CONSTRUCTABILITY FOR REDUCING CONSTRUCTION WASTE AND IMPROVING BUILDING

Ayman Ahmed Ezzat Othman[1]

[1] Architectural Engineering Department, The British University in Egypt (BUE)
[1]E-mail: Ayman.othman@bue.edu.eg / aaeothman@gmail.com

ABSTRACT

Construction is a highly fragmented industry. It tends to create a division between designers and contractors through separating design from construction. This is because of the traditional procurement approach commonly used in construction projects and the multitude of various project participants from different organisations, with diverse objectives, skills and interests. This division obstructs contractors from delivering their comments and suggestions to designers and hinders the application of the concept of constructability which involves the integration of construction knowledge and experiences into the different stages of the project life cycle. Hence, ultimately increases construction waste and hampers the improvement of building performance. Because of the importance of the design phase and the vital role played by contractors in the construction industry, this paper aims to investigate the integration of construction knowledge and contractor's experience in the design process as an approach for reducing construction waste and improving building performance. In order to achieve this aim, a research methodology is designed to accomplish four objectives. Firstly, reviewing the nature of the construction industry; constructability; architecture and the design process; waste management and measuring building performance. Secondly, presenting successful case studies and examples of successful projects benefited from applying the concept of constructability during the design process. Thirdly, developing an innovative yet, theoretical framework to facilitate the integration of construction knowledge and contractor's experience in the design process and establishing the strategies that support its application. Finally, summarising research conclusions and recommendations useful to construction professionals and researchers.

Keywords: Constructability, waste management, building performance, design process

1. INTRODUCTION

Being one of the biggest industries worldwide, the construction industry plays a significant role towards social and economic development at national and international levels. It contributes towards providing communities with places for housing, education, culture, medication, business, leisure and entertainment. In addition, it constructs the infrastructure projects that are essential for these facilities to perform their intended functions. Furthermore, it increases the gross domestic product (GDP), motivates development of other industries and offers employment opportunities. On the other hand, the construction industry has major impact on the environment as it is a huge consumer of non-renewable resources. In addition, it is a substantial source of waste, a polluter of air and water, and an important contributor to land dereliction. About 3 billion tons of raw materials and 40% of the total flow into the global economy are used for manufacturing construction materials worldwide [1]. [2] stated that the construction sector is responsible for 50% of material resources taken from nature, 40% of energy consumption and 50% of total waste generated. Virtually, all modern buildings now have artificial heating or cooling systems and sometimes both. Large amount of energy are wasted in constructing, heating and cooling large and impressive glass cladding skyscrapers particularly in sunny, hot and humid countries [3,4]. Furthermore, the construction industry is plagued with a number

ISSN 1675-5022

of problems that limits achieving its optimum output. One of these important problems is the creation of division between designers and contractors through separating design from construction [5,6,7]. The traditional procurement approaches usually used in construction projects and the large number of organisations, with different and sometime conflicting objectives, skills and interests took part in creating a fragmentation and adversarial relationship between project participants, which eventually affected the performance of the final product [8]. Professional fragmentation in construction has become the theme of many research studies carried out worldwide. This has triggered the emergence of the concepts of 'Buildability' and 'Constructability'. Although both terms are used interchangeably, buildability refers to the extent to which a building design facilitates ease of construction whilst other clients' requirements are met. It focuses on the design of a building. In contrast, constructability, which embraces both design and management functions, is concerned with a wider scope than 'buildability'. It deals with the project management systems that optimally use construction knowledge and experience to enhance efficient project delivery. Particularly, benefits become apparent when constructability is considered at the earliest possible stages [9]. Because of the importance of the design process as many important decisions are made during this phase (e.g., material selection including recycled materials, standard components, construction methods, etc) and for the reason that contractors are one of the main players in the construction industry that is responsible for delivering the designed facility, it becomes crucial that contractors have to be involved early in the design process in order to reduce construction waste and improve building performance.

2. RESEARCH AIM AND OBJECTIVES

This paper aims to investigate the integration of construction knowledge and contractor's experience in the design process as an approach for reducing construction waste and improving building performance. In order to achieve this aim, four objectives have to be accomplished:

- Building a thorough background of the study topic through reviewing the state-of-the-art relating to the nature of the construction industry; constructability; architecture and the design process; waste management and measuring building performance.
- Presenting successful case studies and examples of successful projects benefited from integrating construction knowledge and experience during the design process.
- Developing an innovative yet, theoretical framework to facilitate the integration of construction knowledge and contractor's experience in the design process and establish the strategies that support its application.
- Outlining the research conclusions and recommendations useful for construction professionals and researchers.

3. RESEARCH METHODOLOGY

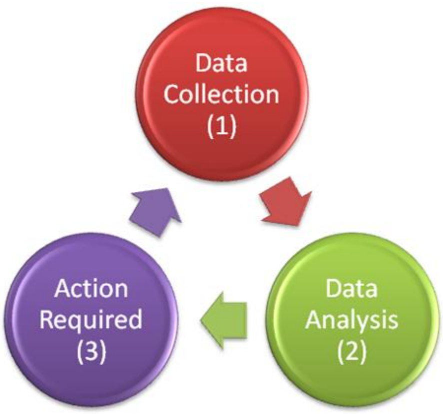

Figure 1: Research Methodology

The research methodology designed to achieve the abovementioned aim and objectives, consisted of three interrelated activities, namely data collection, data analysis and action required, see fig. (1). During the data collection activity, different sources are used to accomplish the first and second objectives. This included textbooks, academic journals, conference proceedings, dissertations and thesis, government publications and related websites. In addition, creative case studies and examples of successful projects benefited from integrating construction knowledge and experience during the design process are presented. They included the re-design of the structural system of Lansing Community College, Michigan, USA; the generation of virtual mock-up model at St. Joseph Mission Hospital; and the integration of contractor in the design of Cannon beach residence project. During the data analysis activity, quantitative and qualitative techniques are used to analyse the collected data. As an action for reducing construction waste and improving building performance, an innovative yet, theoretical framework is developed and the strategies that support its application are established. Because of the importance of validity and reliability, this research depended on facts rather than subjective information which increased the reliability and validity of collected data and research findings.

4. LITERATURE REVIEW

- ***The Nature of the Construction Industry***

The construction industry is a dynamic and ever-expanding business. It plays a significant role towards achieving national and international development objectives. It helps government authorities around the globe to achieve their social and economic development programmes. On the other hand and due to its nature, construction is a complex, risky, fragmented industry and has negative impacts on the environment. It is a time-consuming process that consists of thousand of interrelated design, construction and operation activities. It is characterised by high capital investment, reliance on developers and subcontractors, an extensive and complex regulatory framework, high interest costs and competition. In addition, increasing client expectations coupled with the technological development of materials and equipment as well as the impact of internal and external influences made the construction industry subject to more risks than any other industry [10,11]. Furthermore, the involvement of multitude of participants (e.g. clients, architects, engineers, contractors, labours, etc,) with different objectives, skills and interests coupled with the traditional procurement approach which separates design from construction and creates a division between designers and contractors, made the construction industry a highly fragmented business. This inhibited the design team from utilising and benefiting from the construction knowledge and experience of other project participants, particularly contractors. Hence, design mistakes, incompatible drawings, lack of details, inefficient construction methods, specification ambiguity and errors are repeated which increase construction waste and obstruct improving building performance on the long run.

