Constructability for Sustainability: A Waste Elimination Approach in Construction Projects

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Abstract: The limited and inefficient use of natural resources accompanied with the increasing rate of project waste, called for saving the environment and thinking sustainable. The augmenting demand for sustainable buildings is essential to enable current generations achieving their objectives without compromising new generations from accomplishing their objectives. However, the task of delivering sustainable projects is not easy, if project waste is not eliminated. The problem of this research stems from the need to eliminate the different unnecessary project wastes that are generated throughout the project lifecycle. It is misunderstood that project waste is merely, generated during the construction phase. In fact, waste is generated throughout the project life cycle and has different types including: overproduction, waiting, unnecessary transport, unnecessary movement and defects, all of which have direct impact on the project cost, duration and quality.

This paper aims to investigate the role of the constructability concept in eliminating project waste as an approach to achieve sustainability in construction projects. A research methodology is designed to accomplish four objectives:

- Building an in-depth understanding of the research topic through reviewing the concepts of constructability, sustainability and waste.
- Presenting and analysing examples of best practice projects that benefited from applying constructability to reduce project waste.
- Investigating the perception and application of constructability towards eliminating project waste through conducting a survey questionnaire with a sample of Egyptian design and construction firms.
- Developing a model to facilitate the integration of constructability during the project life cycle as an attempt for eliminating project waste.

The value of this research comes from highlighting a topic that received scant attention in construction literature especially in the Egyptian context. In addition, adopting the developed model will help design and construction firms to eliminate the different types of project waste and achieve sustainability in construction projects.

Keywords: Constructability, Construction Projects, Egypt, Sustainability, Waste Elimination.

1. INTRODUCTION

Being one of the biggest industries worldwide, the construction industry plays a significant role towards achieving social and economic sustainable development objectives. One the one hand, it provides societies with places for housing, education, culture, health care, business, leisure and entertainment. Moreover, it constructs infrastructure projects that are essential for enabling these facilities to perform their planned functions. Furthermore, the construction industry helps increasing the gross domestic product (GDP), motivates development of other industries that sustain the construction process as well as offers employment opportunities (Field and Ofori, 1988; Othman, 2011a&b). On the other hand, the construction industry is perceived to be one of the most resource intensive and environmentally damaging industries worldwide. Construction is responsible for 40% of the total flow of raw materials into the global economy every year. It is a substantial source of waste, pollution and land dereliction (Earth watch Institute, 2012). The construction sector accounts for 50% of material resources taken from nature, 40% of energy consumption and 50% of total waste generated (Anink et al.,1996). Almost, all modern buildings now have artificial heating or cooling systems and sometimes both. These systems consume large amounts of energy in constructing, heating and cooling large and impressive glass cladding skyscrapers particularly in sunny, hot and humid countries (Architectural Review 1995, Abdellatif and Othman 2006). The increasing awareness towards saving the environment and using materials efficiently, called for the construction industry to be more sustainable (Kilpatrick, 2003; Othman, 2010a&b). However, the task of delivering sustainable projects is not that easy, if project waste is not eliminated. Although project waste are generally perceived to be material waste generated during the construction phase, this paper adopts the lean approach which defines seven different types of waste that are produced throughout the different stages of the project life cycle. Project waste could be better eliminated through optimum utilisation of construction knowledge and experience of construction professionals towards making efficient use of resources (Kilpatrick, 2003; Othman, 2011a&b). This paper aims to investigate the role of constructability as an innovative approach for eliminating waste in construction projects.

2. RESEARCH OBJECTIVES AND METHODOLOGY

In order to achieve the above mentioned aim, a research methodology consists of literature review, best practice projects and survey questionnaire, is developed to accomplish four objectives.

- Firstly, conducting in-depth literature review to build a comprehensive understanding of the research topic including constructability, sustainability and waste.
- Secondly, analysing three examples of best practice projects which benefited from applying the concept of constructability to reduce project waste.
- Thirdly, presenting and analysing results of a survey questionnaire conducted with a sample of Egyptian design and construction firms to investigate their perception and application of constructability towards eliminating project waste.
- Developing a conceptual framework to facilitate the integration of constructability during project life cycle as an approach for eliminating project waste.

