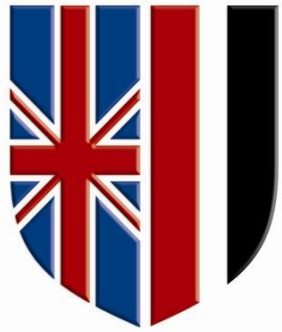


TOWARDS ACHIEVING SUSTAINABILITY IN
CONSTRUCTION: CONSTRUCTABILITY AS A TOOL
FOR REDUCING PROJECT WASTE



By

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Architectural Engineering

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IN CONSTRUCTION: CONSTRUCTABILITY AS A TOOL
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Declaration of Originality

This is to certify that the work is entirely my own and not of any other person, unless explicitly acknowledged (including citation of published and unpublished sources).

The work has not previously been submitted in any form to the British University in Egypt or to any other institution for assessment for any other purpose.

Sarah Hisham Aboul Seoud, June 2013

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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 own objectives. However, the task of delivering sustainable projects is not that 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 life cycle. It is misunderstood that project waste is merely, waste generated during the construction process. In fact, waste has different types including: overproduction, waiting, unnecessary transport, over or incorrect processing, excess inventory, unnecessary movement and defects. All of which have direct impact of the project cost, duration and quality. This paper aims to investigate the role of the concept of constructability 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 analyzing a number of case studies that used 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 conceptual framework to facilitate the project life cycle by integrating constructability as an approach 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.

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Chapter (1) Introduction:

1.1. Introduction:

The demand for sustainable buildings is nowadays an essential issue in the building industry. (Kilpatrick, 2003) However, the task of delivering it is not that easy, if project waste is not resolved. Project waste can be minimized through integrating improvement construction techniques, such as; Constructability. Construction knowledge is integrated during design by using constructability techniques. . (Kilpatrick, 2003)

This research defines project waste and its types of waste and how constructability plays the role to reduce that waste. The research shows constructability techniques can be a tool for achieving sustainability. The current connection between constructability and sustainability is also discussed. In conclusion a set of recommendation is exploded, which will be useful for design and construction industries.

1.2. Research problem:

Main problem:

- There is a lot of unnecessary project wastes that are generated during project processes. Wastes can be minimized with construction techniques, such as; constructability. Types of project wastes during the life cycle of any project can be waiting, defects, rework or unnecessary movements. (Kilpatrick, 2003)

Secondary problem:

- Architects do not take in consideration the waste generated from: overdesign, rework, unnecessary movements.

These things lead to project waste that is unnecessary and can be minimized by constructability techniques.

- Only few researches presented the link between constructability and sustainability, by minimizing the project waste.

1.3. Research Objectives:

Main Objective:

- Investigating the role of constructability towards achieving sustainability, through minimizing project waste.

Secondary Objectives:

- To build an in depth understanding of the research topic through covering different areas of waste, constructability and sustainability.
- Develop a framework to facilitate the integration of constructability during project life cycle to minimize waste.
- Summarize research conclusion and add recommendation useful to reduce waste.

1.4. Research Questions:

- What is project waste, its types, and how can it be minimized?
- What are the constructability techniques?
- Which phase is the most appropriate phase to apply constructability techniques? and what are the benefits of applying it?
- Is there a connection between Constructability and Sustainability?
- How can a sustainable building be achieved?

1.5. Research Methodology:

- Reviewing all researches that discussed project waste, constructability and sustainability.
- Presenting and analyzing case studies that used constructability to reduce project waste.
- Conduct a questionnaire with Egyptian design and construction firms to examine the following:
 1. How firms are handling project waste
 2. If firms are using any improvement techniques to reduce project waste
 3. If firms have applied/ discerned the constructability techniques to reduce project waste

Chapter 2: Project waste vs. Constructability and Sustainability

2.1 Introduction

Waste is unnecessary or deteriorated material produced by manufacturing process. (Merriam-Webster Dictionary, 2012) Waste is a steady element that is found in any type of industry. It appears during design, construction and production processes or after them. Unfortunately, waste cannot be completely evaded, but it can be decreased. Lean Production is a system that seeks to decrease project waste, with the help with some improvement techniques, such as; constructability, partnership, computer integrated construction robotized and automated construction that can help minimizing the waste. This research will be focusing only on Constructability.

This chapter will cover the definition of project waste, and the seven types of wastes that were defined by Ohno during any project. The chapter will also talk about the two most effective concepts in the design and construction industry. First, Constructability will be defined in detail and the twenty-three concepts will be explained. The timing, when constructability must be applied in any project, in order to be most effective. The barriers and benefits of constructability in design and construction industry will be illustrated. Second, Sustainability will be defined, while clearing what a sustainable development, sustainable building, sustainable design and sustainable construction are. Constructability and sustainability share a common theme; both strive for the efficient use of resources through the reduction of waste and integration, the kind of waste each one is reducing will be clarified.

2.2 Project waste

The amount of waste is connected to how every company manages its projects and also on the size of the projects. Project waste does not only include construction waste from the part of the physical waste like materials, it includes waste of time and waste of money. Time and money are the two most important operators in any construction and design industry. If these two operators exist, eventually an inefficient sustainable project will be delivered.

2.2.1 Lean Production

Lean production methods were developed through Toyota Production Systems by Taiichi Ohno, in order to improve the efficiency of the production processes and eliminate waste. (Pulaski, 2005) Lean production abstracts waste by minimizing or reducing supplier, internal variability and customer. It is a processing framework with the objective of arranging the flow of production while constantly attempting to decrease resources, direct and indirect labor, supply, materials, and space to manufacture a given set of items. Remains in the system is mentioned as waste. (Jacobs, 2010)

2.2.2 Types of Project waste

Activities that are not necessary and do not add more value to a project and should be eliminated are defined as wastes. Ohno defined seven types of project waste, as follows; (Kilpatrick, 2003)

1. **Defects:** Defect can be in rework of drawings or correction. It can be in inspection, by production a defective part, because it was not studied well enough or in the material itself. This results in waste in money and time for project to be submitted on schedule.

2. **Waiting:** Waiting produces waste of time, if contractors are waiting for final design drawings to be approved, to start constructing or labours waiting for materials, tools, equipments, directions, or information's.



*Figure 2.1: Labours waiting for directions,
final information's*

3. **Over or incorrect processing:** By taking unneeded steps to achieve an outcome or using inefficient methods, resulting in waste of time and money, due to poor tools or design, that will result in rework and this is considered to be project waste.

4. **Overproduction:** Waste in money if several drawing papers are thrown, and not being recycled or in manufacturing more than what the client asked for, due to inefficient calculations. This leads overstaffing and storage for unneeded staff and producing more than the required quantity. This leads to waste in materials and money.

5. **Excess Inventory:** It is connected to overproduction, dispossess above the clients requirements and what is needed. This has a negative impact, and results in waste in money, due to damaged goods, excess in raw materials, finished goods or storages.

6. **Unnecessary movement:** This type is mainly done in the construction processes, where this movements produce non-productive products and waste employees and labours energy, caused by weak workflows, weak layouts, conflicting or undocumented work methods. Walking itself is considered to be waste, if labours search for equipments or stacking parts. It is also considered to be waste of time, energy and money.

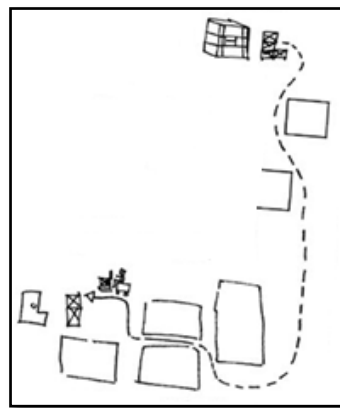


Figure 2.2: Unnecessary movements leads to waste in time

7. **Unnecessary transportation:** This type is also mainly done in the construction processes, where transportation products from one location to another location. Materials have to be transported to its point of use. What is done, is that raw materials are being shipped from the seller to a specific location, then handled, transported into a warehouse, then at the end carried away to the assembly line, where it will be utilized. This unnecessary movements, that can be eliminated, cause waste in time and money.

These types of waste cannot be completely eliminated from a project, but they can be minimized, and as stated above wastes lead to financial losses and waste in time.(shown in table 2.1)

	Waste in Time	Waste in money
Defects	✓	✓
Waiting	✓	✓
Over or incorrect processing	✓	✓
Overproduction	✓	✓
Excess Inventory		✓
Unnecessary movement	✓	✓
Unnecessary transportation	✓	✓

Table 2.1: Types of project wastes and what waste they lead to

One of the tools that can help in minimizing is constructability. By integrating its techniques in the early design stages of a project a lot of waste can be minimized.

3.2. Constructability

2.3.1 Definition of constructability

Douglas and Gransberg (2009) explain that constructability is a project management technique that analyzes the construction processes from start to finish during the pre-construction phase. It is known as Buildability in the UK. Constructability is a project management technique that includes an elaborated study of models, design drawings, specifications and construction procedures. It is reviewed by individuals or a group of extremely high experienced construction specialists or engineers. This review must be made before the project is put out for bids and before the construction processes. It will help to identify the obstacles before a project is actually built. As a result, it tends to prevent; delays, errors and cost overruns. (Othman, 2011)

The concept of constructability was first introduced by the Construction Industry Institute (CII) in year 1986, where it stated" Constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives" (Jergeas & Van der Put, 2001).

The value of integrating construction knowledge early in the design process has been widely examined. Jergeas and Van der Put (2001) state that there are many potential advantages in integrating constructability information early in design. (Pulaski, 2005)

2.3.2 Constructability Concepts

Nima (2001 cited in Othman, 2011) theorizes twenty-three constructability concepts to enhance and facilitate the selection and constructability application through the different phases of the construction process of a project.

The twenty-three concepts are divided into three different phases.(Nawi et al., 2001)

Phase1: Phase one is the conceptual planning phase in a project. It consists of seven concepts.(shown in table 2.2)

Concept 1	All project team members should address the project constructability program, within the project implementation plan.
Concept 2	Constructability issues should take part from the beginning of the project and through all phases, by a project team from the owner, contractor and engineer.
Concept 3	While selecting the number and type of contracts, construction methods should be considered.
Concept 4	The intervention between the constructor and the designer can be avoided, when individuals with current construction knowledge are included at the beginning of the project.
Concept 5	Ease and efficiency of field operation is achieved, if major construction methods are addressed properly as early as possible.
Concept 6	Construction completion date and master project schedule should be set as early as possible and should be precise.
Concept 7	Intervention between project activities is avoided, if the site layout is considered accurately early.

*Table 2.2: Constructability concepts in conceptual planning phase
(Nawi et al., 2001)*

Phase2: Design and procurement phase. It consists of eight concepts.(shown in table 2.3)

Concept 8	Construction schedule must be explored and expanded before the design development and procurement schedule.
Concept 9	To overcome the fragmentation in the field between specialists, advanced information technologies must be used in any, especially in the construction industry.
Concept 10	Through design simplification, efficient construction is configured.
Concept 11	Project cost will not be impacted negatively, if project elements are standardized to an extent.
Concept 12	The application of pre-assembling the project elements should be studied well. Pre-assembling facilities the transportation, installation and fabrication of the objects.
Concept 13	Technical specification should be facilitated and simplified to fulfil efficient construction.
Concept 14	Designer should take the accessibility of materials and equipments to the site in consideration.
Concept 15	Designers should ease construction during reserve weather conditions.

*Table 2.3: Constructability concepts in design and procurement phase
(Nawi et al., 2001)*

Phase3: Phase three is the field operation phase. It consists of eight concepts.

2.3.3 Best timing to apply constructability techniques in a project

A survey made on 500 top design firms in the United States, it was shown that 87% execute constructability review in the developed design stage (during

design and procurement phase). It was also found that 25% execute constructability throughout the entire design process. (as shown in Figure 2.3)

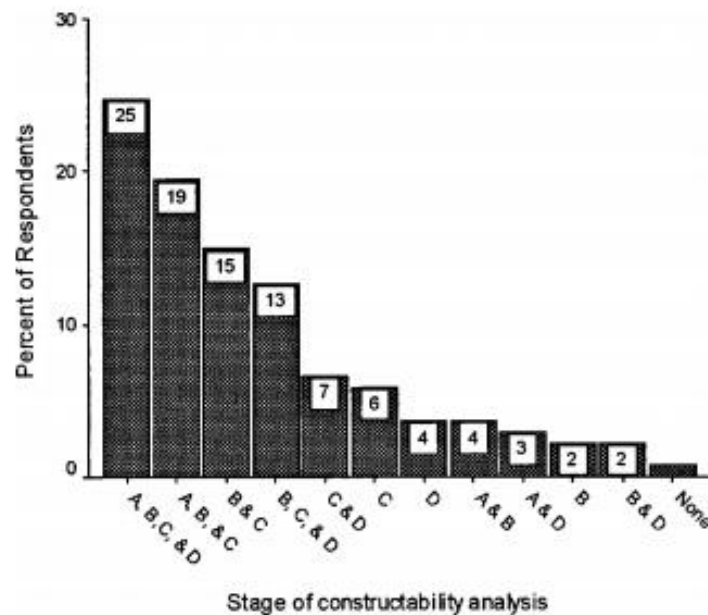


Figure 2.3: Timing of constructability reviews: A, conceptual planning stage; B, preliminary design stage; C, developed design stage; D, after finishing the design (Arditi et al., 2002)

From the sum of the results, it can be observed that 51% of the firms start performing constructability in the very early stages of the design, in the conceptual planning stage. It is generally considered to conduct constructability after plans are completed at a certain level, but there is another process that says that construction professionals must be brought before any design is drawn. In order, to let the designers start their work with some issues in their mind; such as cost and materials and try to find solutions for it. (Arditi et al., 2002) More benefits will be achieved, if constructability is conducted in the early stages of the design. (Jergeas & Van der Put 2001).

