Value Engineering and Constructability Assessment Relating Infrastructure Projects

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Abstract. Construction projects, especially infrastructure projects, are considered as the most important interests of countries, due to their direct effects on economy, countries development, and all life's aspects. Accordingly, many technologies and programs have been developed trying to control projects in terms of costs, time of implementation, and the outputs quality. Among the best practices that have proven successful in this area are constructability and value engineering. In this research infrastructure projects in Iraq were assessed, and found that those projects suffer from failure on several fronts, because they are implemented using traditional methods which lead to a significant waste in resources. A model based on the concepts of constructability and value engineering is proposed and applied to project phases, including the operation & maintenance phases. Results show that applying the suggested model lead to saving time, cost and improving the required quality of materials and work, by taking advantage of experience of all project's partners involved in the project.

1. Introduction
Infrastructures are considered as the most expensive projects, which contribute job development and economic growth. The modern life's welfare and development significantly depend on the physical foundations represented by infrastructures such as dams, rails, roads, schools, houses, and others [1]. Usually construction projects are delivered in distinct phases and are separated by decisions gates. Most decisions are made at the planning and design phases [2]. Those separations lead to neglect opportunities at subsequent phases of the project's life cycle [3].

The development of appropriate techniques and tools is necessary to make project management efficient and to avoid waste in terms of time and resources [4]. Several tools, such as constructability, value engineering, and design review were developed to enhance design process quality and overall project performance [5]. Both constructability and value engineering (VE) focus on using the knowledge management for assessing the construction process inputs and achieve the required outputs successfully [6]. The main objective of value engineering is to reduce the facility life-cycle cost, whereas the constructability focuses on optimizing the whole construction process. In most cases of industry implementation, value engineering is normally applied during design phase, while effective constructability applications ideally begin at the conceptual and planning phase, and continue to construction.

Constructability and VE differ, but this doesn't mean they are mutually exclusive. Rather, activities within the two work processes may complete each other for achieving their goals. This may lead to construction optimization while, achieving minimum life-cycle cost. Actually constructability implementation may act as precursor for value engineering by providing information through the constructor input and the lessons that learned from past implemented projects, so that VE may has more effectiveness [7].
Many studies and have developed programs or models for implementing value engineering and constructability techniques. Given the importance of infrastructure projects, the objective of this paper is to clarify the importance of constructability and value engineering techniques, and the ability of applying them together in an integrated way to infrastructure projects in Iraq, to reduce costs, time, and improve quality. The current status of infrastructure projects in Iraq has been assessed, and consequently a model has been suggested. This model includes the application of constructability review technique at all phases of the project, including maintenance and operation, while value engineering is applied at the design phase only. The following sections present the concepts of constructability review and value engineering in more details.

1.1. Constructability

1.1.1. Constructability Concept
Constructability, which focuses on the productivity, was firstly studied in United Kingdom in the seventies. It has been developed into an integrated concept for each phase, including planning, design, and execution, to improve the cost effectiveness and quality of the construction industry [8].

(Douglas and Gransberg) [9], defined constructability, as an effective technique that implements a detailed review of design drawings, documents, specifications, and construction processes by highly experienced engineers, working with original team of the project before construction mobilization. Actually definitions related to constructability review technique slightly varies from place to place, but the common concept is to use the construction experience and knowledge at early phases of project to improve decision-making [10].

1.1.2. Benefits of Constructability
The positive effects of constructability review process include the whole project and not limited to the construction process. They may improve conceptual planning, procurement processes, construction methods, and also involving stakeholders in making the decisions, and achieve their satisfaction [11].

According to (Douglas and Gransberg) [9], the objective of the constructability technique is to identify the following:
- Fault of the process of design either in dimensions or materials selection.
- The project's difficult specifications or those of high constructing cost.
- The project features that exceed the capability of construction process to properly implemented.
- Project features that are difficult to understand, and are hard to correctly bid.