3. LITERATURE REVIEW

3.1. Constructability

3.1.1. Definition and Concept Development

Constructability is described as the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives (Construction Industry Institute, 1986; Motsa, et al., 2008). Constructability, which is also known as Buildability in the UK, is a project management technique that includes a detailed review of design drawings, models, specifications, and construction processes by one or more highly experienced construction engineers or specialists, working with the project team before a project is put out for bids and also prior to construction mobilization (Douglas and Gransberg, 2010). The concept of Constructability was first emerged in UK during the late 1970's as a result of studies focused on maximizing the efficiency, productivity, cost effectiveness and quality in the construction industry through the early involvement of construction expertise. Later on, the Construction Industry Institute (CII) in the United States promoted the concept of constructability and formulated guidelines for implementation through enlarging the scope by encompassing management practices and procurement approaches. Likewise, CII Australia proposed 12 principles for putting the concept of constructability in action. In the 1990s, Singapore introduced the first assessment system for buildability of designs. These studies and actions showed that the lack of integration of construction knowledge into the design process was considered as one of the main reasons for projects exceeding their budgets and schedule deadlines and increase project waste (Wong et al. 2006; Othman, 2011a&b). Although the constructability concept could be applied at different stages of the project life cycle, it is application during the early stages is more effective as many of the decisions made during these stages have significant impact on the project performance (Pulaski, 2005).

3.1.2. Constructability Reviews Techniques

Many techniques are used in constructability reviews. The most two commonly practices used are peer review and feedback systems. Other practices include brainstorming sessions, computer models, physical models, discussion with clients, contractors and suppliers and quality assurance (Othman, 2011a&b). Peer review has two types namely, project management and project design. Project management focuses on management and planning aspects where project design is an evaluation that focuses on the technical aspects of the project. The two types of peer review are both involved, in order to improve the quality of the project before embarking the construction process. An advantage of conducting peer review is that design inconsistencies are corrected and uncovered; besides alternative construction methods are specified that the designer was not familiar with. Feedback systems include the transition of previous lessons learned in order to avoid mistakes and errors in upcoming projects. Computer models, physical models are very useful techniques for both constructability and sustainability; these techniques allow clients and designers to understand how the building will look like before it is actually built. Brainstorming sessions focus on specific design planning for maintenance, recyclability, dangerous materials and water and energy conservation (Pulaski, 2005).

3.1.3. Barriers to Constructability

O'Connor and Miller (1994) and the Construction Industry Institute (1993) classified the barriers to constructability into general, owner, designer and contractor barriers as follows:

General barriers

- Complacency with status quo

- "This is just another programme"
- "Right people" are not available
- Discontinuity of key project team personnel
- No documentation of lessons learned
- Failure to search out problems and opportunities

Owner barriers

- Lack of awareness of benefits, concepts, etc
- Perception that constructability delays project schedule
- Reluctance to invest additional money and/or effort in early project stages
- Lack of genuine commitment
- Distinctly separate design management and construction management operations
- Lack of construction experience
- Lack of team-building or partnering
- Disregard of constructability in selecting contractors and consultants
- Contracting difficulties in defining constructability scope
- Misdirected design objectives and performance measures
- Lack of financial incentive for designer
- Gold-plated standard specifications
- Limitations of lump-sum competitive contracting
- Unreceptive to contractor innovation

Designer barriers

- Perception that they have considered it
- Lack of awareness of benefits, concepts, etc.
- Lack of construction experience/qualified personnel
- Setting company goals over project goals
- Lack of awareness of construction technologies
- Lack of mutual respect between designers and constructors
- Perception of increased designer liability
- Construction input is requested too late to be of value

Contractor barriers

- Reluctance of field personnel to offer preconstruction advice
- Poor timeliness of input
- Poor communication skills
- Lack of involvement in tool and equipment development

3.2. Sustainability

3.2.1. Definition and Dimensions

The Bruntland commission (1987 cited in McLennan, 2004) defined sustainability as meeting the needs of the present without compromising the needs of the future. Sustainability has three dimensions namely, environmental, social and economic (Othman and Nadim, 2010).