2.3.4 Constructability Techniques

There are many techniques used in constructability reviews, the most common practice is "peer review", while there is other practices, such as; brainstorming sessions, computer models, physical models and feedback system. (as shown in Table 2.4) (Pulaski, 2005)

Constructability Techniques
Peer Reviews
Mock ups (physical models)
Brainstorming sessions
Computer models
Feedback/ Lessons Learned systems (computer systems and workshops)
Discussions with contractors, clients and suppliers
Quality assurance/ quality control after each design stage
Design Checklist Reviews
Constructability Improvement Program
Constructability Project Team
Constructability champion and project coordinator

Table 2.4: Constructability Techniques (Othman, 2011)

There are two types of peer reviews: project management and project design. Project management focuses on management and planning aspects, on the other hand project design is an evaluation that focuses on the technical aspects of a project. The two types of "peer review" are both involved, in order to improve the quality of the project before entering it the construction phase. An advantage of conducting peer review is that design inconsistencies is corrected and uncovered; besides alternative construction methods are specified that the designer was not familiar with them.

Brainstorming sessions focus on specific design planning for maintenance, recyclability, dangerous materials and water and energy conservation.

Computer models, physical models or mock ups are very useful techniques for both constructability and sustainability, these techniques allow for clients and designer to understand how the building will look like before it is build.

Feedback systems include the transition of previous lessons learned in order to avoid them in the upcoming projects. (Pulaski, 2005)

According to the same survey, as stated previous the most two commonly practices used are the "peer review" and the "feedback system", 88 and 87% of the design firms use these two techniques. (as shown in figure 2.4) (Arditi et al., 2002)

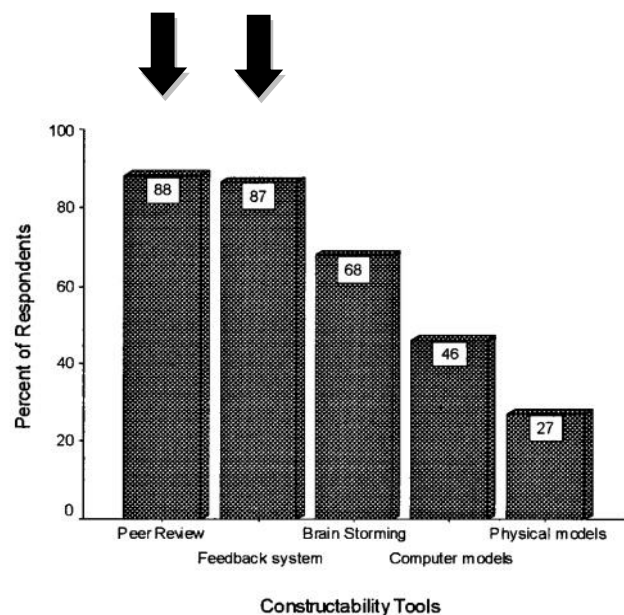


Figure 2.4: Constructability review techniques according to the survey (Arditi et al., 2002)

The reason why "peer review" is very popular is because the government authorities; such as the city of Boston assign "peer reviews" for specific

contracts and before releasing building approvals for complex projects. (Othman, 2011)

In the feedback process they take benefit and feedback from the previous lessons. (Arditi et al., 2002)

2.3.5 Barriers to Constructability

Any resistant that prevents effectiveness of applying constructability is considered to be a barrier. O'Connor and Miller (1995 cited in Al-Ghamdi, 2000) identified that there is fifteen recognizable barriers. Wright and Kreitzberg (1994) identified the same barriers.

The most common barriers are as follow; (Al-Ghamdi, 2000)

1. Limitations of lump sum competitive contracting
2. Unwillingness to invest additional money and effort in early project stages
3. Lack of construction experience in the design organization
4. Lack of mutual respect between constructors and designers
5. Construction input is requested too late to have an input value
6. Designer's think that they take everything in mind

There are some other barriers that were identified by the Construction Management Committee (CMC): (Al-Ghamdi, 2000)

1. Reluctance by the designers, who view such efforts as an intrusion
2. Not enough qualified persons
3. Training in constructability
4. Motivation, priorities, costs

2.3.6 Benefits of Constructability

In order to achieve the most benefits of constructability review is to conduct contractors from the very beginning of a project. (Jergeas & Van der Put, 2000)

The ability to influence project cost is more effective when constructability is applied from the early stage and also considered along all stages of the project. (Othman, 2011)

Motsa et al. (2008 cited in Othman, 2011) study the benefits of conducting constructability and ranked them from scale 1-5. (as shown in figure 2.5)

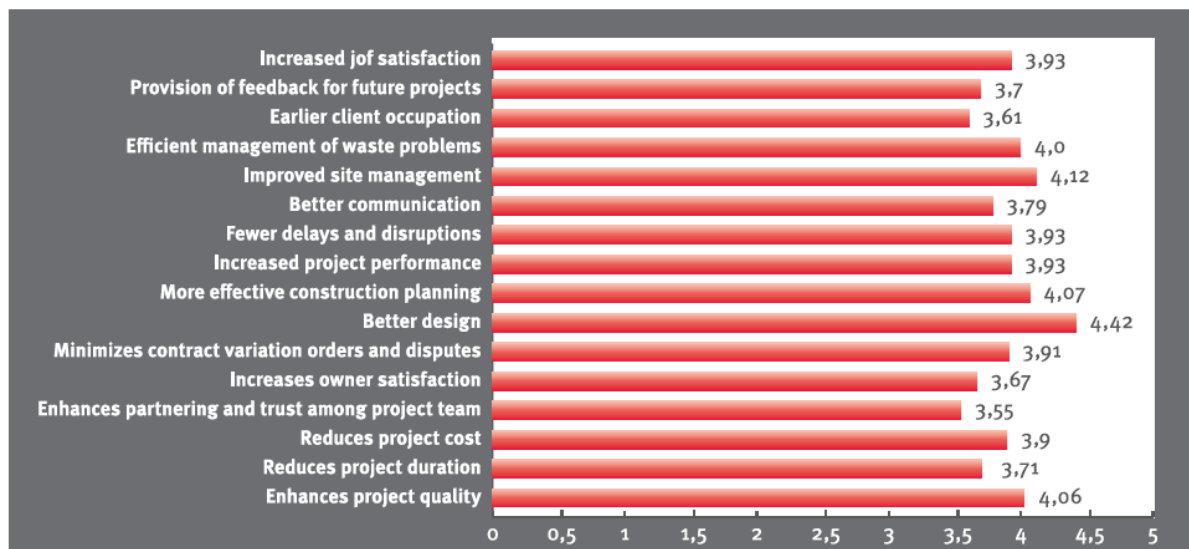


Figure 2. 5: Benefits of implementing constructability (Othman, 2011)

From the ranking, the five highest ranked benefits are: achieving a better design, improving site management, increase project performance, enhancing project quality and efficient management of waste problems.

2.4. Sustainability

2.4.1 Definition of sustainability

Sustainability is briefly defined by Bruntland (1987 cited in McLennan, 2004) Commission as "meeting the needs of the present without compromising the needs of the future."

2.4.3 Sustainable Dimensions

Sustainability dimension are divided into three dimensions; environmental social and economic dimensions. (shown in figure 2.6) (Othman & Nadim, 2010)

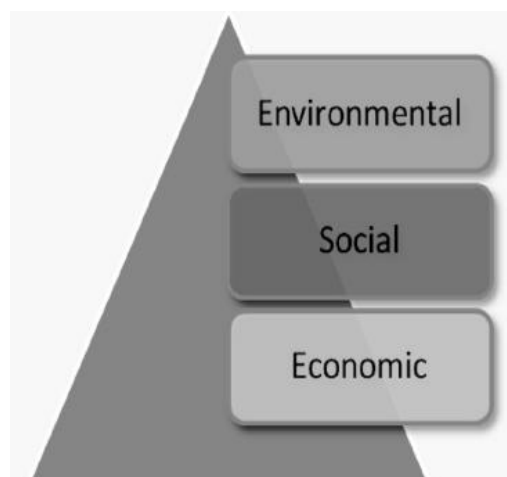


Figure 2.6: Dimensions of sustainability

2.4.3.1 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
4. Decreasing waste, streaming generations, and release to the environment

2.4.3.2 Social Dimension

Social dimension is concerned about the peoples need and please their satisfaction. Sustainability plays a role in supplying good education, upgrading the community consultations and enhance the interest of the different fields.

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
9. Advantages of handicapped and low earners

2.4.3.3 Economic Dimension

The economical dimension is concerned about the economic growth.
Elaborating within the space of the nature environment.

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

7. Make additional added value

2.4.4 Sustainable Development

Sustainable Development is defined as a sum of many resources that seek to meet the human needs, while at the same time preserving the environment. In order, to let these needs for the future generations not only the present generation. (Wheeler et al., 2010)

The World commission on Environment and Development (1987 cited in Pulaski, 2005) defines sustainable development as follow; "sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs"

2.4.5 Sustainable Building

Sustainable building as a part of a sustainable development, which aims to deliver built property that heightens quality of life and offers customer satisfaction, flexibility and the potential to provide user changes in the future and support desirable social and natural environments and maximizes the efficient use of resources. (Raynsford, 2000 cited in Pulaski, 2005) Sustainable building is a substitution approach to construction, based on ecological principles and efficient resources. (Pulaski, 2005)

2.4.6 Sustainable Design

Sustainable Design is a design philosophy that aims to maximize the quality of the built environment, eliminating or reducing the negative impact to the natural environment. (McLennan, 2004) It does not include only environmental considerations, but how it integrates with maintenance, schedule, operations and cost and workers considerations.

Sustainable Design encourages the use of renewable resources and promotes the use of efficient resources over the life of a project. (Pulaski, 2005)

2.4.7 Sustainable Construction

Construction organizations have an important role in delivering a sustainable building project. Many opportunities exist during construction to improve sustainable objectives and maximize project performance. Opportunities can be found in eliminating construction waste, decreasing site disturbance, buying of materials, health and safety of workers and improvement of indoor air quality.

Reducing waste throughout the whole construction processes provides the greatest opportunity to achieve higher levels of sustainability.

Achieving high levels of sustainability can also be achieved in construction, by integrating experts in that discipline and key stakeholders from the early stage of a project, even if the design process are difficult. (Pulaski, 2005)

2.5 Current connection between Constructability and Sustainability

Constructability and Sustainability are two concepts that seek for the efficient use of resources through minimizing waste. Constructability focuses on waste in terms of the efficient use of materials and personnel, by finding easier ways to undertake construction. Constructability concepts are typically used to ease the construction process, but they also influence the design. On the other hand, Sustainability seeks to reduce wasted energy, water and material during the construction and operation processes.

2.5.1 The five areas of the current connection

There is not an explicit connection between both, because very little research has been completed on this topic. Pulaski (2005) clarified five areas that show the current connection between both concepts. The five areas are techniques for constructability and if integrated in a project, sustainability is achieved. Pulaski did not show the explicit connection between both concepts, and how sustainability can be achieved. This is the aim of this research, to show the explicit connection between both. The five areas that Pulaski (2005) refined are:

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 level design decisions that optimize performance of the entire facility
5. Material selections that reduce physical waste and process waste.

Each area will be discussed in detail with an example for each. Pulaski (2005) made a table showing each area with an example and the connection between constructability and sustainability. (as shown in table 2.5)

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

Table 2.5: Connection between Constructability and Sustainability (Pulaski, 2005)

2.5.1.1 Integrated Organizational Structure and Contracting Strategies

This strategy rules are to let the team members and organizations work together within the delivery of a project. Traditional delivery methods, such as design-build, have rules that can control the innovative capabilities of project teams and prevent the integration of design. This integrated approach embraces multi-disciplinary interactions, which as a result supports the goals of a sustainable design and reduces first cost and project schedule. (Horman et al., 2004 cited in Pulaski, 2005)

Performance –based contracting is an opportunity to increase levels of sustainability on buildings and improve project constructability. It decreases the restrictions placed on a project team. There are many elements to performance-based contracting; one of them is performance specifications.

Performance specifications, eliminates contractual barriers and enables project teams to develop creative ways to achieve an optimal solution between the contractor, the designer and the owner. It can also recompense project teams to achieve sustainability and constructability objectives, such as; LEED rating, first cost, project completed on date and energy efficiency marks. (Hawken et al., 1999 cited in Pulaski, 2005)

2.5.1.2 Project Management Practices

Pulaski (2005) identified four project management practices that facilitate project teams in managing both constructability and sustainability knowledge in projects.

The four practices are;

- 1- The use of a combined organizational team
- 2- A full scale physical model "mock-up"
- 3- On board reviews
- 4- Lessons learned workshops

Every practice will be described briefly:

1- The use of a combined organizational team

The roles, consistence and processes of integrated organizational teams to manage constructability and sustainability were found to be closely related. (Pulaski et al., 2004 cited in Pulaski, 2005) CII's Constructability Implementation Guide points out that the objectives of constructability practices shall encourage teamwork, new ideas, creativity, new approaches and will assure total project integration, not individuals. (CII, 1993 cited in Pulaski, 2005) Sustainable design objectives are found to be nearly the same as the constructability objectives. (Peterson & Dorsey, 2000 cited in Pulaski, 2005)

2- A full scale physical model "mock-up"

Pulaski (2005) points out, those mock-ups are useful tools for both constructability and sustainability practices. Mock-ups help contactors "fine-tune" the construction process and allow designers and clients to imagine and understand how the building will look like. (Wilson et al., 1998 cited in Pulaski, 2005)

Wilson et al. (1998 cited in Pulaski, 2005) states that design tools, such as; mock-ups, building models and three-dimensional CAD models are useful tools to use.

3- On board reviews

Review processes are feedback systems and as said previous, this tool is one of the most common and beneficial tools used in constructability practices. The review process allows input from major project stakeholders, such as; maintainers, building worker and third party industry specialists, who have a precious knowledge about constructability and sustainability and how to integrate it throughout the project.

4- Lessons learned workshops

Lessons learned workshops/ brainstorming sessions are definite project management practices for the increasing of constructability and sustainability. Lessons learned, such as facilitated meetings are very effective. All participants should be prepared in advance. These meetings must be run periodically throughout the entire project and when major issues are present. Lessons learned for sustainable design are also critical for project success. Brainstorming sessions can focus on specific design strategies for recyclability, maintenance, water and energy conservation and hazardous reduction. Lessons learned workshops/ brainstorming are very important for managing constructability and sustainability knowledge.