- ***Constructability***
  - **Definitions and Concept Development:** The Construction Industry Institute [12] defined *Constructability* as the optimum integration of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives and improve building performance. Constructability, which is also known as *Buildability in the UK*, is a project management technique that encompasses 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 [13]. It helps identifying obstacles before a project is actually built to reduce or prevent errors, delays, wastes and cost overrun. True incorporation of the constructability philosophy involves thinking through an entire project before beginning the actual design, which is rarely done. It focuses the team on maximizing the simplicity, economy, and speed of construction, while considering the site conditions, code restrictions, and client requirements [14] which increases the probability of project success, reduce construction waste and improve building performance.

    The concept of Constructability was first emerged in the United Kingdom and the States of America during the late 1970’s as a result of studies aimed to maximize the efficiency, productivity, cost effectiveness and quality in the construction industry. Researchers in the UK, e.g. the Construction Industry Research and Information Association (CIRIA), had initially focused their attention on the design process and the early involvement of construction expertise. Later on, researchers tended to enlarge the scope by encompassing management practices and procurement approaches as contributors to the buildability and constructability concepts. In the US, the Construction Industry Institute promoted the concept of constructability and formulated guidelines for implementation. 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 [9,15].

- **Constructability Concepts:** Over the years a number of concepts have been developed to enhance and facilitate the adoption and application of the constructability philosophy throughout the different phases of the construction process, see tables (1, 2 &3) [16].

Table 1: Constructability Enhancement Concepts during Conceptual Planning Phase

Concept C1	The project constructability programme should be discussed and documented within the project execution plan, through the participation of all project team members.
Concept C2	A project team that includes representatives of the owner, engineer and contractor should be formulated and maintained to take the constructability issue into consideration from the outset of the project and through all of its phases.
Concept C3	Individuals with current construction knowledge and experience should achieve the early project planning so that interference between design and construction can be avoided.
Concept C4	The construction methods should be taken into consideration when choosing the type and the number of contracts required for executing the project.
Concept C5	The master project schedule and the construction completion date should be construction-sensitive and should be assigned as early as possible.
Concept C6	In order to accomplish the field operations easily and efficiently, major construction methods should be discussed and analysed in-depth as early as possible to direct the design according to these methods. This could include recovery and recycling methods as well as sustainable and final disposal planning.
Concept C7	Site layout should be studied carefully so that construction, operation and maintenance can be performed efficiently, and to avoid interference between the activities performed during these phases.

Table 2: Constructability Enhancement Concepts During Design and Procurement Phases

Concept C8	Design and procurement schedules should be dictated by construction sequence. Thus, the construction schedule must be discussed and developed prior to the design development and procurement schedule.
Concept C9	Advanced information technologies are important to any field including the construction industry. Therefore, the use of those technologies will overcome the problem of fragmentation into specialized roles in this field, and enhance constructability.
Concept C10	Designs, through design simplification by designers and design review by qualified construction personnel, must be configured to enable efficient construction. This will help minimise material waste, recycling and cost-effectivness.
Concept C11	Project elements should be standardized to an extent that will never affect the project cost negatively.
Concept C12	The project technical specifications should be simplified and configured to achieve efficient construction without sacrificing the level or the efficiency of the project performance.
Concept C13	The implementation of modularization and preassembly for project elements should be taken into consideration and studied carefully. Modularization and preassembly design should be prepared to facilitate fabrication, transportation and installation.
Concept C14	Project design should take into consideration the accessibility of construction personnel, materials and equipment to the required position inside the site.
Concept C15	Design should facilitate construction during adverse weather conditions. Efforts should be made to plan for the construction of the project under suitable weather conditions; otherwise, the designer must increase the project elements that could be prefabricated in workshops.

- **Constructability Awareness and Reviews in Design Firms:** Two international studies by [17] in the United States and [4] in South Africa found that most design firms are aware and perceive the concept of constructability with 95.7% and 84% respectively. 50.7% of respondents in the United States indicated that they have a formalized corporate philosophy about constructability in their organization. Where in South Africa, 76% of the design firms indicated that they required contractors' experience in their design because contractors have better knowledge about material availability and appropriate technology that affects design and cost. In their survey, [18] indicated that 90% of general contractors surveyed did not have formal constructability programs, nor did they take action toward the implementation of constructability programs. There seem to be more explicit constructability programs in design firms than in construction companies. This is probably caused by the general belief [19,20] that constructability review is particularly valuable in the design phase.

Table 3: Constructability Enhancement Concepts During Field Operations Phases

Concept C16	Field tasks sequencing should be configured in order to minimize damages or rework of some project elements, minimize scaffolding needs, formwork used, or congestion of construction personnel, material and equipment.
Concept C17	Innovation in temporary construction materials/systems, or implementing innovative ways of using available temporary construction materials/systems that have not been defined or limited by the design drawings and technical specifications will contribute positively to the enhancement of constructability.
Concept C18	Incorporating innovation of new methods in using off-the-shelf hand tools, or modification of the available tools, or introduction of a new hand tools that reduce labour intensity, increase mobility, safety or accessibility will enhance constructability at the construction phase.
Concept C19	Introduction of innovative methods for using the available equipment or modification of the available equipment to increase their productivity will lead to a better constructability.
Concept C20	In order to increase the productivity, reduce the need for scaffolding, or improve the project constructability under adverse weather conditions, constructors should be encouraged to use any optional preassembly.
Concept C21	Constructability will be enhanced by encouraging the constructor to carry out innovation of temporary facilities.
Concept C22	Good contractors, based on quality and time, should be documented, so that contracts for future construction works would not be awarded based on low bids only, but by considering other project attributes, i.e. quality and time.
Concept C23	Evaluation, documentation and feedback of the issues of the constructability concepts should be maintained throughout the project to be used in later projects as lessons learned.