Environmental Dimension

The environmental dimension concentrates on the following:

1. Decreasing the influence on human health,
2. Utilizing renewable raw materials,
3. Abstract toxic substances, and
4. Decreasing waste, streaming generations, and release to the environment

Social Dimension
The social dimension concentrates on the following:
1. National and international laws,
2. Labours safety and health,
3. Transportation and urban planning,
4. Local and individual lifestyles,
5. The link between human development and human rights,
6. Environmental justice and company powers,
7. Citizens job and global poverty,
8. Effect on local communities and the life quality, and
9. Advantages of handicapped and low earners

Economic Dimension
The economic dimension concentrates on the following:
1. Integrating ecological interests with economic and social ones,
2. Improving the life quality,
3. Supplying opportunities for local businesses,
4. Maximizing market shaft, to improve the public image,
5. Creating new opportunities and markets for sale growth,
6. Minimizing cost through progressing efficiency and minimizing energy and raw material chip, and
7. Make additional added value

3.3. Project waste

The Environmental Protection Agency (EPA, 2007) defined construction waste as building and site improvement materials and other solid waste resulting from construction, remodelling, renovation, or repair operations. About 38%, 25% and 20% of the solid waste are generated from the construction industry in Hong Kong, EU and Japan respectively (Hong Kong Government - Environmental Protection Department, 2006; EIONET, 2006; Japanese Ministry of Environment, 2005). In Egypt, the construction waste represents about 13% of the total solid waste produced by Egyptian Governorates (Tawfik and Othman, 2013). Waste directly affects project's client, construction companies, and their projects through inefficient use of resources; jeopardising companies' image and public trust, and exceeding project budget and duration. In addition, construction waste has a negative effect on the environment as well. This called for the construction industry to manage its waste efficiently as an approach to achieve sustainability objectives (Othman, 2011a&b). From the lean perspective, waste is not only related to materials, Toyota Company identified 7 types of waste (see table 1).

Table 1: Toyota's 7 Types of Waste (Kotelnikov, 2001)

1	Overproduction	Producing items for which there is no order resulting in overstaffing, storage or transportation
2	Waiting	Workers idled watching a machine or waiting for material, equipment, approvals or directions
3	Unnecessary Transport	Moving work-in-process or inventory
4	Over or incorrect processing	Taking unneeded steps to achieve an outcome, inefficiencies due to poor tools or design; procuring to higher standard than required

5	Excess Inventory	Raw material, WIP or finished goods, increasing lead time, obsolescence, damaged goods, storage, transportation; also hides production and delivery problems
6	Unnecessary movement	Wasted employee motion – looking for, reaching for, stacking parts or tools. Walking is waste
7	Defects	Production of defective parts or correction. Repair, rework, Scrap and inspection

4. RELATIONSHIP BETWEEN CONSTRUCTABILITY AND SUSTAINABILITY

Constructability and Sustainability are two complementary concepts. While constructability aims to utilise the construction knowledge and experience of construction professionals to improve project performance; sustainability integrates with constructability through efficient use of resources and minimise waste. Pulaski (2005) identified five areas that show the current relationship connection between both concepts (see table 2).

1. Integrating organizational structures and contracting strategies.
2. Project management practices to manage both sustainability and constructability.
3. Principles that reduce waste by simplifying the construction process and enhancing the level of sustainability.
4. Systems of level design decisions that optimize performance of the entire facility.
5. Material selections that reduce physical waste and process waste.

Table 2:Current connection between Constructability and Sustainability (Pulaski, 2005)

Connections between Sustainability and Constructability

Area	Examples	Connection
Integrated Organizational Structures and Contracting Strategies	Design-build Performance-Based Contracting	Cross-discipline integration fosters innovation necessary to identify high performance solutions
Project Management Practices	Integrated organizational team, Full scale physical model (mock-up). Drawing reviews, Lessons learned workshops	Similar project management practices can be used to manage sustainability and constructability knowledge.
Principles	Simplify and standardize construction details	Reduce waste by simplifying the construction process and enhancing the levels of sustainability
Systems	Energy engineer designed the layout of the piping system first and then placing the pumps in the most efficient location. This improved energy efficiency and reduced installation time and cost.	Design decisions can optimize performance of the entire facility
Materials	Waterless urinals Pervious pavement Light paint	Reduce physical waste and process waste