2.5.1.3 Principles that reduce waste

There are twenty-one principles that reduce waste and achieve "synergy" between constructability and sustainability. These principles were identified by Pulaski (2004 cited in Pulaski, 2005) from projects at PENREN

Principles that should be addressed during the design phase: (Pulaski 2005)

- 1- Simplify and standardize construction details
- 2- Standardize repeatable components
- 3- Ensure proper sizing & specification of equipment, products and materials
- 4- Consider alternative water conservation and site drainage solutions
- 5- Simplify and separate building systems and components to facilitate maintenance and future renovations
- 6- Consider construction worker safety and efficiency during design
- 7- Use structural elements as finished materials

Principles that should be addressed throughout project design and construction:

- 8- Reduce area disturbed during construction
- 9- Optimize dimensions to utilize entire product or material
- 10- Continuously search for alternative environmentally safe products or materials
- 11- Use local materials and construction methods
- 12- Reuse construction materials, existing finish materials and products
- 13- Use methods and materials that allow for ease of reconfiguration, renovation or deconstruction
- 14- Select fittings, adhesives that allow for quicker disassembly and facilitate the removal of reusable materials
- 15- Minimize the use of all building components and materials
- 16- Minimize piping and ductwork bends

17- Prefabricate building components and/or modularize construction

The basic connection between all these principles is that they all reduce waste by simplifying the construction process and enhancing the level of sustainability.

The rest of the principles are related to the construction phase.

2.5.1.4 Systems level

The connection between constructability and sustainability at the systems level is that both focuses on selecting and designing building systems in a way that simplifies the construction process while enhancing levels of sustainability.

2.5.1.5 Material selection

The selection of material can enhance both concepts by reducing process and physical waste.

These five areas show the strong connection between constructability and sustainability and how if both concepts are integrated together a good project with no waste from both concepts can be delivered. (Pulaski 2005)

2.6 Conclusion

Project waste cannot be completely eliminated from a project, but it can be decreased using Constructability technique.

Constructability is a project management technique that reviews all the construction phases during all project phases, but it's most effective if applied during the early stages of a project. The involvement of construction expertise during the early stages, minimizes the some of the project waste that were mentioned previous in the research. The more sooner constructability techniques are used, the more beneficial it is. The most two popular techniques used nowadays are "peer review" and "feedback systems". Constructability, like every other technique, has benefits and constrains.

This chapter shows that constructability and sustainability are two concepts that cannot be separated from each other, in order to achieve a high sustainable building. Both concepts focus on reducing waste, but each one focuses on reducing a different kind of waste.

Constructability focuses on project waste, while Sustainability focuses on energy and environmental waste.

Chapter (3): Case Studies applying the concept of Constructability to reduce project waste

3.1 Introduction:

This chapter will display some case studies that integrated the constructability techniques during the projects. The projects are based on the timing of integrating the constructability, the different techniques used and on the dimension of sustainability achieved.

3.2. Case study (1): The Pentagon Renovation Project, Arlington, Virginia



Figure 3.1: "The Pentagon Renovation Program" (Heller, 2006)

3.2.1 Project Background

The renovation of the Pentagon started in 1993 and ended in 2003. (shown in Figure 3.1) It was led by Design build Institute of America (DBIA) Lee Evey. Evey wrote a motivational contract that focuses on motivating team members to figure out solutions for problems that occur and the out coming results.

3.2.2 Client requirements

Some points that were stated in the contract was that the government expects to participate in the " design decision making" process, while knowing and maintaining the essential role of the contractor's. The contract also stated that the government will reward the contractor's and any team member, if the result is pleasing. (Heller, 2006)

Speed construction for this project was fundamental, the timing for the program and the construction schedules were from twenty-four to forty months.

3.2.3 Constructability techniques used and timing of it

General Services Administration (GSA) was required to use Building Information Models (BIM), because it was proven to be effective in previous work, such as the OR Courthouse. BIM is integrated in the **beginning of the design stages, in the conceptual design stage**. Jackson, is one of the existing leader, who used the BIM. He used it to the building from inside and outside in 3D and experience virtual walkthroughs.(shown in Figure 3.2)

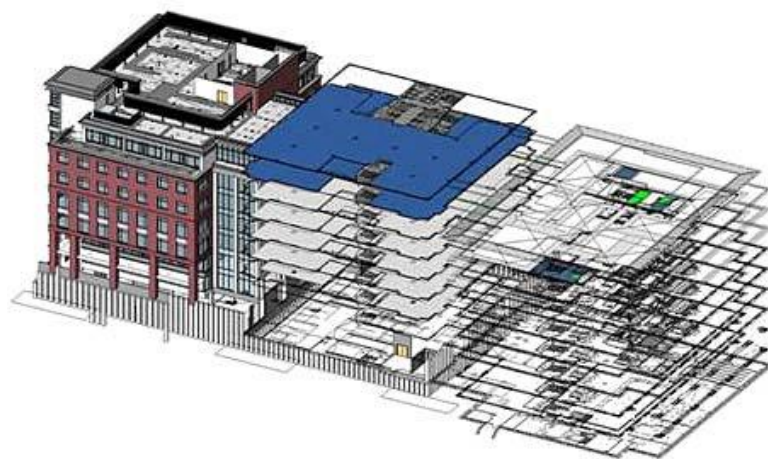


Figure 3.2: The Pentagon using BIM, 3D computer model (Heller, 2006)

The **3D computer models** eases the way of understanding of drawings than a 2D drawing. (shown in Figure 3.3)

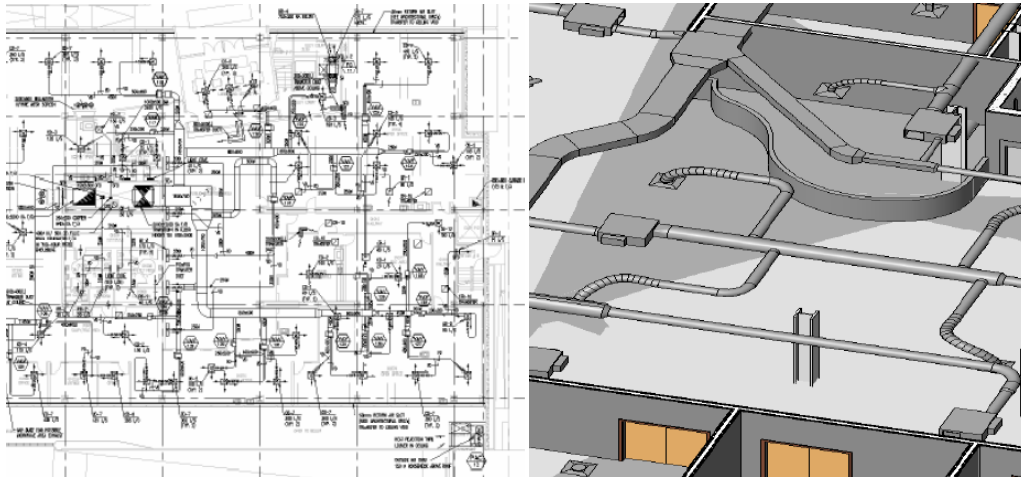


Figure 3.3: On the left a 2D drawing, on the right the same drawing but 3D (Heller, 2006)

These drawings give the ability to visualize the building before it is build and it decreases the change in orders and the conflicts. **Life cycling cost is achieved** and exact materials and building volume can be produced. (Heller, 2006)

3.2.4 Project Analysis

One of the constructability techniques, as stated previous in this research, was the computer model tool and how it can be a tool for minimizing waste by helping the client, constructor and all other team members to understand how the building is going to look like. (Pulaski, 2005)

In conclusion this case study shows the integration of the constructability techniques from computer modelling in the previous stages of a the project and how it was effective in helping the team members to visualize the project and redesign any part of the building, before it goes to bidding and construction. As

a result the project increased time project waste and it was delivered on time and saved money.

3.3. Case study (2):The Lansing Community College, Michigan, USA



Figure 3.4: "LLC Health and Human Services Career Building" (Ruby, 2006)

3.3.1 Project Background

The college was set in 1957 to collide the growing matter for the specialized and the technical education in the Greater Lansing zone, Michigan, USA. A three-story building was primarily designed for the " LCC Health and Human Services Career Building", with a future fourth floor extension.(shown in figure 3.4) (Othman, 2011)

3.3.2 Client requirements

The fourth floor extension must be built and within the budget, but the three-story was already exceeding the budget with \$200,000 from the steel fabrication.

3.3.3 Constructability techniques used and timing of it

Constructability was first informed in the Lansing Community College (LCC) **at the phase of bidding**, installation and fabrication. At this point, project schedule and architectural envelope had been settled. (Ruby, 2006)

So Ruby and Associate Consulting Structural Engineers collaborated with Douglas steel fabrication corporation in the project and applied the constructability techniques to set a cost effective re-design and fully redesign the structural steel fabrication and set the project within the budget. Constructability techniques was not integrated in the early stages of the design, it was applied in the bidding stage and in the redesign stage.(Ruby, 2006)

After applying the techniques four points were achieved:

1. Decrease labour required for the structure and construction hours through shifting the fabrication to the shop instead of the field. It also reinforced the work quality and efficiency.
2. The deck thickness is enlarged from 5cm to 7.65cm, which permitted the floor beam spacing to be enlarged by 25.4cm. As a result, the quantity of floor beams was decreased by 78%.
3. Modify the blended sidelong load resistance system to moment frames in both ways. The joints were drawn as " field-bolted moment joints" utilizing the effective moments and they were linked together using the actual moments and hardness demanded. As a result, a decrease in the

field labour was achieved and the shop fabrication was eased.(shown in figure 3.5)



Figure 3.5: Health and Human Services Building during construction(Ruby, 2006)

4. The re-design time is reduced and increased the communication between different parties when information technology in communication is used. (Othman, 2011)

3.3.4 Project Analysis

The new design facilitated the construction of the project. 700 steel members, 1,400 joints were removed, while shear studs were decreased by 11,000. In total, almost 300 tons of steel were conserved. Adequate money was consumed to allowing Lansing Community College to build the 4th floor, while getting the project \$100,000 beneath budget and on schedule. (Othman, 2001 cited in Aeck & Ruby, 2006)

Although constructability techniques were integrated in a very late stage in the project, but it was effective to integrate it. In this case the **discussion technique**

between the contractors, suppliers was used, it helped recognizing the problems that increase time and add a non value activity and solved it. As a result, project time waste is decreased and project was delivered on time with the budget below than the proposed one.

3.4. Case study (3): Cannon Beach Residence, Oregon, USA



Figure 3.6: Cannon Beach Residence, Oregon, USA(Othman, 2011)

3.4.1 Project Background

This case is about integrating all project team members, from architects, client, designer, landscape architect and interior designer together from the beginning and also integrating the provider after the schematic design was finished. By integrating the provider, constructability techniques will be applied and the contractor will contribute in the design and be able to give his opinion and better suggestions.

3.4.2 Client requirements

The client's of this project had some requirements for their house design.(shown in figure 3.6) They wanted it to provide shelter, be comfort, cost effective, low maintained, durable, use of sustainable materials, environment friendly and reflect the figure of the beautiful Cannon beach. The project team, as stated above held sundry meetings to discuss the main goals and objectives of the project.

3.4.3 Constructability techniques used and timing of it

Throughout the design procedure, the design party assumed five " half-day eco-charrettes", each formed of the centre team, signification experts, and guests of the owners, involving friends, neighbour and artist. The **contractor was integrated from the first stages of the design**. The contractor's assumption in the three brief life-cycle cost estimations was critical, due to the chosen materials and building systems. The provider also gave a share in the durability of the design, the low maintenance, immortality and waste reduction.

3.4.4 Project Analysis

According to the contractor's opinion , the domestic knowledge of green building was lower than sufficient to fulfil the green objectives for this project. Afterwards, the design party and owner undertook a green building seminar open to building officials, sub provider's, business people and the public in order to modify it. (Othman, 2011)

The contractor was integrated in the early design stages of the project, and was able to give his feedback before the project was gone to bidding and before construction started.

3.5 Conclusion

By integrating the concept of constructability in these project a lot of benefits are achieved. Delivering the project below the budget, below the time specified and this benefits result in satisfying the client. A table shown below summarizes all case studies together and showing what kind of constructability techniques were used and the timing of integrating and the dimension of sustainability achieved. (shown in table 3.1)

Case studies	Timing of integrating	Constructability techniques used	Dimension of sustainability achieved
Case study 1	The Conceptual Phase	Computer models	Economical sustainability
Case study 2	The Bidding Phase	Discussion with contractors, clients and suppliers	Economical sustainability
Case study 3	The Conceptual Phase	Discussion with contractors, clients and suppliers	Environmental, economical and social sustainability

Table 3.1: Summary of all case studies together

Chapter (4): Data Analysis and developing a conceptual framework

4.1. Purpose of the Questionnaire

The purpose for doing a questionnaire is to investigate, if the design and construction companies in Egypt use any improvement techniques to minimize project wastes that occur during any projects life cycle. Also, to see if the companies have heard about the concept of Constructability before and how it can be an effective tool for reducing the project waste and how by minimizing the waste, Sustainability can be achieved.

Another questionnaire is done for the contractors in order to know why they are not involved with the architects during the early stage of a project. Refer to the questionnaires in the appendix.

4.2. Analysis of the architects questionnaire

After giving the Questionnaire to twenty-seven different architects from different design firms of different scales in Egypt, the results were as follow:

Question 1: Does your company make waste evaluations during/ after a project?

The **purpose** of this question was to get a general understanding if the firm is handling waste that is made during any projects life cycle or not.

The responses were as follow: (shown in figure 4.1)

- 17 architects out of 27 responded that they do make waste evaluations during/ after any project.

- 10 architects out of 27 do not make waste evaluations.