- **Techniques Used in Constructability Reviews:** There are a number of techniques used in construability reviews. [13] mentioned in their study that ‘‘peer review’’ and ‘‘feedback systems’’ are the most popular tools used in conducting constructability reviews in design firms with 88% and 87%, respectively, see fig. (2). This is because government authorities mandate project peer reviews for specific contracts. For example, the city of Boston requires that prior to the issuance of a building permit for ‘‘complex fixtures or systems’’ an examination by a second engineer be performed. Also, the state of Connecticut requires independent engineering reviews on certain projects that meet established threshold limits [21]. The reason behind the peer review requirement is to benefit from the accumulated construction experience of designers at large. There are two types of peer reviews: project management and project design. The first focuses on the planning or management aspects of a project; whereas, the latter is an evaluation that focuses on the technical aspects of a project. Peer reviews may involve both of these reviews to improve the quality of a project prior to entering the construction phase. A major advantage of peer reviews is that they uncover and correct design inconsistencies, and they specify alternative construction methods with which the designer was not familiar.

  The feedback process involves the capture and transfer of past lessons learned, using either hard copy records or multimedia tools. In the latter, the computer tool captures, records, and stores constructability concepts and lessons learned, while providing design professionals with easy access and graphical retrieval of concepts and lessons to deepen their understanding of constructability issues [22]. 27% of the respondents mentioned that the least common tool used in constructability analysis is a small-scale physical model. This finding indicates that this once popular tool used to visualize the project is on its way to becoming obsolete except for highly sophisticated structures like petrochemical plants. Design firms appear to rely more on computer generated models to pursue constructability of design than building physical models, probably because of cost and time considerations. It is worth mentioning here that design firms utilize various different tools in their pursuit of constructability, depending on the characteristics of the projects undertaken. Other techniques included discussions with contractors, clients, and suppliers; quality assurance/quality control after each design stage; the construction manager participating in design reviews; and design checklist reviews

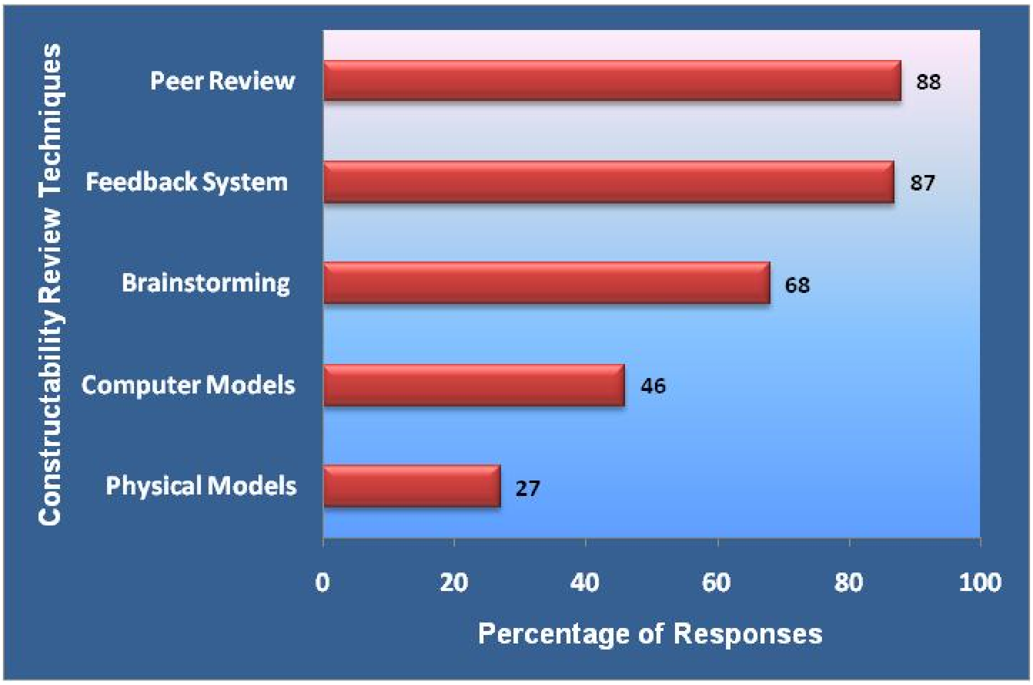

Figure 2: Constructability Review Techniques

- **When to Apply Constructability Reviews?** Because of its ability to reduce construction waste and improve building performance, constructability could be applied at any phase of the project life cycle. But due to the different nature of every phase in terms of the involved parties, technical requirements, inputs, tools and techniques as well as expected output, the potential contribution of constructability varies, see table (4) [13, 23].

  Table (4) shows that early integration of contractors in the project life cycle significantly enhances the opportunity of achieving tangible benefits through reducing cost, compressing delivery schedules, enhancing quality and integrating up to date construction tools and techniques into the design process. This is supported by [17] as they indicated that 87% of the surveyed design firms used constructability reviews during the developed design stage. In addition, [8] confirmed that 58% of South African design firms use constructability during the outline proposal stage and 50% during the detailed proposal stage. This means that most design firms surveyed treat constructability integration as part of an overall continuous project improvement process, which is the recommended by most researchers [24]. Having another approach, [25] stated that it is generally believed that implementing constructability reviews should be conducted after plans are completed to a certain level in order for reviewers to have something to work with. Alternatively, construction knowledge and expertise must be brought in before any design is put onto paper. This approach enables designers to begin their work with certain key issues in mind, issues that can frequently be accommodated without adverse cost to the design
- **Professionals Involved in the Constructability Reviews:** Although achieving constructability objectives is the responsibility of all project participants, not all professionals have the same chance to be involved in the design process. [8] mentioned in their studies that, the surveyed design firms were asked to indicate the professionals that are usually involved in the design process. All respondents indicated that structural engineers were the most commonly involved professionals, while 44.7% of the respondents stated that specialist subcontractors were the least commonly involved, see table (5). This could be attributed to the perception that some project participants can contribute more than others towards achieving constructability objectives. In addition, time constrains, client encouragement and participant's willingness could be other reasons to be considered.