5. EXAMPLES OF BEST PRACTICE PROJECTS BENEFITED FROM APPLYING CONSTRUCTABILITY TO REDUCE PROJECT WASTE

5.1. Project (1): The Pentagon Renovation Project, Arlington, Virginia, USA

The renovation process of the Pentagon began in 1993 and completed in 2003. The contract stated that the government should participate in the design decision making process, while knowing and maintaining the essential role of the contractors. Speed construction was fundamental, the timing for the program and the construction schedules were from 24-40 months. The concept of constructability was adopted and a number of techniques were used. Computer models were utilised through the building information modelling (BIM) to facilitate visualizing the building before its construction, to decrease any potential changes and conflicts (see figure 1). It was integrated in the conceptual design phase. This helped reducing the building life cycle cost through using only needed materials (Heller, 2006).

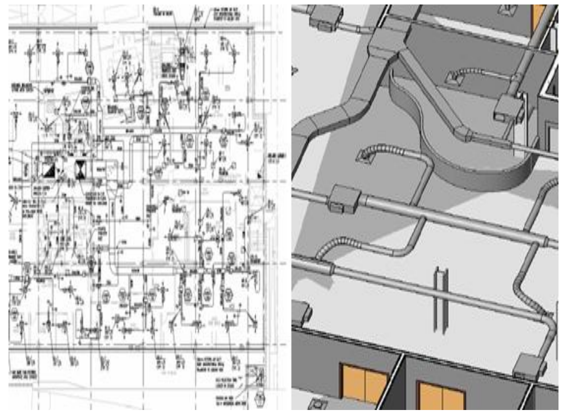

Figure 1: 2D and 3D of Pentagon Renovation Project (Heller, 2006).

5.2. Project (2): The Lansing Community College, Michigan, USA

Lansing Community College (LCC) was established in 1957 to meet the growing demand for technical and specialized education in the Greater Lansing area, Michigan, USA. The LCC Health and Human Services Career Building was originally designed as a three story building with a future fourth-floor expansion. The expansion exceeded the $2.5 million budget for steel fabrication and erection by $200,000. Ruby and Associates Consulting Structural Engineers entered the project and applied the constructability principle to completely re-design the structural steel fabrication. The re-design process helped eliminating 700 steel members and 1400 connections, while shear studs were reduced by 11,000. Overall, approximately 300 tons of steel were saved. This saved enough money to enable LCC to construct the fourth floor upfront while bringing the project in approximately $100,000 under budget and on schedule (Aeck and Ruby 2006).

5.3. Project (3): Cannon Beach Residence, Oregon, USA

Based on the client’s needs, the architect was asked to design a small home that provides its users with shelter, comfort, and rejuvenation. The house should use natural materials that are durable for generations, require little maintenance, healthy to live in using systems that dramatically reduce the adverse impact on the environment. Towards delivering such a building, the design team decided to use the concept of constructability and involve the client of the project and his guests, the contractor as well as experts to participate in the design decision making process at early stages of the project. As a result, the design team was able to select building systems and materials that meet the client requirements at minimum waste and increase house longevity. In addition, the design team and the client escalated their knowledge through conducting a green building seminar open to subcontractors and building officials (Cascadia, 2009).

Analysis of the presented best practice projects showed that by integrating the concept of constructability a number of benefits have been achieved. These benefits included reducing the number of changes and potential conflicts during the execution of the project, reducing project time, cost and waste and achieving client satisfaction. Table (3) summarizes the integration timing, constructability techniques and the dimension of sustainability achieved.

Table 3: Summary of Best Practice Project (developed by the authors).