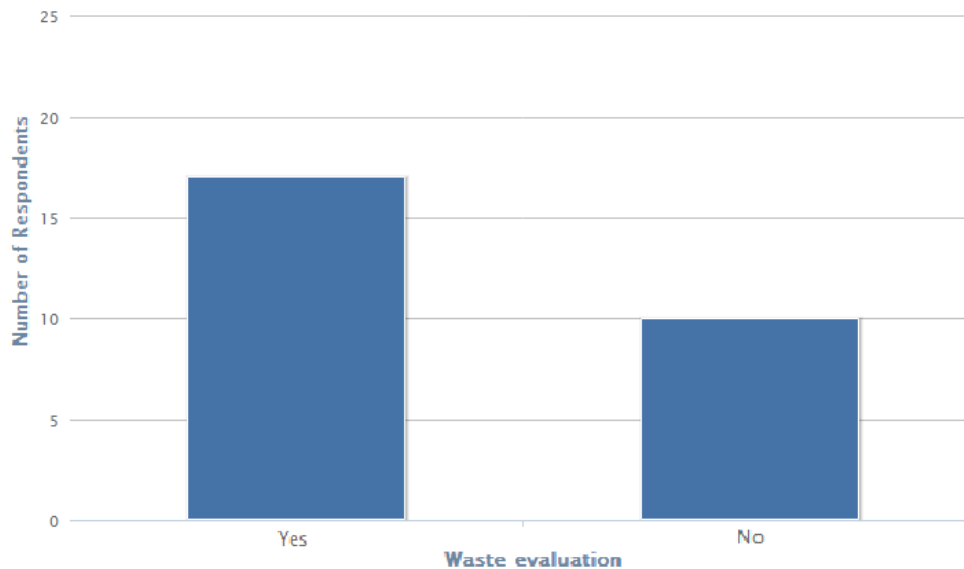


Figure 4.1: Respondents of design firms that make waste evaluations

Question 2: Does your company go through any of these types of waste during design phase?

- **Defects** (rework, inefficient drawings)
- **Waiting** (Contractors waiting for final approval on drawings)
- **Over or incorrect processing** (taking unneeded steps to achieve an outcome or using inefficient methods)
- **Overproduction** (drawing papers not recycled, storage of unneeded materials)
- **Excess Inventory** (damaged goods, excess in raw materials or finished goods)
- **Unnecessary movement** (unnecessary movements that wastes workers and labors energy)
- **Unnecessary Transport** (distance to transport a product from one location to another)

The **purpose** of this question was to know what kind of wastes a company is going through during a project. The wastes stated in the question are the seven types of waste that Ohno defined previous in this research.

The responses were as follow:

- The two highest percentage rates were: defects with 27.5% and waiting with 23.75% and over or incorrect processing follows them with 18%. Excess Inventory 5% and unnecessary transportation 2.5% are the lowest rankings.(shown in figure 4.2)

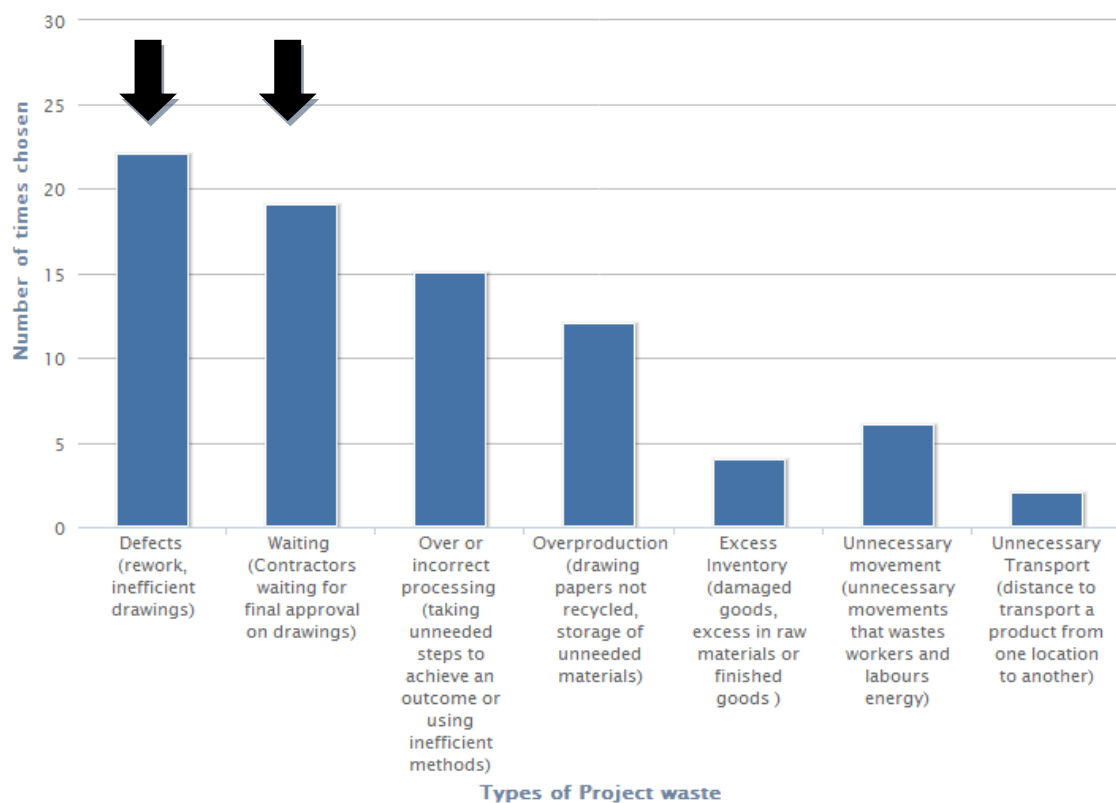


Figure 4.2: Types of project waste against times of chosen

Question 3: Does your company use any improvement techniques to reduce project waste?

The **purpose** of this question was to get a general understanding if design firms are handling waste that is made during any projects life cycle or not.

The responses were as follow:(shown in figure 4.3)

- 18 architects out of 27 responded that they use improvement techniques to minimize project waste. The most techniques that the architects mentioned were the quality control, internal department checker, coordinator meetings, design safety review and feedback system after every project.
- 9 architects out of 27 do not use any improvement techniques in their companies.

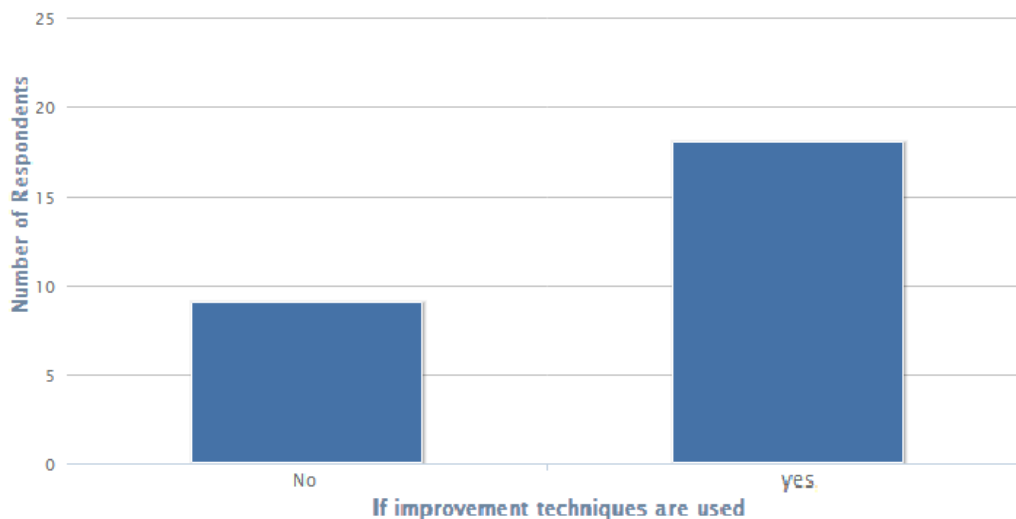


Figure 4.3: Respondents if firms use improvement techniques

Question 4: Is the contractor involved during the early stage of the design of a project?

This question has been asked in two different ways, first one asking normally if the contractor is involved in the early stage, which is same definition of Constructability, but is asked in an easy way. The second question, which is stated below is taking about the concept of Constructability itself, if they have heard about it before.

The **purpose** of this question was to know, if the architects let the contractor be involved in the early stages of the design, even before the bidding or not. The response of this question will give a hint also if the architects are applying the concept or not.

The responses were as follow: (shown in figure 4.4)

- 18 architects out of 27 responded that they do not involve the contractor during the early stages of a project.
- 9 architects out of 27 involve them.

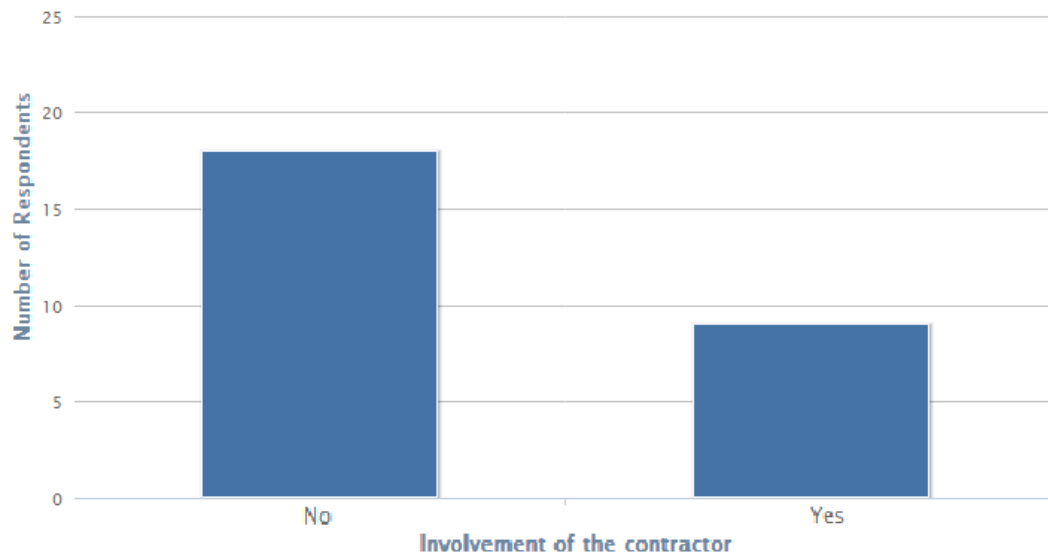


Figure 4.4: Respondents of the contractor involvement

The reason why the negative respondent were higher, because according to the designers , the type of contract the project is agreed on does not involve the contractor in the early stages. The contractor is involved only after the bidding is completed. Another reason, is that the designer depend on their experience about the problems that may occur in that late stages of a project, that concern the problems that the contractor may handle, because of the design.

Question 5: Have your company heard about the concept of constructability before? Constructability is “the optimum use of construction knowledge and experience in planning, design phase.”

As mentioned in the previous question, this question’s **purpose** was to figure out how many architects have heard about the concept of Constructability before and on the other hand know if they are applying it or not.

The response were as follow: (shown in figure 4.5)

- 21 architects out of 27 answered that they have heard about the concept of Constructability before
- 6 architects out of 27 answered that they have not heard about it before.

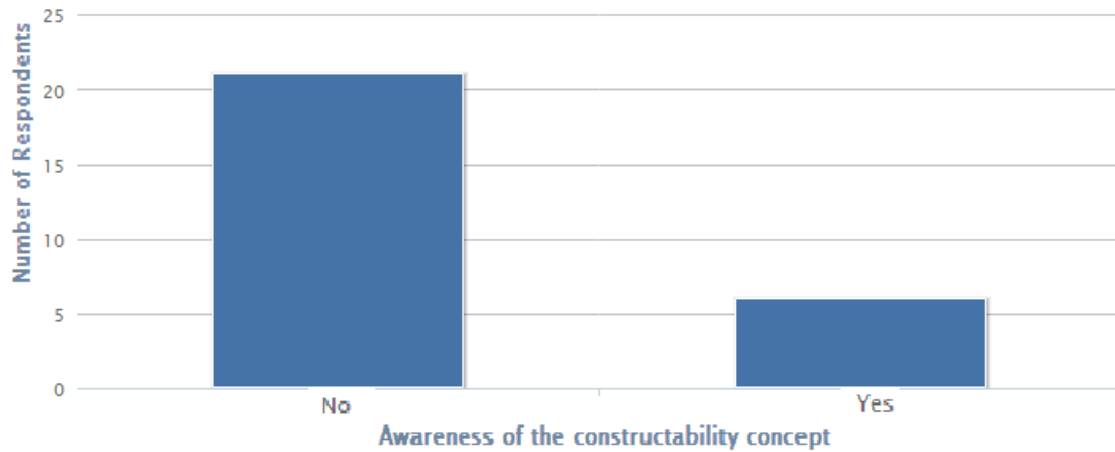


Figure 4.5: Awareness of the constructability concept in design firms

The majority of respondents have not discerned of the constructability concept before. There should be more awareness about the concept. The constructability techniques should be applied and the contractor should be involved from the early stages, to be able to reduce waste and therefore, achieve sustainability. The next questions will answer if the companies apply its techniques or not during the projects.

Question 6: Does your company apply any of the following techniques:

- **Peer review** (focuses on management and planning aspects or on technical aspects of a project)
- **Feedback system** (learning mistakes from previous projects to avoid them in the upcoming projects)
- **Brainstorming sessions** (sessions focuses on maintenance, recyclability, water and energy conservation)

- **Computer models**
- **Physical models**

The **purpose** of this question was to know, what types of techniques national design firms are applying. Also if the positive responses in this question are high and the positive responses in the previous question are low, that means that the firms apply constructability techniques, without knowing the concept itself.

The response were as follow:

- The most three common practices used are the "computer models" 24.3%, the "feedback system" 23.3% and "peer review" 21.3%. "Physical models" comes after with 17.4% and at least "brainstorming sessions" 13.6%. (shown in figure 4.6)

The reason why "computer models" are in Egypt the most famous, because design firms go into a bit trouble in visualizing the project from the early stages, so this technique is used the most. Compared with the international survey stated previously the most two commonly practices used are the "peer review" and the "feedback system", (as shown in figure 4.7) (Arditi et al., 2002)

The problem is that design and construction firms already apply the constructability techniques but without knowing the concept itself or integrating the contractor. Firms apply these techniques, depending on their experience in the construction field. It is good that architects have experience in the construction field, to reduce the conflicts and wastes, but a contractor must be applied earlier. The contractor is more updated and has a wider knowledge about the problems that may occur later in a project.