Table 4: Constructability Contributions During Project Phases

Project Phase	**Phase Characteristics and Constructability Contribution**
Feasibility Phase	Often clients of projects do not have any "in-house" capability for construction services, so they procure the services of a consulting firm to perform the initial "feasibility phase" constructability review. The consulting firm works from the preliminary design documents and provides useful suggestions (e.g., selecting sustainable and recyclable materials, reducing design complexity, etc.) that are incorporated into the design package. The focus of a feasibility phase constructability review is to generate alternatives that can be expanded by conceptual design decisions in a manner that permits the necessary financial and schedule considerations for each alternative to be determined with the requisite degree of certainty by cost engineering specialists or equivalent. Essentially, the constructability reviewer/consultant will furnish the client with options that were not contemplated by the designer. The results of the constructability review can literally make or break a project's viability.
Early Design Phase	As the architects/engineers develop the project design; the client typically retains a second team of specialists who specialize in providing construction management (CM) services. The constructability review takes place as the construction documents are being developed. This CM team will perform a detailed constructability review (CR) of the proposed project documents: design drawings, technical specifications including specified construction materials, the proposed site layout and if available; the construction cost estimate and project milestone schedule. This review effort will focus on whether the project can be built as designed. This CM/CR team effort will provide suggestions on ways to improve the project: such as a more efficient site layout, alternate construction materials including recycled ones, identifies possibly detrimental design specifications that could result in long lead time procurements or exotic construction techniques, using standard components as well as ease of design and disassembly.
Procurement Phase	When the overall project design is approximately 60%-90% complete, the client retains a construction management firm to prepare the project for the procurement phase that prepares the subcontracts and procurement bid packages, pre-qualification of vendors, suppliers and trade contractors. These procurement bid packages must be complete design packages in order to provide the qualified bidders with the information necessary to make intelligent cost proposals for the overall success of the project. During the subcontractor procurement process, after receipt of the request for proposal (RFP), the various bidding contractors will normally conduct their own constructability reviews prior to bidding. Constructability clarification questions are frequently transmitted to the client's representative who provides additional information about site conditions, ambiguous or missing construction details, and often the bidding contractors may propose alternate construction methods for consideration.
Construction Phase	Constructability continues to be a viable tool for the success of the project after the award of the major contracts and purchase orders. For example, a mechanical contractor, employing constructability reviews, may determine that certain piping components could be fabricated in their shop and economically transported by truck to the project site, thereby improving both labour productivity and reduce the field costs for that large component of the work on a project. The client, the engineer, and the CM must remember that trade subcontractors are the technical experts in their field and must include construction contract language that encourages constructability improvement suggestions as well as requests for material and means substitutions. The submittal review process must be established to identify potential constructability improvements and then analyze the impact of implementing them on both project budget and schedule.
After Action Reviews	Constructability does not end when the project is completed. Often the project participants are in a hurry to close out the project and move on to another assignment. Either there is happiness over the success of the project, or there is a strong desire to put their bad experiences behind them and move on. In either case, there should be a formal review to capture the constructability lessons learned on the project. The

	corporation should establish a constructability database.

Table 5: Professionals involved in the Constructability Reviews

Professionals	**No. of respondents**	**% Response**
Quantity Surveyors	36	94.7
Main Contractors	18	47.4
Subcontractors	18	47.4
Specialist Subcontractors	17	44.7
Structural Engineers	38	100
Electrical Engineers	33	86.8
Mechanical Engineers	33	86.8
Land Surveyors	28	73.7

- **Construction Engineer's Involvement in Design:** [17] mentioned in their study that 95% of the respondents are of the opinion that construction engineers should be involved in the design phase in addition to other professionals that are already participating in this stage. This finding indicates that designers are aware of the need for a construction expert to provide the design team with insights into the construction phase of the project. Although 57% of the respondents believe that construction engineers should be involved regardless of project conditions, 38% indicated that the involvement of construction engineers should depend on the size, complexity, and type of project. Several respondents made remarks like ‘‘sometimes our office engineers do not see things as our construction people do.’’ This kind of remark indicates that the designers are not against the potential advisory role that experienced construction personnel might play in their organizations. It emphasizes the fundamental differences between designers and contractors that a designer has a conceptual mind that relates to intangibles and a contractor has a practical mind that relates to tangibles.
- **Constructability Reviews and Procumbent Methods:** There are a number of procurement methods used in construction projects such as Traditional route; Design and Build; Design, Build and Maintain; Management Contracting, Construction Management, Build-Own-Operate (BOO) and Build-Own-Operate-Transfer (BOOT). [26] stated that the traditional procurement method is the most typical method used in the construction industry. One of the main burdens in using this method in construction projects is the lack of contractor involvement in the design stage. It should be noted that separation of designers and contractors in handling design and construction activities largely affects project constructability. The traditional procurement method lacks co-ordination between design and construction phases of the project, in which individual parties mainly concern on their own interests. Therefore, other procurement approaches are highly encouraged for construction projects to utilise the construction knowledge and contractor's experience to deliver better construction projects and develop common interests between project participants. An interviewed main contractor highlighted that the involvement of contractors at the early design stage in a project can bring advantages in considering construction methods (such as the use of prefabrication in major activities including concreting, plastering and formworking, rather than wet-trade construction activities) before project commencement on site and to improve project constructability.
- **Barriers to Constructability:** [24] identified barriers to constructability as significant inhibitors that prevent effective implementation of a constructability programme. The Construction Industry Institute [12] has classified the barriers into general, owner, designer and contractor barriers detailed 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

Waste Management and Recycling Barriers

- Lack of understanding the importance and benefits of managing and recycling waste
- Lack of awareness and integration of the waste management philosophy in the design process
- Not specifying the use of recycled materials in design
- Over specification
- Using materials / products that generate waste
- Poor communication with waste management specialists who need to be integrated early in the design process
- Lack of considering life cycle cost and specify non-durable or sustainable materials results in replacing materials / products many times during the project life span [4]

[13] added some factors that hinder the application constructability, namely:

- Faulty, ambiguous, or defective working drawings
- Incomplete specifications
- Adversarial relationships
- Budgetary limitations
- Resistance of the owner to formal constructability programmes
- Non-standardisation of design

- **Benefits of Constructability in the Design Process:** Constructability should be applied at the early stage and considered as an important objective in all stages of the construction process. This is because of its ability to influence project cost and add better value for money. Based on their construction knowledge and experience, contractors can play a major role in reducing construction waste and enhancing building performance during the design stage [16]. On a scale of 1-5, [8] identified and ranked the benefits of implementing constructability, see fig. (3). In addition, [17] Identified and ranked the benefits of constructability to design firms, see table (6).