1.1.3. Application of Constructability during Life Cycle of Project
Constructability is not limited to design phase, but it should be processed during the whole lifecycle of the project. As the project progresses, the influence of the design becoming less on the overall project costs. Thus, it is better to apply constructability at the earlier stages including the design phase to achieve a higher impact [12].

Othman [13], summarized the contributions of constructability during the project phases as follows:
- Feasibility Phase: focusing on generating alternatives that can be analyzed and expanded using the conceptual and design decisions in the manner of the financial and time considerations.
- Early Design Phase: As construction documents being developed the constructability team should make detailed constructability reviews on documents, such as: drawings, specifications, etc.
- Procurement Phase: When the overall design process is completed by 60% to 90%, the procurement process should be prepared, which includes subcontracts and bid packages, qualification of vendors, etc. The bidders are provided with complete and detailed comprehensive design so they may provide intelligent proposals that lead to a successful project.
- Construction Phase: Subcontractors who have constructability reviews can use their implementation experience well and make valuable suggestions. Such suggestions should be taken seriously to be analyzed, and assessed.
- After Action Reviews: Either the project has succeeded or not the participants try to put their possible bad experiences behind them to move on. There should be in either cases a formal review to document the constructability lessons that learned from that project.
1.1.4. Barriers of implementing Constructability

According to O'Connor and Miller [14], the purpose for using constructability technique is to improve performance of the building process. But it faces many barriers, which constrain the effective implementation. The barriers for constructability review may classified within four main groups [13].

- **Owner barriers**: Lack of knowledge of constructability, fear of project delays, fear of adding additional costs, and finally rejecting contractor’s innovative ideas and alternatives.
- **Designer barriers**: Lack of awareness of advantages of implementing constructability, lack of construction experience, setting the objectives of the company before the objectives of the project, and finally budget constraints.
- **Contractor barriers**: Poor input timing, poor communication skills, and lack of participation in the development of equipment and tools.
- **Barriers relating waste and recycling management**: Lack of understanding of the significance of waste recycling management, and poor communication with the waste.

1.2. Value Engineering

This section will focus on Value Engineering in terms of the general concept, application, benefits, in addition to the barriers encountered the application.

1.2.1. Value Engineering Concept

Value engineering is an analytical structured process to achieve money value by providing the functions which are necessary at the minimum costs with the required quality and performance. This practice in most cases tries to identify and remove unnecessary expenditures, thereby to increase value for manufacturers and their customers [6]. Atabay and Galipogullari [15], define value engineering technique as a tool used to analyze functions of a specific item or a specific process to obtain the best value, i.e., achieving the optimal combination of worth and cost. Best value refers to the item or the process which performs the same required function with minimum cost. According to Ilayaraja and Eqyaabal [16], value engineering is a powerful technique to solve problems, and can efficiently reduce costs with combination of improving performance, and the quality requirements. This technique is successful because of its ability to identify opportunities of eliminating the unnecessary costs, and enhancing or at least maintaining the performance, quality, reliability, and other basic required factors

1.2.2. Benefits of Value Engineering

Whyte and Cammarano [17], mentioned the potential benefits from value application on the projects as: enhancing project's value, effectiveness, communication and cooperation between different parties, costs saving, and documenting opportunities and issues.

According to Ahmed and Pandey [18], benefits of value engineering application are as follows:

- Simplification of methods and procedures resulting in less recurrent costs, and more effective processes.
- Better communication and better understanding for the project's objectives.
- Value engineering doesn't mean cost reduction, this approach generates greater benefits than cost reduction, such as: improving project quality, insuring efficient investments through risk mitigating, increasing profits by avoiding unnecessary and expensive elements [19].

1.2.3. Value Engineering Job Plan

According to Al-Yafei et al [20], value engineering job plan consist of three major stages: pre study, value study, and post study. The most important stage is the value study, which includes six phases: Information Phase, Function Analysis Phase, Creative Phase, Evaluation phase, Development Phase, and Presentation Phase.