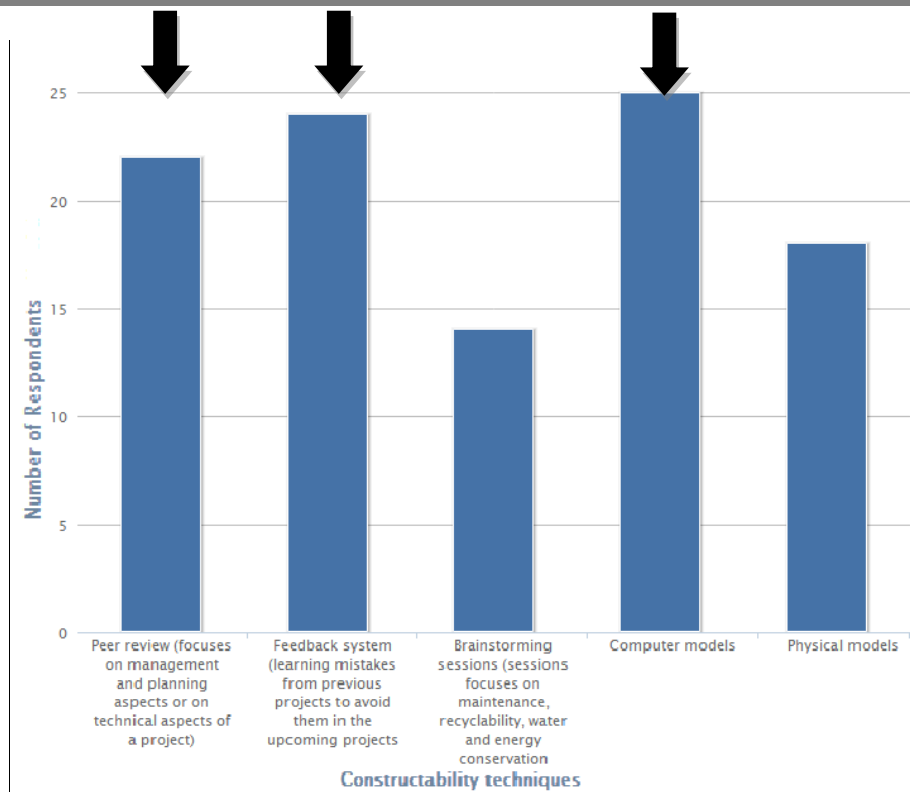


Figure 4.6: Constructability techniques according to the architects national questionnaire

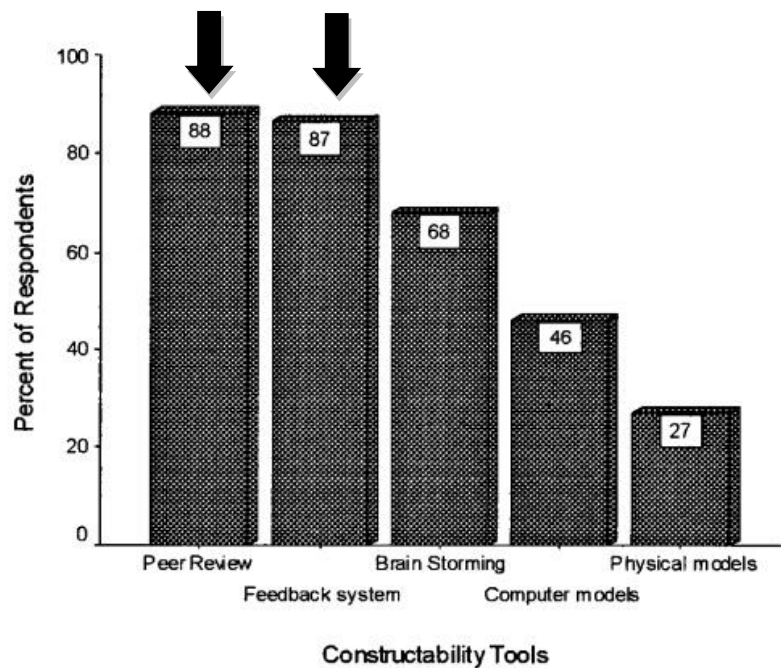


Figure 4.7: Constructability techniques according to the international questionnaire (Arditi et al., 2002)

Question 7: Have your company heard about the concept of sustainability before? Sustainability is "meeting the needs of the present without compromising the needs of the future".

The **purpose** of this question was to know, if the design firms put in their consideration the sustainable issues in any project the firm designs. If the majority of the responses was positive, this means that the firms will be willing to integrate new improvement techniques during any project life cycle in order to achieve Sustainability at the end.

The responses were as follow: (shown in figure 4.8)

- 26 architects out of 27 have heard about the concept of Sustainability before.
- 1 architect out of 27 have not heard about it.

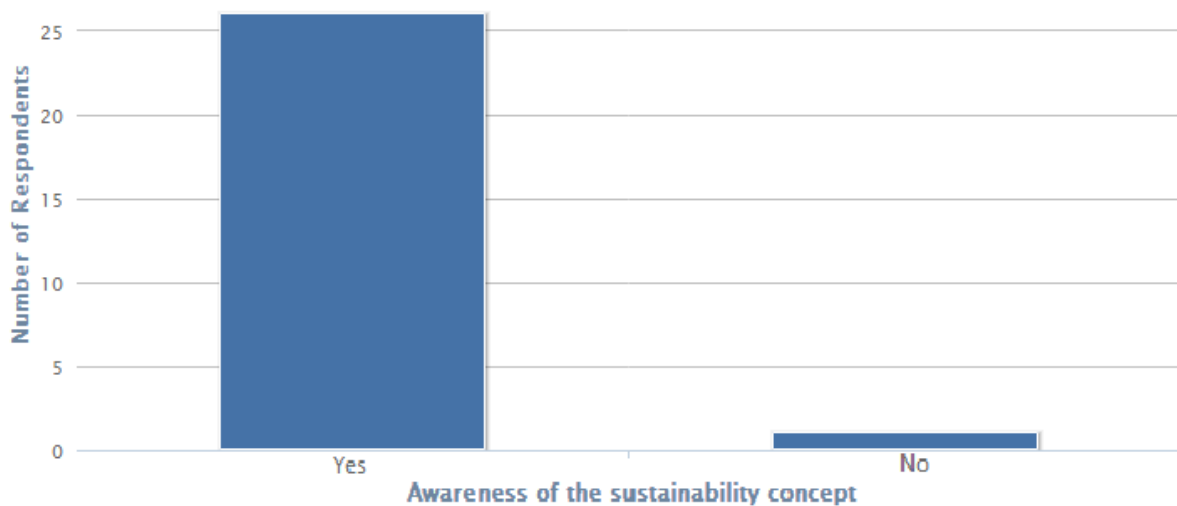


Figure 4.8: Awareness of the sustainability concept in design firms

Question 8: In which project phases do these project waste types occur?

The **purpose** of this question was to know, in which from phases of the five project phases (Programming phase, Schematic design phase, Design development phase, Construction document phase and Construction phase), project waste occur the most, and what kind of waste is made often in a specific phase. More than one type of waste can occur in a specific phase or in more than one phase. After knowing when and which type of waste is made during the project phases, wastes will be known and can be minimized and handled.

Each phase will be shown in a figure showing which type of wastes appear the most in each phase. At the end, there will be a figure showing all phases together with the different types of waste, in order to know in which phases, it is very important to minimize the waste that happens, because that stops the project from achieving Sustainability.

1. Programming Phase:

According to the number of respondents (shown in figure 4.9), 17 out of 27 said that the most type of waste that appears in this phase is defects, due to change of client requirements mistakes from previous projects. After the defects, comes waiting. 9 responded that waste of time occurs, due to waiting for the project objectives to be finalized, demands of the client to be final and the total area of the building to be determined.

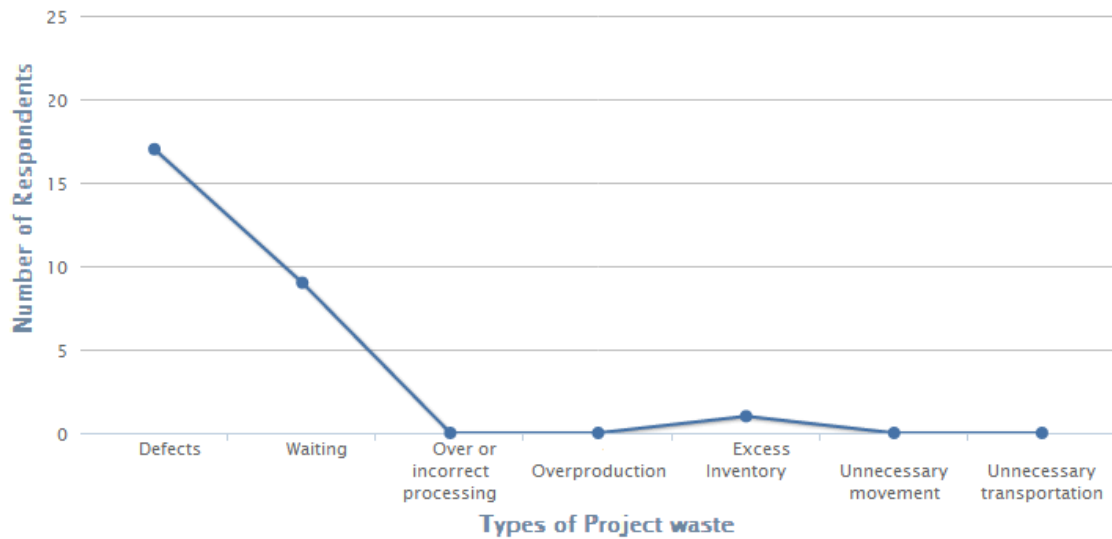


Figure 4.9: Wastes that occur in the programming phase

2. Schematic Design Phase:

The types of waste that occur in the schematic design phase (shown in figure 4.10) are almost the same as in the programming phase, due to rework of drawings and corrections. 16 out of 27 responded that defects, is the most type of waste that occurs in this stage, then waiting with 6 responses, 3 responses with over or incorrect processing, 2 responded that there is unnecessary movement waste in this phase, if the client wants something that is not applicable in reality, and the client insist till he realizes at the end that it is not applicable like the architects told him/her before. This is considered to be waste of time and movements that can be eliminated.

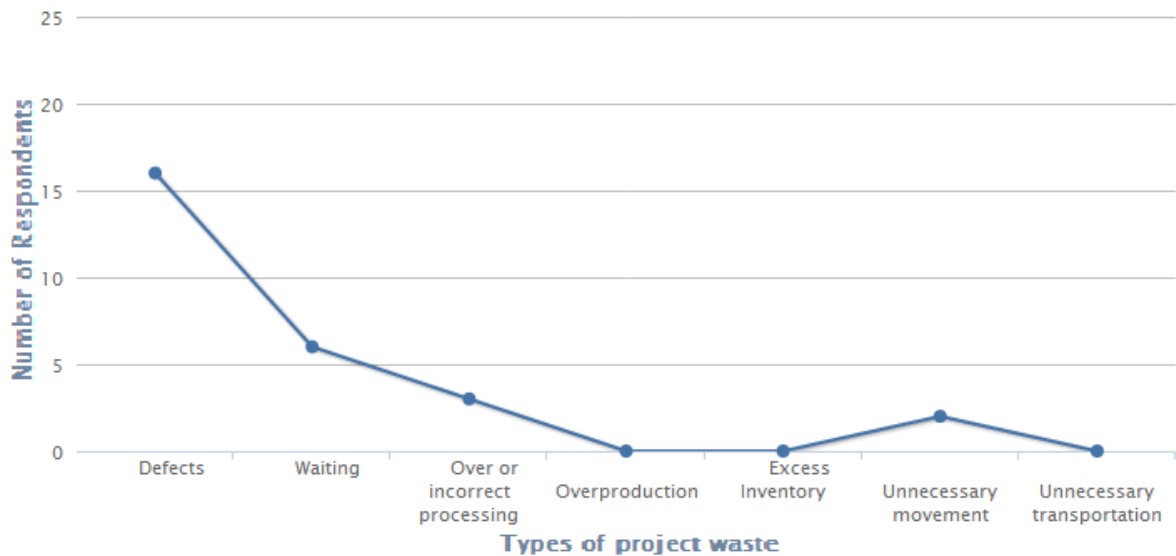


Figure 4.10: Wastes that occur in the schematic design phase

3. Design Development Phase:

The types of waste that occur in the design development phase (shown in figure 4.11) are waiting, over or incorrect processing and defects. These waste are the most rated wastes in this phase. Waste of time is due to the changes of the client or waiting for approvals from the client, defects occur, because of previous mistakes that happen in projects before and keep repeating. Over or incorrect processing is because incorrect calculations and drawings. 11 out of 27 responded that waiting is the highest wastes that occurs in this stage, followed by 7 responses for over or incorrect processing, 5 responded with defects, 3 with excess inventory and 1 respond with overproduction.

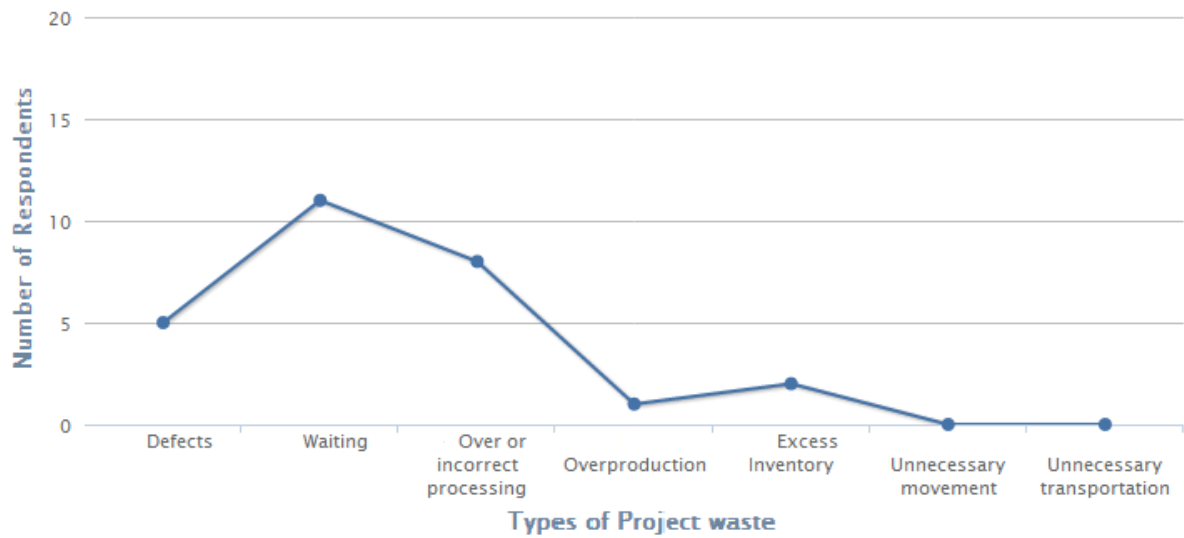


Figure 4.11: Wastes that occur in the design development phase

4. Construction Document Phase:

The types of waste that occur in the construction document phase (shown in figure 4.12) are waiting with 8 responses, due to waiting for final approvals, excess inventory with 5 responses, and 4 responses in overproduction and over or incorrect processing, due to incorrect drawings and calculations, 3 responses in defects and unnecessary movement.