Best Practice Project	**Timing of integrating**	**Constructability techniques used**	**Dimension of sustainability achieved**
Project 1	The conceptual phase	Computer models	Economical Social sustainability
Project 2	The bidding phase	Discussion with contractors, clients and suppliers	Economical sustainability
Project 3	The conceptual phase	Discussion with contractors, clients and suppliers	Environmental, economical and social sustainability

6. DATA ANALYSIS

This section presents and analyses the results of two survey questionnaires directed to architectural design firms and construction firms respectively to investigate the perception and application of constructability as a tool for reducing project waste. The population of the architectural design firms was the list of 186 design organisation registered with the Egyptian Syndicate of Engineers at Cairo region, Egypt. These 186 organisations are classified according to their disciplinary specialisation at three categories: Category (A) 22 Expertise Houses which have all disciplinarians; Category (B) 76 Multi disciplinary Bureaus which have more than one disciplinary and Category (C) 97 organisation that are Specialist Architectural Bureaus. Duo to time constraints and limited resources, it was difficult to meet all theses organisation. As a result a sampling factor of 1:5 was selected to result in 37 firms. Out of 37 organisations, only 27 agreed to participate in the survey questionnaire. Managers of the surveyed architectural design firms were asked to recommend a sample of construction firms that could participate and support achieving the questionnaire objectives. The sample of construction firms was 13 companies. Although both questionnaires have different questions to suit the different nature of architectural and construction firms, there are some common questions, such as “if the company applies any of the constructability techniques” and “the company’s awareness of constructability and sustainability”. For instance, the architectural design firms’ questionnaire focused more on the type of project waste generated and the occurrence phase. On the other hand, the contraction firms’ questionnaire focused on perceiving whether the contractors are involved during the early stage of a project life cycle. The researchers’ role was to explain questions or unfamiliar terms.

- Analysis of respondents showed that "Defects" and "Waiting" represent the highest type of waste in the design process with average of (37.5%) and (23.5%) respectively. This could be attributed to the improper understating of the client requirements which results in developing a design that does not meet his/her needs. In addition, "Defects" waste also could be generated due to design errors and mistakes. Furthermore, waiting client approval and his/her feedback on the developed design as well as waiting governmental revision and approval of design could be considered as waste of time. Other types of waste included "incorrect processing" (18%), "excess Inventory" (12%) and "unnecessary transportation" (9%).
- 18 respondents out of 27 stated that contractors are not involved during the early stages of the project life cycle. This could be attributed to two reasons. Firstly, the traditional procurement approach commonly adopted in Egypt does not involve or consider the contractor as part of the design team. Secondly, designers depend on their knowledge and experience and contractors are usually approached after the completion of design. The remaining respondents mentioned that they involve contractors to gain their advise and feedback towards improving their design.
- Respondents stated that the most common constructability practices used are "computer models" (24.5%), "feedback system" (23.5%) and "peer review" (21.5%). On the other hand, "Physical models" and "brainstorming sessions" were the least used practices with average of (17%) and (13.5%) respectively.
- 10 out of 13 construction firms mentioned that they were not involved in the early stages of the project life cycle. This is because during the design process, under the traditional procurement approach which is commonly used in Egypt, contractors are usually unknown and are only invited in the bidding stage. This procurement approach separates between the design and construction. These results are supported by literature review, for example (Arditi, et al., 2002; Othman, 2011a&b).

7. A CONCEPTUAL FRAMEWORK TO FACILITATE INTEGRATING CONSTRUCTABILITY DURING PROJECT LIFE CYCLE AS AN APPROACH FOR ELIMINATING PROJECT WASTE

Results of literature review and analysis of best practice projects showed the importance of using constructability to reduce project waste. In addition, analysis of survey questionnaires highlighted the lack of using constructability in eliminating waste in the Egyptian construction industry. This necessitated the development of a framework to facilitate its adoption and application as an approach to eliminate project waste in Egypt. The conceptual framework is developed based on Deming cycle, the Plan, Do, Check & Act (PDCA).

Plan Phase

Defining the objectives

- Constructability a tool for reducing project waste and achieving sustainability.
- Building an in depth understanding and awareness of the constructability concept.

Defining methods how to achieve these objectives

- Integrating constructability techniques in each project phase, based on what type of project waste it generates, according to the questionnaire conducted in Egypt.
- Increasing the awareness of architects and contractors with the benefits, that constructability can offer, if integrated within the design process.