Most literatures agree with this classification with sometimes a small differences, as combining two or more phases into one phase. For example Shahhosseini et al [21], had classified value job plan into four phases: information phase; function analysis phase; creative, evaluation and development phases; and finally conclusion phase. However the main stages are still the same, and are described as follows:

- **Information Phase**: The VE team should collect information before starting the VE workshop.
- **When supported facts cannot be obtained, the opinions of knowledgeable people can be used.**
- **Those people may be involved and participate in the workshop, or their opinions can be**
documented. The Information Phase is typically used to familiarize the team members with the data and the data sources in the context of defining the problem. Documentation sources includes: Site condition, Available resource, Requirements resulting from public participation, Cost estimates, design drawings, and project specifications [22].

- Function Analysis Phase: for pointing out and eliminating unnecessary costs, the project functions have to be identified. The functions represent the expecting results of the construction of the project/product. In VE, functions are gathered into two groups: basic functions and secondary functions. The performance features that must be performed are named basic functions. Secondary functions answer the question, ‘What else does it do?’ Indeed, the basic functions are the project’s aims and the secondary ones cause to increase the project value [21].

- Creative Phase: exploring the effective alternative designs that required to provide the identified functions through the brainstorming meeting. This meeting involves the free flow ideas, the VE members are permitted to put forward each idea even the most ridiculous one. (Brainstorming meeting, Criticism is not acceptable) [19].

- Evaluation Phase: after all ideas are listed, a series of screening processes are needed to sort them. Ideas comparison, feasibility ranking, and analysis matrix are some of the techniques that will be utilized. These techniques focus on ideas that are closer to the user's concerns, needs and requirements. At the end of this phase, the outstanding ideas will emerge for the development stage [16].

- Development Phase good results are obtained by merging strengths of various ideas. Development should include the following steps [16].
  a) Research and add information to substantiate the approach, including separating ideas that are industry standards, recognize ideas that are not tested, and become aware of ideas those are controversial.
  b) Recognize ideas that may be unique.
  c) Involve specialists to support and perfect ideas.
  d) Prepare cost estimation, which include: considering impact on customer(s), using cost to perform rate of return analysis, and considering the cost of the life cycle. Then Analyze risks and back up ideas accordingly

- Presentation Phase: This phase tries to obtain commitment from the designer, sponsor of the project and other involved management, to proceed with implementation of the recommended alternative. This include oral presentation then a written report. This report documents all the proposed alternative with supporting information, also confirms and supports the implementation plan accepted by the management [22].

Value engineering should be applied at project's early stages to maximize results. If applied at later stages, it may increase two things: the investments required for implementation, and the resistance to change [20]. Although value engineering is applicable at any stage of the project, savings are usually reduced as the program's life increases. Early implementation of the VE leads to greater savings, because when reviewing the design, approximately eighty percent of costs are committed. However, the more advanced the VE is applied, the higher the gain of the investment in time and efforts [23].

1.2.4. Barriers of Implementing Value Engineering

Causes of poor value can be: lack of information, decisions which based on wrong beliefs, ordinary thinking, negative attitudes, dislike to seek advice, shortage of time, changing of technology, lack of value measurement standards, old standards and specifications, and poor relations between partners [24].

The barriers for successfully applying VE are based on the recognition of the contract participants, also the experience and familiarity of the project team in applying the principles of VE. Some of those barriers include:

- The owner's perception of the desire of the engineering firm's to increase their profit margins by maximizing their fees.
- Owners who are unfamiliar with value engineering objectives may view value engineering proposals developed by the contractors as a failure on the engineering and design, believing those savings should be a part of the original design [25].
- Little capabilities for the hired design companies in terms of VE concept and application.
The time given to VE workshop which may lead to unimpressive results is inadequate. Evaluation team may have no motivation because of the low client's incentives during VE evaluation phase. Lack of professional experience in VE team which cannot bring a different perspective to the project [6].