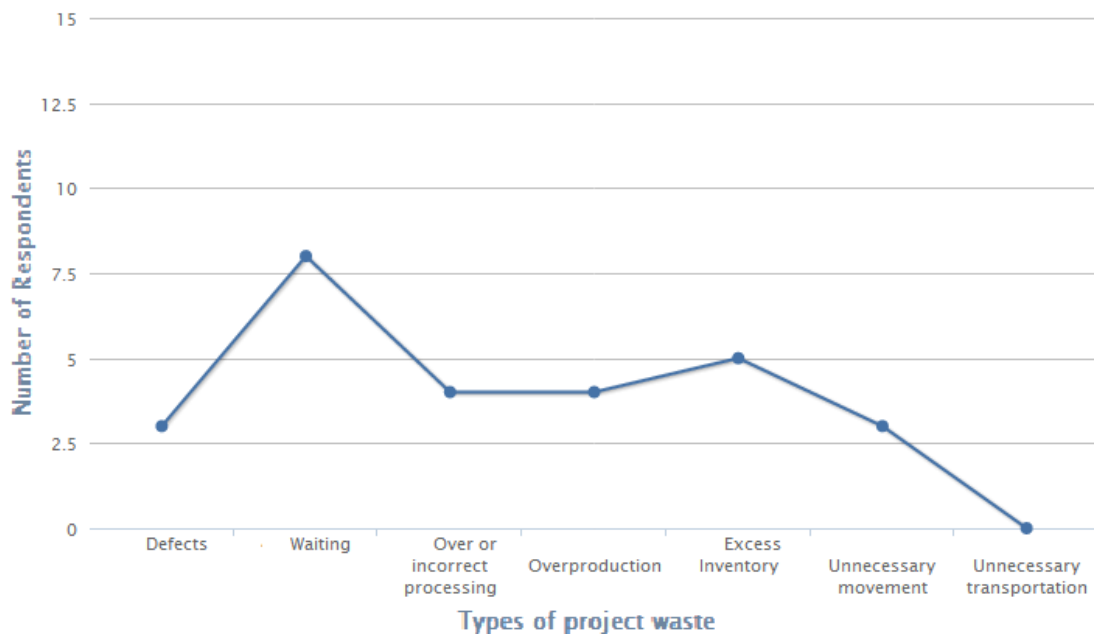


Figure 4.12: Wastes that occur in the construction document phase

5. Construction Phase:

The types of waste that occur in the construction phase (shown in figure 4.13) are all types of waste, due in waste in construction, materials, unnecessary movements and transportations.

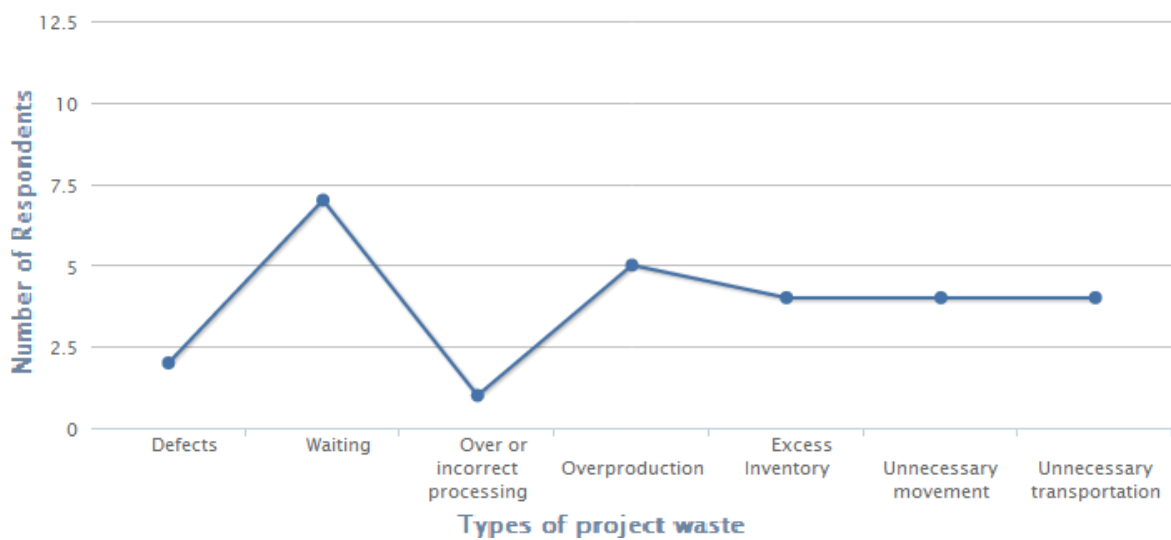


Figure 4.13: Wastes that occur in the construction phase

A graph is summing up all types of wastes that occur in each phase with all phases together. This graph shows that the type of waste that have the highest responses in all phases is waiting. Time is an important factor that cause the overrunning in budget and client unsatisfactory, because the project is not delivered in time and is over budget. (shown in figure 4.14)

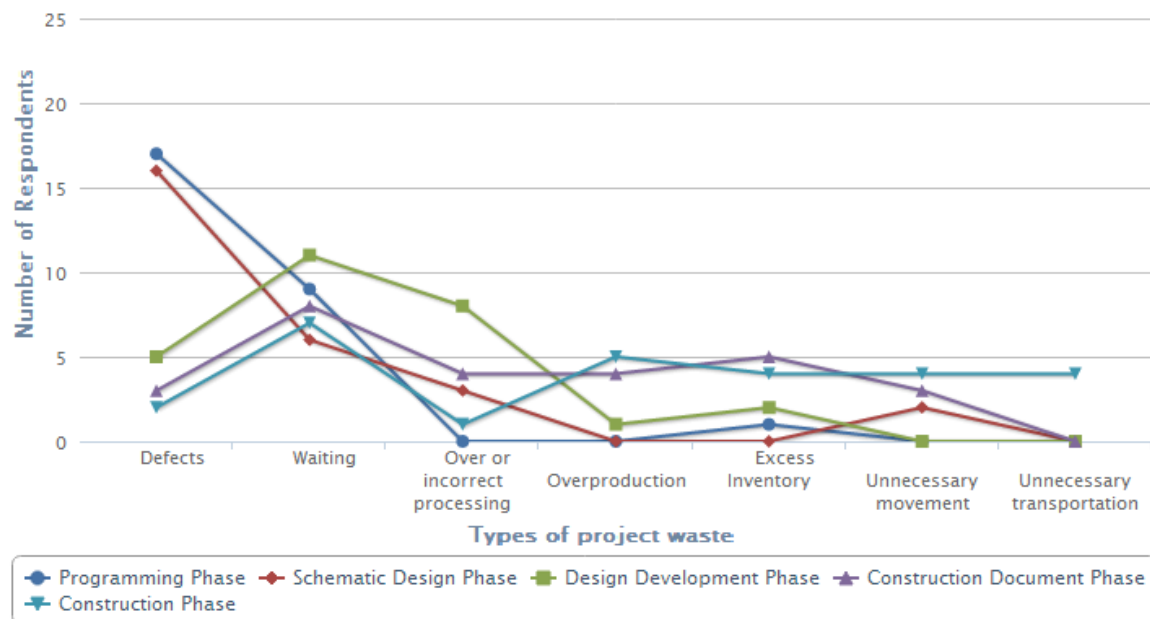


Figure 4.14: All project phases together

Question 9: Is your company aware that by applying constructability techniques, sustainability can be achieved?

The **purpose** of this question was to know, how much is the awareness in design firms, that Constructability can be a tool for achieving .

The response were as follow: (shown in figure 4.15)

- 24 architects out of 27 are aware with that.
- 3 architect out of 27 are not aware with the significant outcomes that can happen if Constructability is applied.

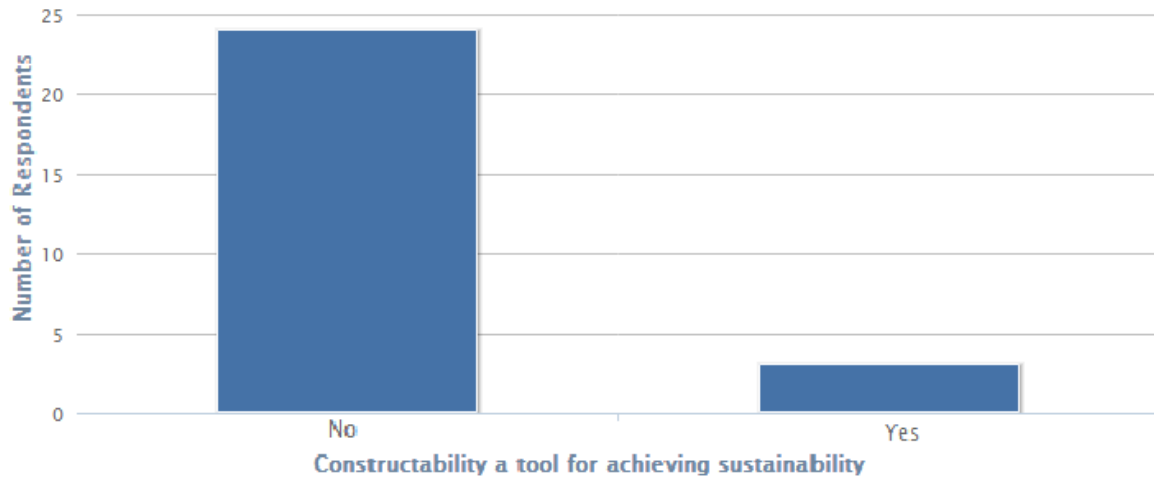


Figure 4.15: Awareness that constructability is a tool for achieving sustainability in design firms

The majority of respondents is not aware that sustainability can be achieved if constructability techniques are integrated during a project life cycle to reduce its wastes.

4.3. Analysis of the contractors questionnaire

After giving the Questionnaire to thirteen different contractors from different firms of different scales in Egypt, to investigate the reasons why the contractors are not involved during the early stages. The results were as follow:

Question 1: Is the contractor involved during the early stage of the design of a project ?

This question is the most important question in the questionnaire, because **it displays the reasons that restrict the contractors from integrating in the project from the beginning.**

The responses were as follow: (shown in figure 4.16)

- 10 contractors out of 13 responded that they do not get involved in the early stages of a project.
- 3 contractors out of 13 get involved from the early stages.

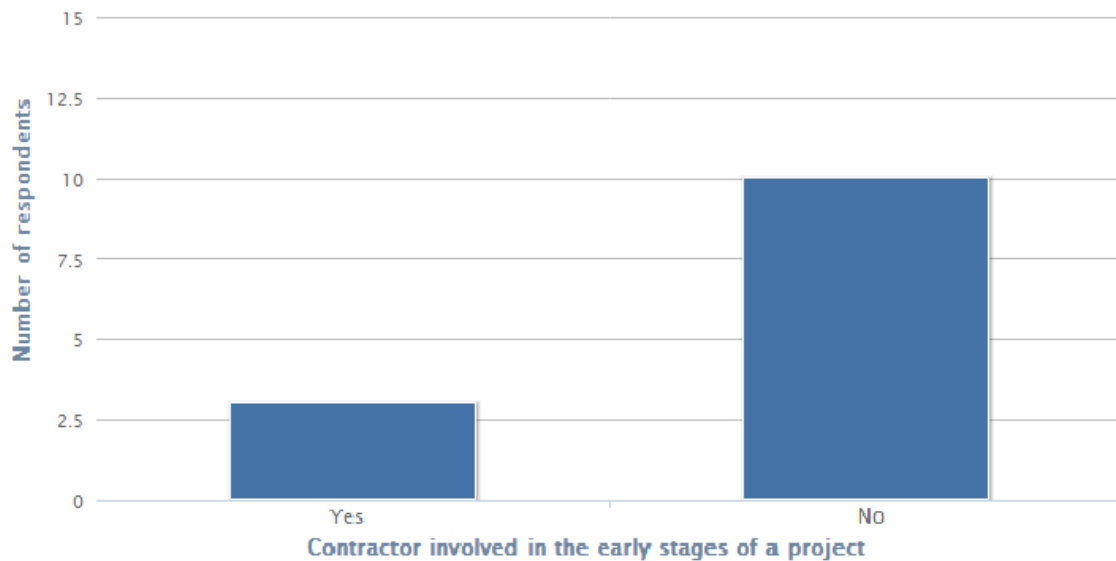


Figure 4.16: Contractor involvement in the early stages of a project

The majority of respondents was negative, because during this stage the contractor is usually unknown, the contractor gets involved after the bidding. The uninvolvement of the contractor depends also on the type of contract chosen for the project. In Egypt most of the contracts used are the traditional contracts. This contract separates between the architects and the contractors. It does not include any integration between the two parties. Each member does the job required at a specific time, which is that the architect draws the design and the contractor executes it.

Question 2: Have your company heard about the concept of constructability before? Constructability is “the optimum use of construction knowledge and experience in planning, design phase.”

The **purpose** of this question was to know, how many contractors have heard about the constructability concept. Contractors play a huge role in integrating and awaring team members about this concept, because if they knew it, and knew its benefits, they will start integrating.

The responses were as follow: (shown in figure 4.17)

- 7 contractors out of 13 have not heard about the constructability concept before.
- 6 contractors out of 13 have heard about the concept.