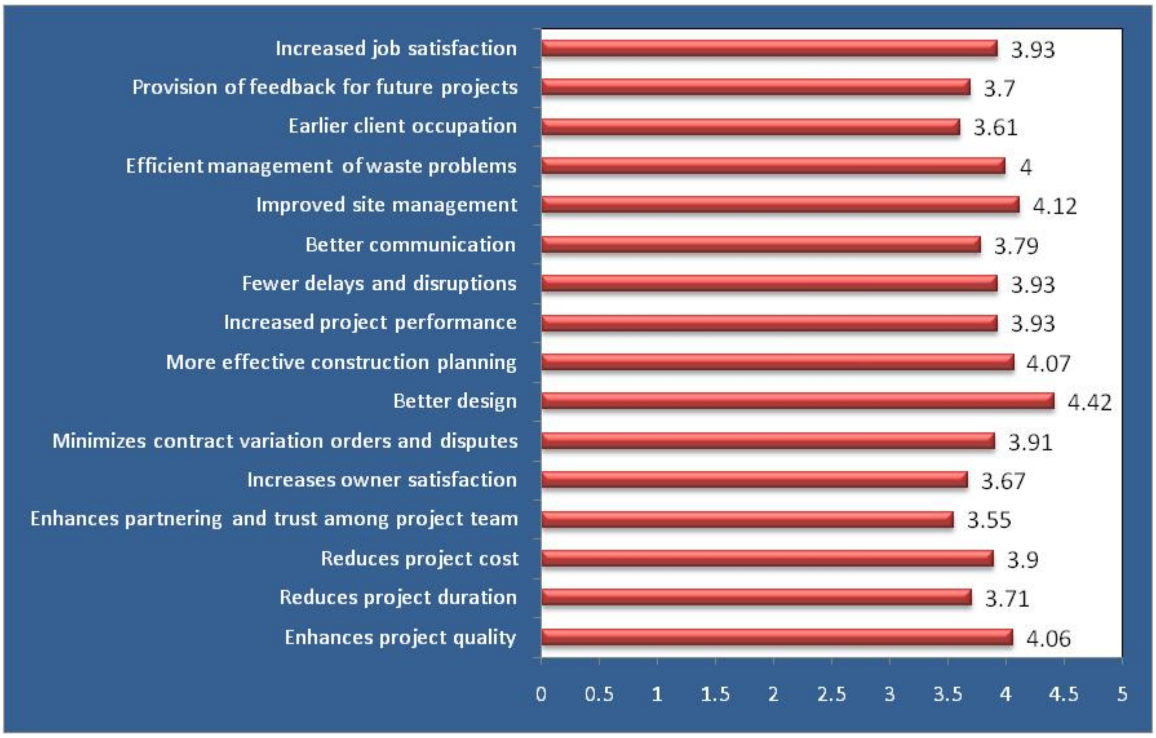

Figure 3: Benefits of Implementing Constructability

Table 6: The Opportunities for Implementing Constructability Reviews

Developing better relationships with clients and contractors	**2.7**
Being involved in fewer lawsuits	**2.5**
Building a good reputation	**2.5**
Professional satisfaction	**2.4**
Efficient Design	**2.3**

- ***Architecture and the Design Process***
  - **Definitions:** By referring to Webster Dictionary, “Architecture" has one of the following meanings:
    - The art of making plans for buildings, the work of an architect
    - The style or styles of building that an architect produces or imitates; as a church or modern architecture

    It could be defined as the science and the art of building. It is understood to be the whole of the environment built by humans, including buildings, urban spaces, and landscape [27].

    The Architect is defined as the person who designs buildings. The role of the architect is to design buildings within the framework of the national building bylaws and the local planning restrictions and to document and supervise the erection thereof in order that it will meet the client requirements [28].
  - **An Introduction to Design:** Every construction project starts with a plan. The plan identifies all the details of the project. It is developed by many different people, such as architects, engineers, draughtsmen, and specification writers. Design is the first step in a construction project. It could be defined as "the process of deciding what a structure will look like and how it will function. Designing a project can be entirely new or it can be a result of several ideas combined together to meet the needs of a specific project [29].
    - ***Design Theories:*** There are two opposing views of the theories of design. In one view, termed the "Glass Box Theory", design is taken to be a rational, explicable decision making process, while the opposing view, the "Black Box Theory", holds design ability to be a talent which cannot as yet be rationally explained.

      The “Glass Box Theory”, assumes that the process is a transparent, rational one where objectives are fixed in advance, information relevant to the problem is gathered, this data is analysed, a possible solution is synthesised and then evaluated against the objectives. If it is thought that the attempt at the solution can be improved upon, then a re-iterative process follows where the solution is refined until some optimum is achieved.

The "Black Box Theory" maintains that the most important part of the design process is the creative act on the part of the designer. They point out that the unpredictable, associative abilities of the human mind which produce an idea cannot be accounted for by any rational model. It is to this theory that many practising designers subscribe, they offend the attempts to explain their abilities and argue that designers cannot always give convincing reasons for their design decisions.

Design problems are extremely complex, requiring the designer to deal interrelationship between many sub-problems. When dealing with problems requiring the manipulation of more than one a few parameters then, the designer must initially focus on a well-structured sub-problem as a point of entry to the design problem. The environment in which the design problem is being solved brings various pressures to bear on the designer. Principals among these pressures are lack of time and increasing professionalism. It is argued that architects gain more esteem from peer approval than from the satisfaction of the client or users. It is therefore in their interest at times to pursue their own aims in designing a building, particularly from the aesthetic point of view, and deny the client group the opportunity of interfering with his own ideas of how the building should be designed [22].

- ***The RIBA Plan of Work:*** In 1964 the Royal Institute of British Architects (RIBA) published the RIBA Handbook in which was published a model procedure for methodical design process, termed the RIBA plan of Work. Subsequently, the plan of work was revised in 2000 and then updated in 2007 to cope with the ever-changing business environment, meet clients and users' expectations as well as technology enhancement. The process is typically broken down into 5 main phases, see fig. (4). Detailed description of the activities to be carried out in each phase is mentioned in table (7) [30].

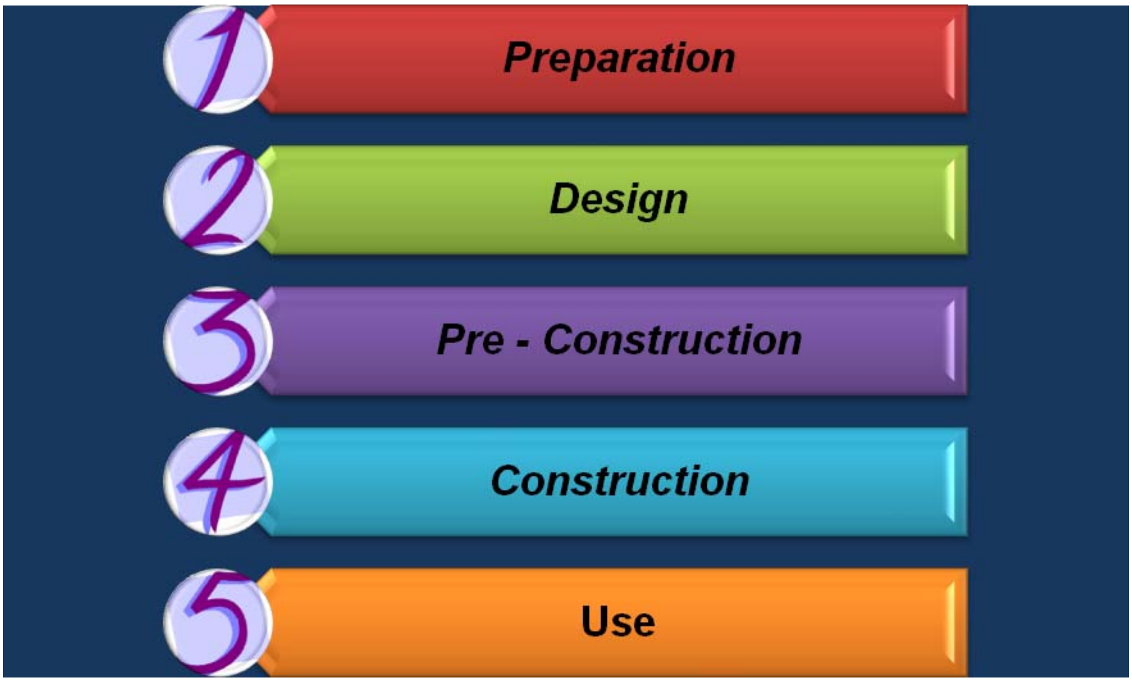

Figure 4: The RIBA Plan of Work

- *Waste Management*
  - **Definition and Background:** Waste management is defined as the collection, transport, processing, recycling or disposal, and monitoring of waste materials. The term usually relates to materials produced by human activity, and is generally undertaken to reduce their effect on health, the environment or aesthetics. Waste management is also carried out to recover resources from it. Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each [31].