2. Methodology
The research methodology undertaken for this research is summarized as follows:

- Starting with literature reviews for topics related to infrastructure, constructability, and value engineering in publications, which provided information that used to build the research framework and its base material.
- Field survey; an empirical questionnaire survey with two stages was undertaken. The first stage was done to explore the challenges that face the applications of constructability and VE in infrastructure projects, also to diagnose areas of failure in their implementation, as well as to explore the applicability of the concepts of constructability and value engineering at the different stages of infrastructure plc.
- After first stage of surveying the data was collected, analyzed, and discussed. The data collected from respondents was analyzed by using the "Statistical Package for Social Sciences" (S.P.S.S) version 25. The output of the analysis process was presented in form of tables and charts.
- Based on the conclusions of first stage of questionnaire, an integrated model was developed for applying constructability and value engineering to infrastructure projects.
- To evaluate the proposed model, the second stage of the field survey was conducted using the same respondents' population. Finally conclusions were drawn and presented with recommendations for future research.

2.1. Field Survey
Field survey which relied on questionnaire was designed to generate the data required for analysis. The sample of the study respondents consisted of specialists in design and construction fields in Iraq. The questionnaire forms were distributed to respondents with a description of the research, purpose of questionnaire, and the explanation of its statements. 100 forms were distributed, the response rate was 94%. Data collected were analyzed using the "Statistical Package for Social Sciences" (S.P.S.S) ver. 25. The questionnaire had two main parts. First one related to the characteristics of the respondents. The second part included 23 statements organized into four main groups: The first group consisted of six statements related to infrastructure projects and their extent of success, and diagnosis of the most failed phases of those projects. The second group also included six statements concerned with the concept of constructability, and its applicability to infrastructure projects. The third one included six statements concerned with the concept of value engineering, and its applicability to infrastructure projects. The last group focused on the possibility of applying the concepts of constructability and value engineering simultaneously in an integrated way to infrastructure projects, it included 5 statements. Data collected were organized and processed statistically using the SPSS V. 25 statistical program. Weights of the Likert scale were determined, as: Strongly disagree= 1, Disagree= 2, Neutral= 3, Agree= 4, and Strongly agree = 5. Reliability analysis was applied to the collected data to know reliability of questionnaire responses. Cronbach’s alpha (α) represents an index usually calculated to estimate the scale of reliability of several items. The closer (α) is to 1.00, the greater the consistency of items in the data being assessed. The lower acceptable limits of (α) are 0.50 and 0.60 [26]. Table 1 indicates that Cronbach’s alpha is 0.720, which is an acceptable reliability value.

| Reliability Statistics |
|------------------------|
| Cronbach's Alpha       | .720       |
| N of Items             | 23         |

2.2. Survey Results and Discussion
-Results related to demographic characteristics of respondents show that the highest percentage (73.4%) of respondents were working in construction companies while (26.6%) of the respondents
were working in consultant companies. Results also show that (51.06%) of the respondents had the BSc as qualification, while (30.85%) had the M.Sc. and (18.09%) had the PhD. Finally demographic results show that (19.15%) of respondents had 5-10 years of experience, (54.25%) had 11-16 years of experience, and (26.6%) had 17-25 years of experience.

Results achieved from the SPSS program (for the 23 statements) are arranged and summarized into four groups, as in the questionnaire form, as follows.

- Results of first group statements show that, (62.77%) of respondents strongly believed that the implementation of infrastructure projects in Iraq are unsuccessful. The highest percentages of responses (90.93, 94.68, 94.68, 94.68, and 92.55) % indicated that there are failures in (feasibility, design, procurement, construction, and O&M phases) respectively. Therefore most of the respondents believed that the implementing of infrastructure projects in Iraq is unsuccessful and there are failures in all stages of implementation.

- Results of second group statement show: The highest percentage (59.14%) of respondents had no idea about the constructability concept or how to be applied to the infrastructure projects. The highest percentages of responses (91.49, 95.74, 93.62, 94.68, and 92.55) % indicate that it is better for infrastructure projects to apply the constructability technique in the phases of (feasibility, design, procurement, construction, and O&M) respectively.

- Results of third group statement show: The highest percentage (67.02%) of the respondents had no idea about value engineering concept or how to be applied to infrastructure projects. The highest percentages (89.36, 94.68, 89.36, 91.49, and 95.74) % indicate that it is better for infrastructure projects to apply the value engineering technique at (feasibility phases, design phases, procurement phases, construction phases, and O&M phases) respectively.