Do Phase: Implementing the work:

Each phase displays what type of waste it generates, and what type of constructability techniques is the most suitable to be integrated and be able to achieve sustainability at the end.

Check Phase: Checking the effect of implementing these solutions

If these techniques are applied in all project phase, project waste could be eliminated an different sustainability objectives achieved.

Act Phase: If the results were satisfying then the solutions should be standardized in all project phases, and architects and contractors must start integrating constructability techniques throughout the project life cycle to reduce waste. In addition, successful projects have to be disseminated and shared with peers to increase the awareness of constructability towards eliminating waste in construction projects. On the other hand, if the results were not effective, then the project team members should take corrective actions and investigate the root causes and shortcoming of not meeting the planned objectives (see figure 2).

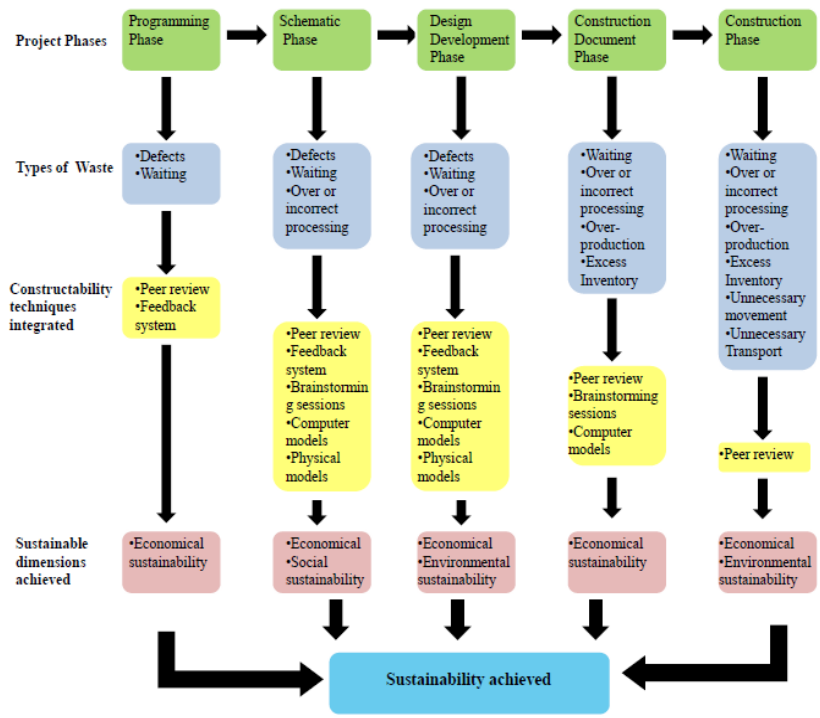

Figure 2: Conceptual framework structure (developed by the authors)

8. CONCLUSION AND RECOMMENDATIONS

The increasing awareness for saving the environment and using materials efficiently called for the construction industry to be more sustainable. One of the most important elements to achieve sustainability is to eliminate project waste. This research adopted the lean approach, which defined 7 types of waste namely, defects, waiting, over or incorrect processing, over production, excess inventory, unnecessary movement and unnecessary transportation. Eliminating project waste needs collaboration between different project participants especially contractors and making better use of their construction knowledge and experience. Using constructability concept at early stages of the project life cycle helps improving performance and eliminates waste. Different techniques are used such as peer review, feedback system, brainstorming sessions, computer models and physical models. This research presented and analysed results of two survey questionnaires directed towards investigating the perception and application of constructability to eliminate project waste in the Egyptian construction industry. As a result a conceptual framework was developed to facilitate the integration of constructability in design and construction firms. Based on the above the research comes to the following recommendations

- Design and construction firms are advised to adopt different procurement approach that encourages contractors' involvement in the early stages of the design process. This helps improving communication between the design and construction team and make better use of construction knowledge and experience to improve project performance and eliminate project waste.
- Benefits of adopting the constructability concept have to be explained to clients, design team and senior management in design and construction firms to facilitate its adoption and offer needed facilitates to ensure its success and achieving its objectives.
- Adopting the developed framework as an approach for reducing project waste in construction projects.

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