Table 7: The RIBA Plan of Work

Preparation	**(A) Appraisal** • Identification of Client's needs and objective, business case and of possible constraints on development. • Preparation of feasibility studies to enable the client to decide whether to proceed. **(B) Design Brief** • Development of initial statement of requirements into the design brief by or on behalf of the Client confirming key requirements and constraints. • Identification of procurement method, procedures, organisational structure and range of Consultants and others to be engaged for the Project.
Design	**(C) Concept** • Implementation of design brief and preparation of additional data. • Preparation of Concept Design including outline proposals for structural and building services systems, outline specifications and preliminary cost plan. • Review of procurement route. **(D) Design Development** • Development of concept design to include structural and building services systems, updated outline specifications and cost plan. • Completion of Project Brief. • Application for detailed planning approval. **(E) Technical Design** Preparation of Technical design(s) and specifications sufficient for co-ordination of all components and elements of the Project. and information for statutory standards and construction safety.
Pre - Construction	**(F) Production Information** • F1 Preparation of detailed information for construction. Application for statutory approvals. • F2 Preparation of further information for construction required under the building contract. Review of information provided by specialists **(G) Tender documentation** • Preparation and collation of tender documentation in sufficient detail to enable a tender or tenders to be obtained for the construction of the Project. **(H) Tender action** • Identification and evaluation of potential contractors and/or specialists for the construction of the Project. • Obtaining and appraising tenders and submission of recommendations to the Client.
Construction	**(J) Mobilisation** • Letting the building contract, appointing the Contractor. • Issuing of production information to the Contractor. • Arranging site handover to the Contractor. **(K) To practical completion** • Administration of the building contract up to and including practical completion. • Provision to the Contractor of further information as and when reasonably required. • Review of information provided by contractors and specialists.
Use	**(L) Post Practical Completion** • L1 Administration of the building contract after Practical Completion and making final inspections. • L2 Assisting building user during initial occupation period • L3 Review of project performance in use

Effective waste management can reduce building and operating costs, enhance the reputation of the building industry, and also generate new revenue streams through developing recycling and reclaiming markets. Reducing construction waste also saves landfill space, conserves valuable natural resources, saves energy and creates less pollution by reducing transportation and manufacturing processes, with a mitigating effect on climate change [32], see tables 1, 2, 3 &4.

Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial producers. Management for non-hazardous residential and institutional waste in metropolitan areas is usually the responsibility of local government authorities, while management for non-hazardous commercial and industrial waste is usually the responsibility of the generator.

The scarcity of natural resources and the increasing volume of wasted materials and energy during the construction process called for the construction industry to be sustainable. This could be achieved through generating creative solutions and utilising the construction knowledge and practical expertise of construction professionals towards producing facilities that save the environment, prosper society and enhance economy.

- **Types of Construction Waste:** Wastes produced during construction vary according to the phase of construction, the method and the type of building. For instance, during plastering, painting and finishing, a lot of rubble is produced. A whole range of waste materials are produced throughout the build project including: concrete, dirt, drywall, insulation, tiles, carpet, vinyl flooring, cardboard, bricks, paint, metals, wood, and window glass. Most waste is produced on site through overordering, or damage by mishandling, inadequate storage or the weather.
- **Strategies for Waste Management:** Reducing construction waste requires a detailed strategy based on careful planning throughout the design, build and occupancy phases, to ensure its success, effectiveness and compliance with building regulations. There are three basic strategies for dealing with waste: (1) reducing waste, (2) reusing waste and (3) recycling waste. Waste reduction or prevention is the ideal strategy. It could be achieved through identifying possible waste streams early in the design process, and then designing for their minimisation such as using standard sizes for building components (windows, doors, etc.) to prevent future waste. It has been estimated that over ordering accounts for 13 million tonnes of new building materials being thrown out every year. Better communication and involvement of construction professionals during the early stages of the project life cycle ensures that exact calculations of required materials are made which ultimately reduces waste of materials. Once waste has been produced, the best method of managing it is through reuse either on the existing site, or a nearby site. Many materials can be usefully reclaimed, and even sold to offset the costs of a building project. Recycling materials is the final option for managing waste. Materials that can be reused or recycled need to be identified early on the build process, and segregated for easy storage, collection and transfer. For the strategy to be effective, links also need to be established with local recycling and reuse facilities and contractors. Going one step further than conventional practice, sustainable building practice design for waste minimisation in the operation of the building, through greywater recycling, composting toilets, on site food composting and off-site recycling facilities, thus helping to reduce residential waste [32].
- **Material Selection and Sustainability:** Construction materials have been traditionally, selected on the basis of economic and technological considerations to meet the client requirements and cover the project life span. The impact of the construction industry on the environment called for the construction process to be more sustainable. Material selection has dramatic effect on the construction process in terms of design efficiency and related material use, recycled content, recyclability, and the potential for reuse. These considerations contribute directly to improve building sustainability. In addition to the above criteria, material section should be based on (1) minimizing energy consumption during production and operation (Roberts 1994, Rees, 1990) with minimal packaging made by local manufacturers to reduce transportation energy expenditure, (2) maximising human satisfaction, minimising cost, ensuring human comfort and safety, and edifying human spirit, (3) minimising negative environmental impacts on ecosystems whose ongoing health is essential for human survival on earth. Databases and measures of sustainability for materials are essential to facilitate the approval and integration of more sustainable materials into future facility designs by helping designers quantify how they compare between materials already permitted under existing codes [33].