- Results of fourth group statement show: Most respondents didn't agree in a high percentage to apply both constructability and value engineering simultaneously on the phases of (feasibility, procurement, construction, and O&M). Most of respondents (92.55%), agreed with applying both constructability and value engineering simultaneously in the design phase.

2.3. Proposed Model

The results analysis showed that the infrastructure projects face many challenges during their life cycle. The results also showed that there is need to apply constructability technique at all stages of project life cycle and there is a need to apply the value engineering to all stages of the project. But, in case of applying both techniques together, results showed its better to apply constructability at all phases of the project combined with applying value engineering in the design phase only, where the impact is significant. Figure 1 shows the proposed model that applies the constructability at all stages (feasibility, design, procurement, construction, and O&M phases) of project life cycle, and simultaneously applies value engineering application at design phase.
2.4. Model Evaluation
The evaluation questionnaire included eight statements organized into three main groups as follows:
- First group included three statements that related to the applicability of the proposed model.
Second group included two statements concerning the benefits of applying the model in terms of enhancing communications between partners, and the possibility of taking advantage from the experience of contractors and subcontractors.

Third group statements concerned with of enhancing performance in time, cost, and quality. Data collected were processed statistically using the SPSS V. 25 statistical program. The weights of the Likert scale were: Strongly disagree= 1, Disagree= 2, Neutral= 3, Agree= 4, and Strongly agree=5.

The questionnaire reliability analysis was applied to the collected data to know reliability of questionnaire responses. Table 2 indicates that Cronbach's alpha is 0.742, which is an acceptable reliability value.

Table 2. "Cronbach’s Coefficient Value for Proposed Model"

| Reliability Statistics | Cronbach's Alpha | N of Items |
|------------------------|------------------|------------|
|                        | .742             | 8          |

3. Results Discussion

- Results of first group statement: Figure 2 shows the following points:
  - As in Figure 2(a) the highest percentage (83.70%) of the respondents believed that the proposed model is applicable.
  - As in Figure 2(b) the highest percentage (86.96%) of the respondents agreed with focusing on the design phase by the proposed model.
  - As in Figure 2(c) the highest percentage (57.61%) of the respondents strongly disagree with applying constructability and value engineering simultaneously for all the project phases

![Figure 2. "First Group Results"

- Results of second group statement: Figure 3 shows the following points:
  - Figure 3(a) shows that (83.70%) of the respondents believed the proposed model will improve relationships and communication between different parties of the project.
  - Figure 3(b) shows that (86.96%) of the respondents believed that applying the proposed model will benefit from contractors' experience in suggesting practical alternatives

![Figure 3. "Second Group Results"

- Results of third group statement: Figure 4 shows the following points:
  - Figure 4(a) shows that (83.70%) of respondents believed that proposed model will contribute in saving money.
  - Figure 4(b) shows that (86.96%) of respondents believe that proposed model will contribute in saving time.
  - Figure 4(c) shows that (83.70%) of the respondents believe that the proposed model will contribute in enhancing or at least maintaining the same quality.
4. Conclusions
The conclusions drawn from this research are summarized as follows:

- There is need to apply effective techniques, such as constructability and value engineering, to overcome problems and improve performance in projects in general and in infrastructure projects in particular. Those two techniques may be applied simultaneously to obtain significant results.
- It is not preferred to apply both techniques simultaneously to all project's stages. Rather, it is preferred to apply constructability at all project's stages, including the stage of operation and maintenance, while the value engineering should be applied only to the design phase.
- Applying the proposed model will lead to saving time, cost and improving or at least maintaining the required quality of materials and work, by taking advantage of the experience of all the involved project's partners.
- The research strongly recommends applying the proposed model to infrastructure projects in particular in Iraq, due to their significant importance and direct impact on the growth and economy.

For future study, the research recommends testing the suggested model by applying into case studies of projects that have been implemented, or are in progress, to examine its effect on savings time and costs.

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