledge cost savings of more than 5% of the total project budget and schedule reductions of up to 7% of the total project duration resulting from implementing constructability in their industrial construction projects. The designers and contractors also acknowledge cost savings of up to 3% of the total project budget and schedule reductions of more than 7% of the total project duration.

A direct face-to-face interview with key personnel of one of the ongoing industrial projects belonging to one of the owners was conducted to evaluate the constructability implementation realized benefits. The team believes that implementing value-improving practices has improved and maximized the project's performance in terms of safety, quality, cost, and schedule. The team believes that implementing constructability and lessons learned implementation practices have actively contributed to achieving the project's targeted Key Performance Index (KPIs). A total of 45 ideas/suggestions were generated during constructability workshops. The integrated project team highlighted the significant benefits of implementing these constructability items:

- Cost-saving of 5-7% of the project allocated budget and 10-15% schedule optimization of the project completion schedule. Most of the cost-saving and schedule optimization was contributed from the proper planning of procurement, logistics, cutover/shutdown, and commissioning & start-up activities.
- The team achieved the corporate and the project targeted KPIs in terms of safety. Most of it was contributed to improving the site accessibility, ensuring the massive lifting plan's adequacy, adverse weather consideration, and reducing the congestion of the construction area during peak load of the project.
- The team achieved the corporate and the project targeted KPIs in terms of quality. Most of it was contributed to the developed QA/QC plan reviewed and approved by the owner before the construction activities.

5. Conclusion

Project stakeholders (owners, designers, and contractors) involved in developing industrial projects in Saudi Arabia are cognizant of constructability and consider it an integral part of their project management practices. The stakeholders implement constructability at the project level; however, all owners, good portions of the designers, and contractors implement it at the corporate level.

Owners consider constructability concepts with emphasis on front-end planning, design, procurement, and planning. Designers consider constructability implementation plans as innovative construction management; important early design decisions concerning modularization/preassembly, construction automation, and other major construction method options; and fabrication facilitator for Module/preassembly designs, transport, and field installation. Contractors consider construction-related concepts, including "Project schedules are construction - and start-up sensitive," "Design and procurement schedules are construction-sensitive," "Procurement, construction, and start-up efficiency are considered in the development of contract documents," and "Designs promote construction accessibility of personnel, material, and equipment."

The above concepts emerge mostly from several constructability principles, including the "Project integration," "Construction knowledge," "Team skills," "Accessibility," and "Feedback." In general, the stakeholders utilize exciting constructability concepts that originate from well-defined constructability principles.

The owners usually establish for each project a constructability team with a responsibility to enhance project performance. The constructability team usually consists of key personnel chosen from the owner, the prospective designer, the prospective contractor, and a constructability facilitator who is mostly selected from a constructability consultant organization. The stakeholders differ in the in the importance of key personnel for the constructability teams.

The stakeholders use various constructability review techniques in the quest to enhance the performances of construction projects. The stakeholders' most popular constructability review techniques are the corporate constructability log/file, the formal implementation, the brainstorming, and the design review checklist techniques.

The stakeholders realize many great benefits resulting from constructability implementation in industrial projects. The benefits are "Reduce engineering cost," "Reduce construction cost," "Reduce the amount of rework," "Reduce disruption to production," "Improve project quality" "Improve site accessibility," "Smoothen the start-up," "Increase construction flexibility," "Improve project safety," and "Enhance team building and cooperation," "Reduce schedule duration," "Reduce maintenance cost," and "Improve communication." The total benefits amount to at least 5% cost savings and more than 7% schedule reductions.

The stakeholders are encouraged to:

- Ensure implementing the constructability practices irrespective of the volume, type of work, type of contract, project delivery system of their industrial construction projects,
- Frequently assist their constructability programs at the corporate level to identify opportunities for improvement,
- Ensure that the right individuals are part of the constructability implementation team,
- Ensure utilizing their lesson-learned database and/or best-practices during their constructability review and should ensure the implementation of the constructability recommendations,
- Include clauses in the design and construction contracts stating clearly to communicate identified constructability issues, findings, and/or recommendations.

The designers are advised to:

- Ensure considering the construction personnel qualifications as part of the contract framework, evaluate the utilization of the current developed construction technologies, and standardize the design elements during their constructability review,
- Establish a program and/or agreement with clients (owner and/or contractor firms), allowing them to obtain their client's lessons learned from each design package they have developed after being implemented or during the construction phase,

This study is limited to the constructability implementation in developing industrial projects.

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