- **Waste Handling in Construction Sites:** Waste in construction sites consists of unwanted material produced directly or incidentally by construction team. This waste includes insulation, nails, electrical wiring, and rebar, as well as waste originating from site preparation such as dredging materials, tree stumps, and rubble. Construction waste may contain lead, asbestos, or other hazardous substances. Much building waste is made up of materials such as bricks, concrete and wood damaged or unused for various reasons during construction. Construction waste could be classified as hazardous and non-hazardous. There is the potential to recycle many elements of construction waste. Often roll-off containers are used to transport the waste. Rubble can be crushed and reused in construction projects. Waste wood can also be recovered and recycled. Government authorities often make rules about how much waste should be sorted before it is hauled away to landfills or other waste treatment facilities. Some hazardous materials may not be moved, before the authorities have ascertained that safety guidelines and restrictions have been followed. Among their concerns would be the proper handling and disposal of such toxic elements as lead, asbestos or radioactive materials. The Hazardous Waste Regulations 2005 is the transposition of the EU's Directive on Hazardous Waste. It outlines the procedures for handling, disposing of and receiving hazardous waste. Waste is hazardous when it contains properties that might make it harmful to human health and the environment. The construction sector is the largest producer of Hazardous Waste in the UK. Hazardous wastes are tracked by the Environment Agency (EA) to ensure that they are responsibly managed from their point of origin until they reach a suitably licensed or exempt facility to be recovered or disposed of [34].

  As a good practice for waste handling, construction companies are required to establish plans and draw strategies to support achieving these plans. These plans include, providing waste containers in different sizes and materials that can store the intended and at clean places that do not disturb the movement of workers and vehicles. In addition, site signage that direct the workers towards handling wastes procedures. Furthermore, issues that need to be considered include data collection, reusing or recycling methods, Good Housekeeping, Runon/Runoff Prevention, inspection, training programmes and Spill Response and Prevention [35].

- ***Measuring Building Performance***
  - **Definitions and Background:** Generally speaking, performance is defined as the action or process of performing. Hence, measuring building performance could be defined as the evaluation of the ability of a building to accomplish its intended function and satisfy its users. It is an ongoing process which aims to identify what is going well and why and what is going wrong or could be improved, and why. In addition, corrective actions have to be taken in order to overcome shortcomings and enhance performance. Performance measurement can only be effective if it is carried out against specific aim and objectives [36]. In the past, the performance of construction projects was typically evaluated informally and in terms of cost, time, and quality. This type of evaluation was perhaps sufficient at that time because building projects were relatively less complex and the level of technology in design was low. But things have changed dramatically and the three categories of project evaluation of time, cost and quality have been described as insufficient [37, 38]. Building performance evaluation has to be improved to cope with the ever-increasing proliferation and specialisation in the construction industry in terms of building types, services, technology, code and regulatory requirements, energy conservation, fire safety, environmental health, and safety constraints [39].
  - **Building Performance Criteria:** In order to improve building performance it is of prime importance to establish the criteria to be used for evaluating building performance. This will help design firms to utilise the construction knowledge and experience of project participants, contractors in particular, to achieve these criteria as an approach for improving building performance. Building performance criteria could be carried out at three levels.
    - Health, safety and security performance
    - Functional, efficiency and work flow performance
    - Psychological, social, cultural and aesthetic performance, see fig. (5) [40]
  - **Benefits of Measuring Building Performance:** Although measuring building performance helps understanding current building performance and end-users' requirements, it is an

important tool for managing and planning for new facilities. The benefits of measuring building performance range from short term to long term [41].

- ***At the short-term:*** Measuring building performance allows clients and facility management team to have a better understanding of the functionality and performance of their buildings compared with the stated criteria during design. In addition, active user participation in the evaluation process plays an important role in defining and considering their needs and requirements in the design of new buildings.

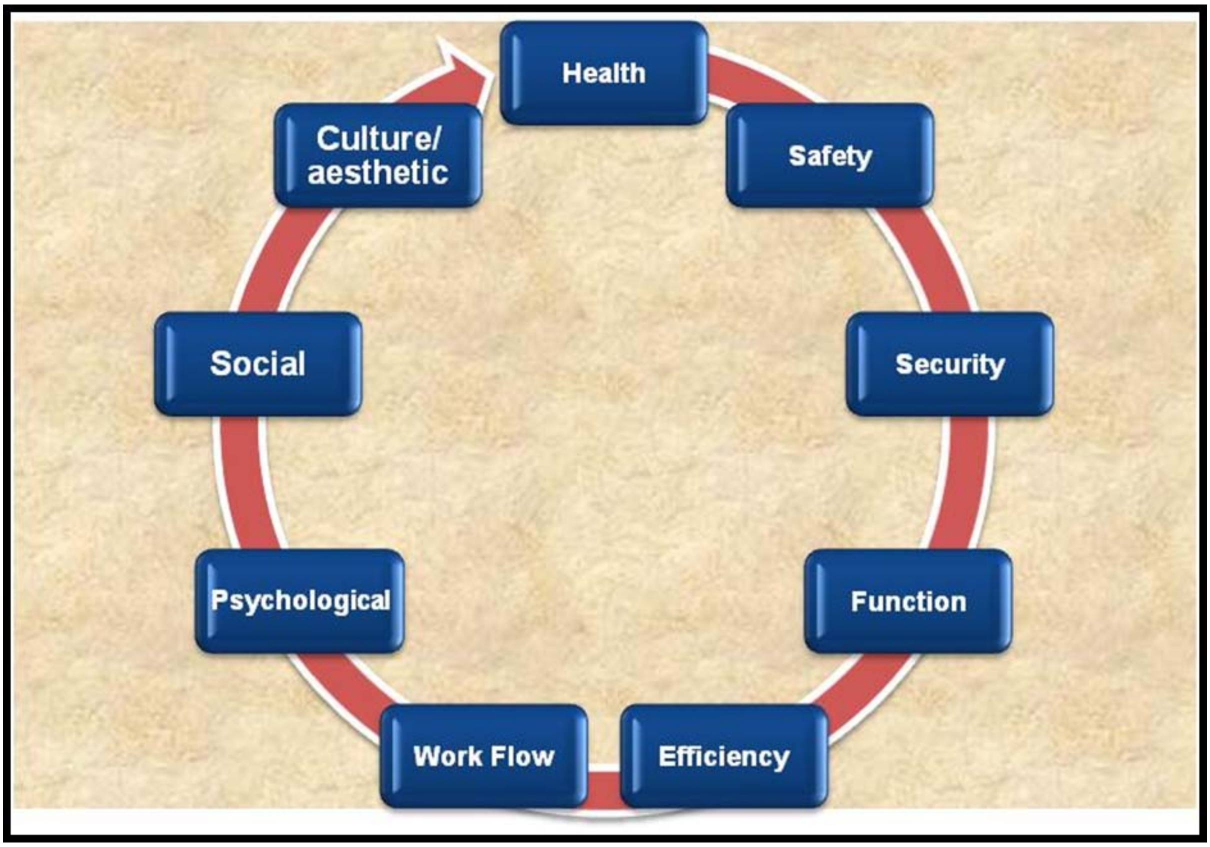

Figure 5: Levels of Performance Criteria

- ***At the medium-term:*** The data collected during the assessment of building performance can be used as a source of knowledge for planning new buildings of similar type. Designers equipped with user feedback are helped to design future buildings that more closely meet the needs of the users.
- ***At the long term:*** Measuring building performance helps establishing databases, generates planning and design criteria for specific building types and enables designers to consider documented past experience. This is important to avoid repeating past errors and recognise past success. The accumulated information plays a pivotal role in improving the quality of future buildings and services to the client and users. Assessment results may also improve design practice by making designers aware that their buildings may be subject of scrutiny. Thus design of future buildings may lead to better value for money to clients and society. This concern not only issues of functionality, but overall sustainability, energy efficiency and environmental impact.