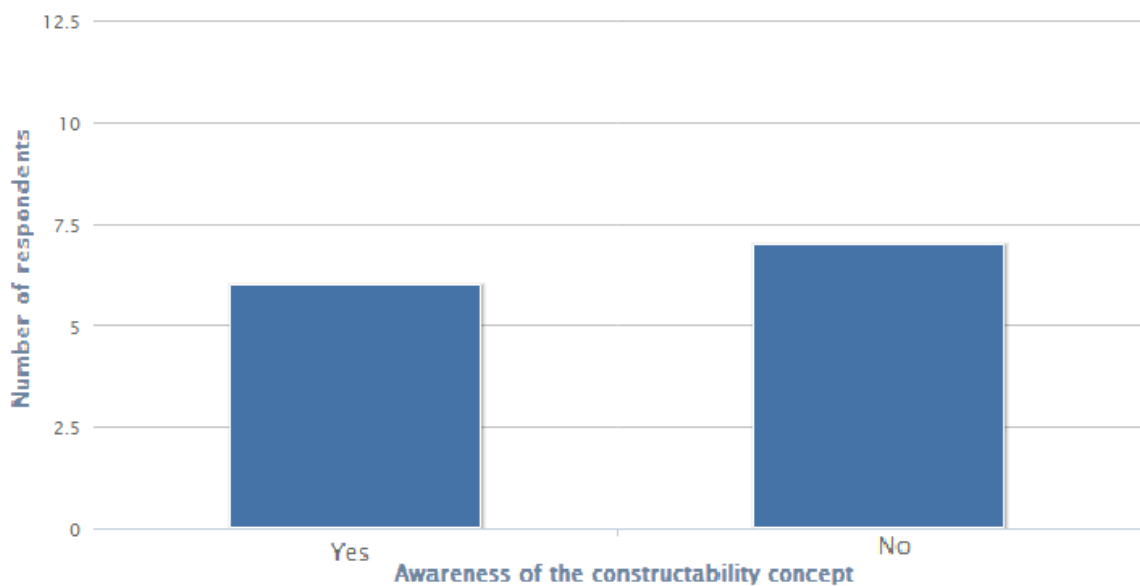


Figure 4.17: Awareness of the constructability concept

The responses were very close to each other. This means that by applying some awarenesses in the firms the concept can be easy spread and then applied.

Question 3: Does your company apply any of the following techniques:

- **Peer review** (focuses on management and planning aspects or on technical aspects of a project)
- **Feedback system** (learning mistakes from previous projects to avoid them in the upcoming projects)
- **Brainstorming sessions** (sessions focuses on maintenance, recyclability, water and energy conservation)
- **Computer models**
- **Physical models**

The **purpose** of this question was to know, if contracting firms apply any of the constructability techniques.

The response were as follow: (shown in figure 4.18)

The most practice used is the "peer review" 34.2%, then the "feedback system" 26.3% , "brainstorming sessions" 21%. "computer models" comes after with 15.8% and at least "physical models" 2.6%.

Compared with the architects answers, contractors use the "peer review" technique a lot more than the other techniques, while architects use "computer models" more. This is due that designers need the "computer models" more in order to visulise the building or project, unlike the contractors they need the project management reviews more to manage the project.

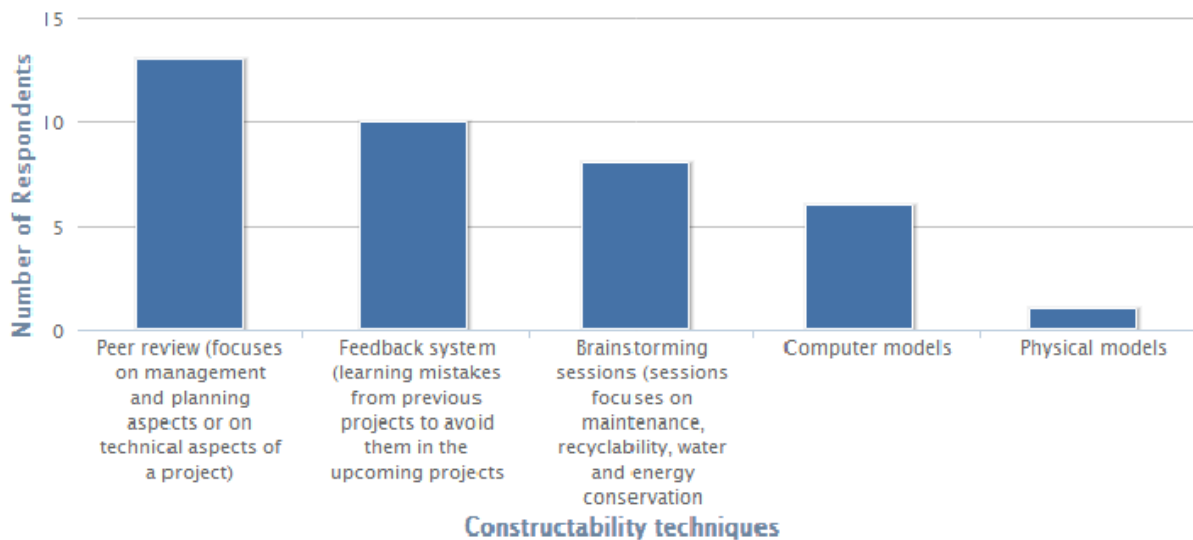


Figure 4.18: Constructability techniques according to the contractors national questionnaire

Question 4: Have your company heard about the concept of sustainability before? Sustainability is "meeting the needs of the present without compromising the needs of the future".

The **purpose** of this question is the purpose as mentioned before in the architects questionnaire analysis.

The responses were as follow: (shown in figure 4.19)

- 13 architects out of 13 have heard about the concept of Sustainability before.

All responses were positive, that shows that there is a huge ability that firms can accept integrating the constructability techniques, because firms try to achieve high levels of sustainability and constructability will play a role in that.

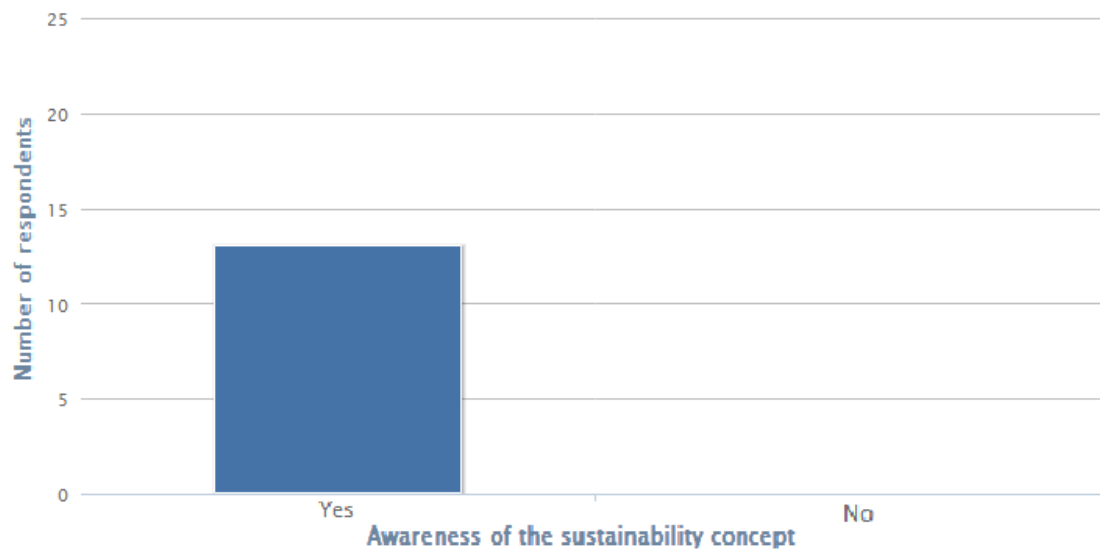


Figure 4.19: Awareness of the sustainability concept

Question 5: Is your company aware that by applying constructability techniques, sustainability can be achieved?

The **purpose** of this question was to know, if the contractor are not aware what constructability can achieve if integrated or not.

The response were as follow: (shown in figure 4.20)

- 3 contractors out of 13 are aware with that.
- 10 contractors out of 13 are not aware with the significant outcomes that can happen if Constructability is applied.

The responses display that neither the architects nor the contractors know the benefits that constructability can achieve if integrated from the early stages of a project.

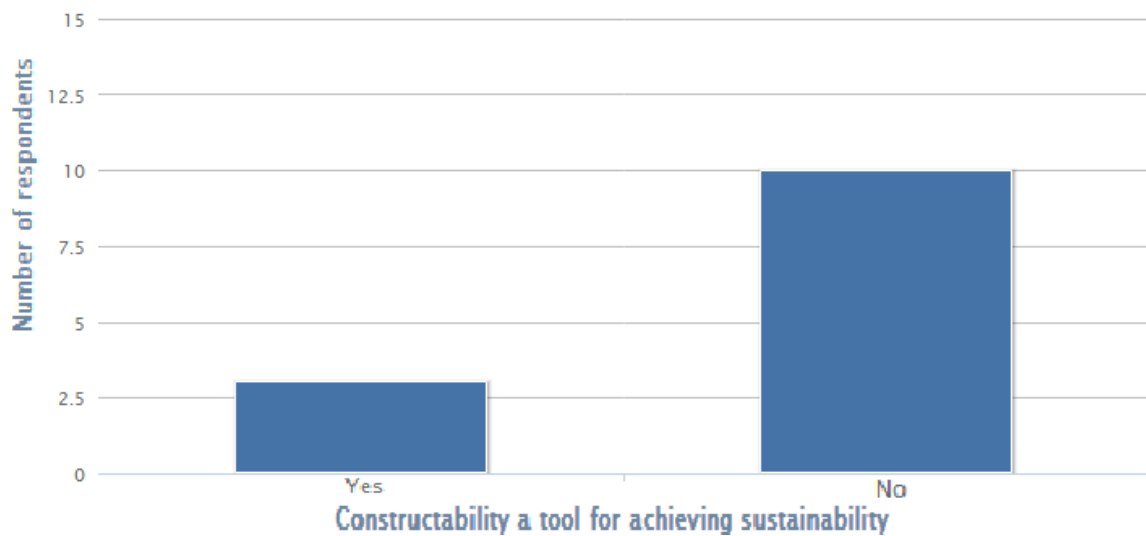


Figure 4.20: Awareness that constructability is a tool for achieving sustainability

4.4 Conclusion

The results of the questionnaire display, that most of the architect apply the constructability techniques, but without knowing the concept itself and the architects use these techniques between the team members themselves, without integrating contractors. Architects depend on their experiences in previous projects. Contractors do not involve from the early stages, because the contract that most firms use in the traditional contract, that states that the contract will get involved after the bidding is done. Both parties, architects and contractors are not aware that by integrating the contractor from the beginning and applying constructability techniques a lot of project waste can be minimized and as a result sustainability can be achieved.

4.5 Developing a conceptual framework

A conceptual framework is suggested according to Deming cycle, the PDCA, in order to reduce project waste during project life cycle, through using constructability techniques. As a result, sustainability can be achieved.

The PDCA cycle contains of: (Moen and Norman, 2010) (shown in figure 4.21)

1. **Plan:** Determine the problems and possible solutions, objectives.
2. **Do:** Implementing the work
3. **Check:** Checking the effect of implementing these solutions
4. **Act:** Get back to the first step, the plan, if the results are displeasing or solutions can be standardized, if the results are pleasing.

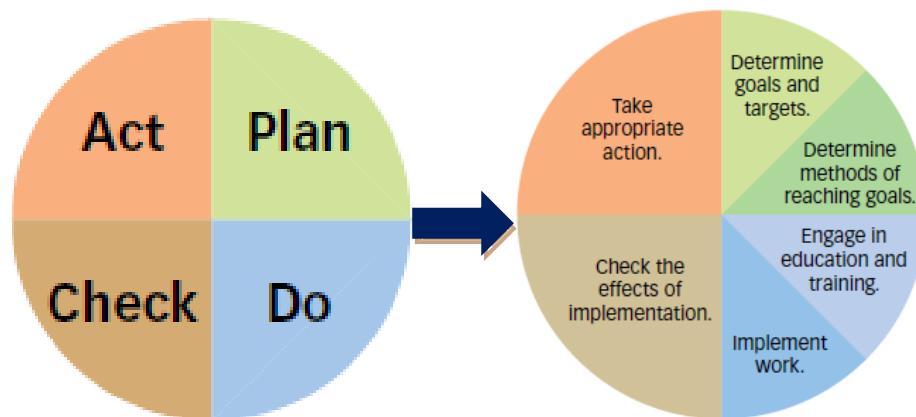


Figure 4.21: The Deming PDCA cycle detailed

According to Deming cycle the conceptual framework will be as follow:

1. **Plan:** 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 that was done in the national design firms.
- Aware architects and contractors with the benefits, that constructability can achieve if integrated, regarding the cost effectiveness and time reduction.

2. **Do:** Implementing the work:

Each phase is displaying 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. The sustainability dimension that each phase produces is also displayed in the table. (shown in figure 4.22)

In the **programming phase**, types of waste that occurred the most are defects and waiting, and the reason was mentioned previous in this chapter. In order to overcome these wastes, the two peer review techniques and feedback system must be integrated. The two peer reviews are project management, which focuses on the management, planning and scheduling aspects and the other review is project design, which focuses on the technical aspects and makes quality control on the project. That will help in minimizing the time wasted, because schedules and critical activities are displayed from the early stages of a project. The other technique is the feedback system. This technique will help in minimizing the defects, because it makes the team members review previous mistakes that occurred in previous projects, so members can learn from the mistakes and do not make them again and have a better knowledge in the upcoming projects.

In the **schematic phase**, types of waste that occurred are defects, waiting and over or incorrect processing. These wastes can be minimized through integrating the peer review, feedback system and brainstorming sessions. In order to reduce waste of time in trying to visualize a project or problems that may occur later in a project, techniques such as; computer models and physical models are also integrated in this phase. The over or incorrect processing type of waste can be overcome with the two peer reviews; project management and project design and also through computer models.

In the **design development phase**, types of waste that occurred are the same type as in the schematic phase; defects, waiting and over or incorrect processing, due to, that these two phases are connected with each other.

In the **construction document phase**, types of waste are waiting, over or incorrect processing, over production and excess inventory. These types of waste can be minimized through applying project management techniques, brainstorming before the project starts and computer models to able to visualize the problems that may occur as it helped in the Pentagon renovation, mentioned previous in the case studies chapter.

In the **construction phase**, almost all types of wastes occur, wastes are waiting, over or incorrect processing, overproduction, excess inventory, unnecessary movement and unnecessary transportation. It is known that construction phase is the most phase that waste occurs in it, and in order to minimize this waste project management review, from the peer review technique must be integrated from the start of the project.

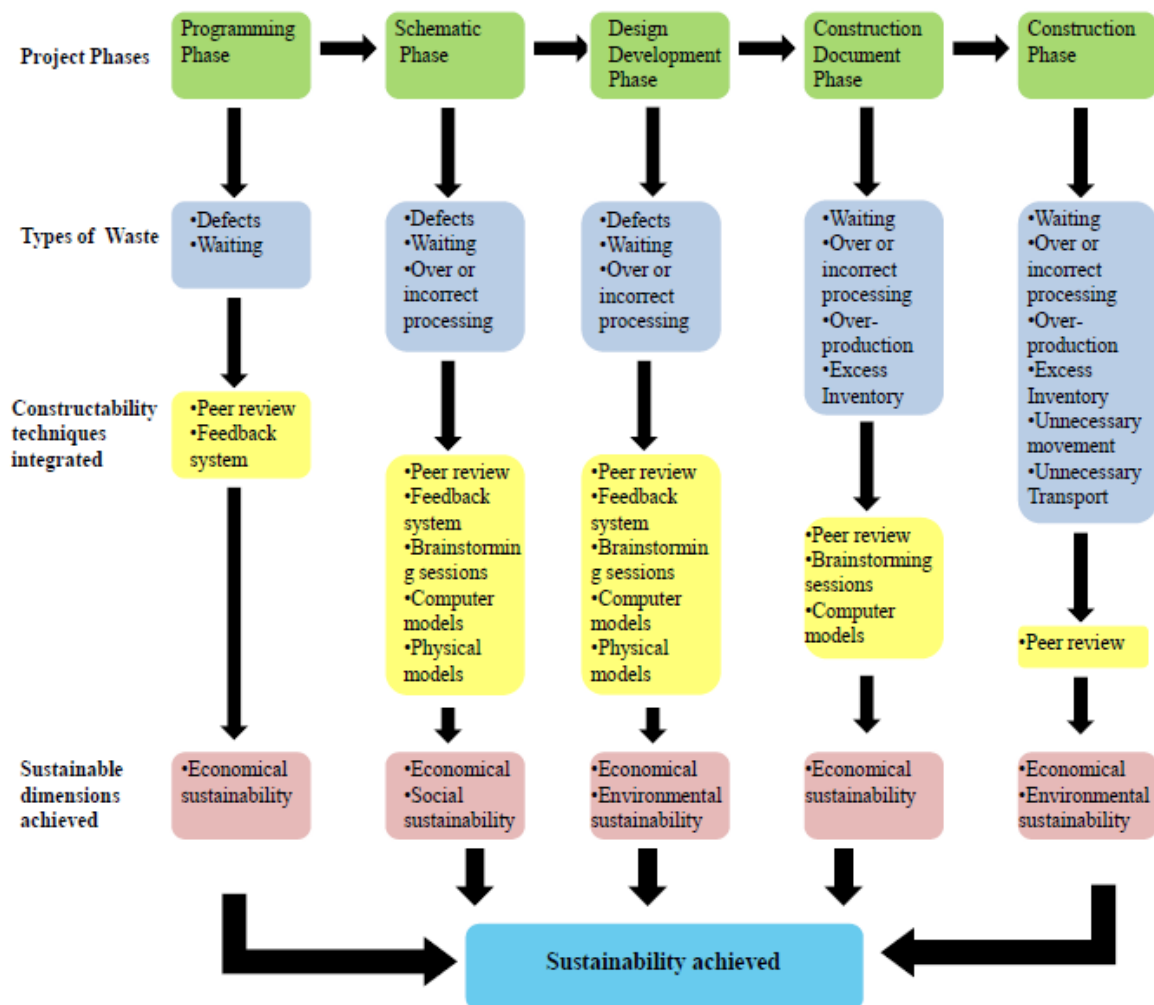


Figure 4.22: A graph showing the kind of waste each phase generates and what constructability techniques must be applied to achieve sustainability

3. **Check:** Checking the effect of implementing these solutions

If these techniques are applied in all project phase, economical sustainability is achieved, because constructability techniques reduce the cost of the project, and it was proven by case studies mentioned in the case study chapter previous. It also reduce time waste, due that everything is written and known from the

beginning of the project and the critical activities that cannot be delayed are known.

Social sustainability is also achieved in the schematic, design development and construction phase, due to satisfying the client's requirements on time and under budget.

Environmental sustainability is achieved in the construction phase, due to minimizing the waste in construction from materials and construction.

4. **Act:** If the results are not effective, then team members should get one step or two back and check the results and find where the problem contains. On the other hand, if the results were satisfying then the solutions should be standardize in all firms and architects and contractors must start integrating these constructability techniques in each phase to reduce waste, in order to achieve sustainability and start the awareness in all design and construction firms, about these kind of wastes and how they can be reduced, and show how constructability can be an effective tool for achieving sustainability.

4.5.1 Diagram for the conceptual framework

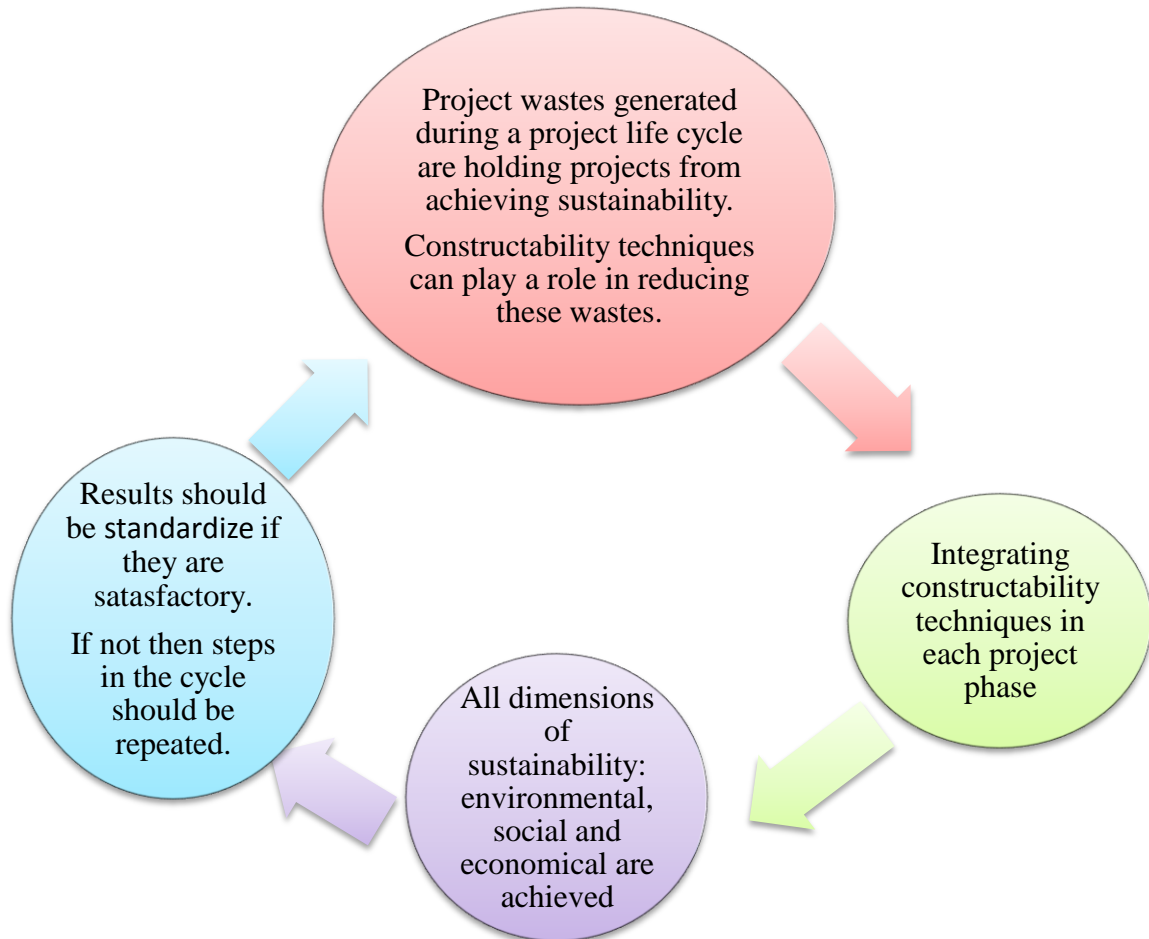


Figure 4.23: A conceptual framework to integrate constructability techniques to reduce project waste and achieve sustainability

5.1 Research Conclusions

Project waste is waste that occurs during any project, it cannot be eliminated but it can be decreased. Defects, waiting, over or incorrect processing, over production, excess inventory, unnecessary movement and unnecessary transportation are the types of project waste that appear. Constructability concept, is a concept that help in minimizing these waste. It consists in integrating the contractor from the beginning of a project and by applying some techniques, such as; peer review, feedback system, brainstorming sessions, computer models and physical models, project waste can be minimized. This research helped in displaying how by integrating constructability techniques, project waste can be decreased and as a result dimension or more of the sustainability dimensions is achieved.

5.2 Findings of this paper

The main objective of investigating the role of constructability towards achieving sustainability, through minimizing project waste, is achieved by displaying case studies that used the constructability techniques, in different times of a project and showing how the firms were able to minimize time and produce the project below the specified budget. Also displaying what dimension of sustainability the firms achieved.

The first secondary objective, of building an in depth understanding of the research topic through covering different areas of waste, constructability and sustainability, is achieved through the literature review.

The second secondary objective, of developing a conceptual framework to facilitate the integration of constructability during project life cycle to

minimize waste, is achieved through putting points and specific techniques in each project phase to minimize the waste that is occurred.

5.3 Recommendations

Design and construction firms should be willing to change the type of the contract. The most suitable contract that integrates the architects with the contractors is the design and built contract, because one of the boundaries of not integrating the contract is the type of the contract chosen for a project.

Contractors and clients should know the constructability benefits that they achieve in the cost and time, so they will be willing to integrate the concept and techniques, because one the barriers is budget of a project. Clients and contractors are not aware that, if the concept is integrated it will reduce time of the project and deliver the project under budget.

There should be more awareness about the constructability concept in design and construction firms.

5.4 Limitations

Few researches investigated the link between project waste and sustainability through the use of constructability techniques.

National case studies that applied the concept of constructability are very rare.

5.5 Future Research

For future studies, investigating why not all of the dimensions of the sustainability are achieved. Focus will be on trying to achieve the social and environmental sustainable dimension and not only the economical dimension.

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Architects Questionnaire

Name:
Company Name:
Experience (In years):
Position:

I am a student at the British University in Egypt, Architectural Engineering Department and I am currently doing my thesis on how Constructability can be a tool for reducing project waste and achieve Sustainability. I would be thankful if you answered these questions, it will not take more than 5 minutes.

1. Does your company make waste evaluations during/ after a project?

Yes	
No	

2. Does your company go through any of these types of waste during design phase?

Defects (rework, inefficient drawings)	
Waiting (Contractors waiting for final approval on drawings)	
Over or incorrect processing (taking unneeded steps to achieve an outcome or using inefficient methods)	
Overproduction (drawing papers not recycled, storage of unneeded materials)	
Excess Inventory (damaged goods, excess in raw materials or finished goods)	
Unnecessary movement (unnecessary movements that wastes workers and labours energy)	
Unnecessary Transport (distance to transport a product from one location to another)	

3. Does your company use any improvement techniques to reduce project waste?

Yes	
No	

If yes, what kind of techniques:...Efficiency, Use new technology, and educating staff to be more efficient,

Is the contractor involved during the early stage of the design of a project?

Yes	
No	

4. Have your company heard about the concept of constructability before?

Constructability is "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives".

Yes	
No	

5. Does your company apply any of the following techniques:

Peer review (focuses on management and planning aspects or on technical aspects of a project)	
Feedback system (learning mistakes from previous projects to avoid them in the upcoming projects)	
Brainstorming sessions (sessions focuses on maintenance, recyclability, water and energy conservation)	
Computer models	
Physical models	

6. Have your company heard about the concept of sustainability before?

Sustainability is "meeting the needs of the present without compromising the needs of the future".

Yes	
No	

7. In which project phases do these project waste types occur?

More than one type can be chosen.

	Types of Project waste	Defects	Waiting	Over or Incorrect	Over-production	Excess Inventory	Unnecessary movement	Unnecessary transportation
Design Phases								
Programming Phase								
Schematic Design Phase								
Design Development Phase								
Construction Document Phase								
Construction Phase								

8. Is your company aware that by applying constructability techniques, sustainability can be achieved?

Yes	
No	

Contractors Questionnaire

Name:
Company Name:
Experience (In years):
Position:

I am a student at the British University in Egypt, Architectural Engineering Department and I am currently doing my thesis on how Constructability can be a tool for reducing project waste and achieve Sustainability. I would be thankful if you answered these questions, it will not take more than 5 minutes.

1. Is the contractor involved during the early stage of the design of a project?

Yes	
No	

If No, can you please state why

.....
.....

2. Have your company heard about the concept of constructability before?

Constructability is "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives".

Yes	
No	

3. Does your company apply any of the following techniques:

Peer review (focuses on management and planning aspects or on technical aspects of a project)	
Feedback system (learning mistakes from previous projects to avoid them in the upcoming projects)	

Brainstorming sessions (sessions focuses on maintenance, recyclability, water and energy conservation)	
Computer models	
Physical models	

4. Have your company heard about the concept of sustainability before?
Sustainability is "meeting the needs of the present without compromising the needs of the future".

Yes	
No	

5. Is your company aware that by applying constructability techniques, sustainability can be achieved?

Yes	
No	