5. CASE STUDIES AND EXAMPLES OF SUCCESSFUL PROJECTS BENEFITED FROM INTEGRATING CONSTRUCTABILITY IN THE DESIGN PROCESS

- ***The Lansing Community College, Michigan, USA***

Since the cost of the new campus building exceeded the allocated budget, Lansing Community College (LCC) decided to redesign the project or scrap part of it. LLC 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 principles to completely re-design the structural steel fabrication. Utilising their construction knowledge and the practical experience of Douglas Steel Fabrication Corporation, the re-design process included:

- Increasing the deck thickness from 2” to 3” allowed the floor beams spacing to increase by 10”. This reduced the number of floor beams by 78%.
- Changing the mixed lateral load resisting system to moment frames in both directions and the connections were designed as field-bolted moment connections using the actual moments and stiffness require. This reduced field labour required and simplified shop fabrication.
- Reducing construction hours and labour needed for the structure through moving the fabrication from the field to the shop which enhanced the quality and increased work efficiency, see fig. (6).

Using Information technology in communication and exchange of files and information reduced the re-design time and enhanced communication between different parties. The new design maintained design intent and made the project easier to build. 700 steel members and 1,400 connections were eliminated, 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 [14]. Waste Management provides rubbish removal services for Lansing Community College. All rubbish is collected and transported to the Grand Rapids sorting facility. This is called "single stream" recycling where recyclable materials are sorted from rubbish that goes into the landfill. Waste Management's renewable energy projects create enough energy to power nearly 1 million homes.

Figure 6: Lansing Community College, Michigan, USA [14]

- ***St. Joseph’s Mission Hospital’s Virtual Mock-Up, California, USA***

Realizing that the waterproofing and fireproofing systems were causing interference with the design of the new exterior cladding facade, the client determined that the constructability risk was too much to bear. In the worst case scenario, leaking and mold could close the entire hospital and incur significant warranty work. The first opinion, which was managed by the architect, is a $150,000 floor-to-floor height physical mock-up. This mock-up was to be brought on-site to help the General Contractor on the project to visualize the intersection of the glass curtain wall, the steel cladding, the gusset plate, the waterproofing, and the fireproofing solutions. St. Joseph's client turned to VICO Software Integrating Construction Company for a second opinion. The company generated a virtual mock-up: a highly detailed model to quickly analyze design alternatives and solve design and constructability issues. The virtual mock-up has proactively identified and resolved over 50 clashes, not just the gusset plate, see fig. (7) [42].

Figure 7: St. Joseph's Mission Hospital's, California, USA [43]

Due to its nature of work waste management specially hazardous material is paramount to St. Joseph's Mission Hospital's. Wastes are classified and proper collection and disposing method is used, see table (8) and fig. (8 & 9) shows two different data collection systems where table (8) represents the waste management procedures adopted in St. Joseph's Mission Hospital [44].

Table 8: Waste Management at St. Joseph's Mission Hospital [44]

Regular Waste: Clear Bag	**Biohazardous Waste: Red Bag**	**Sharps: Sharps Disposal Containers**	**Pharmaceutical Waste: Blue and White boxes**	**Yellow Chemo Boxes**	**Special Waste**
❑ Trash ❑ Paper, Wrappers ❑ **Blood tinged** Dressings ❑ Chux ❑ Diapers ❑ Gloves ❑ Empty Foley Bags and Other Drainage Bags ❑ Disposable Patient Items ❑ Sanitary Napkins ❑ Empty syringes with **no needle** attached	❑ Blood Tubing/ Bags/Hemovacs/ Pleurevacs with **trace** blood ❑ Soaked/ Dripping Bloody Dressings. ❑ Suction Liners with Bloody Fluid or OPIM **with isolyzer added** ❑ **Bulk blood – bags, tubing, etc**	❑ **All sharps** *Example: needles, ,blades, scalpels, razors, pins, clips, staples, lancets* ❑ Intact Glass or Plastic Bottles with Bloody Fluid or OPIM ❑ Trocars, introducers, guide wires, sharps from procedures	❑ **NO NEEDLES OR SYRINGES-Discard residual meds into container then put needle/syringe in sharps container** ❑ **Glass Vials, ampules with residual medication** ❑ IV bags and tubing with **residual medication** ❑ Partially used/ **residual** prescription or over-the-counter medication *Example:vials,tablets, capsules, powders,liquids, creams/lotions, eye drops suppositories, ½ tablet* ❑ **Residual or wasted narcotics** and/or controlled drugs ❑ Narcotic patches (cut in half) **Unopened/Unused or Expired Medications: Return to Pharmacy**	**Trace Chemo*:*** ❑ All supplies used to make and administer chemo medication *Example: tubing, empty **bags/ bottles/ vials, syringes,** gloves, pads, masks, gowns, wipes etc.* **Return all unused Chemo to Pharmacy**	**Radioactive*:*** ❑ Dispose of body-fluid soaked disposable items **into radioactive trash cans only**. **Hazardous R.C.R.A.* Pharmaceuticals:** ❑ Return to Pharmacy *Examples: Inhalers with residual (if empty-regular trash)**, unused** nicotine gum or patches, nitroglycerine tablets**, unused/residual** acetone, coumadin, cough syrup with alcohol content greater than 24%* **Batteries: Dispose of all batteries in designated containers** *Federal Resource Conservation and Recovery Act (RCRA)

Figure 8: Regular Waste Collection System
Green: Compost Blue: Recyclables Black: Garbage

Figure 9: Hazardous Waste Collection System

- ***Cannon Beach Residence, Oregon, USA***

The owners' request to the architect was for "a small home that will provide shelter, comfort, and rejuvenation." The request continued, "We will need for it to be equally comfortable when inhabited by just the two of us as when a gathering of family and friends joins us. Our new home should reflect the character of Cannon Beach and capture our love of materials and forms found in nature. We prefer for it to be low profile and understated. The home should be durable for generations and require little maintenance. Our goal is to build a home that is healthy to live in using materials and systems with a dramatically reduced impact on the environment." The project's integrated design team included the owners, architect, interior designer, and landscape architect. The contractor joined the team after schematic design was complete. The team held several meetings to establish clear and concise goals for the project, see Fig. (10).

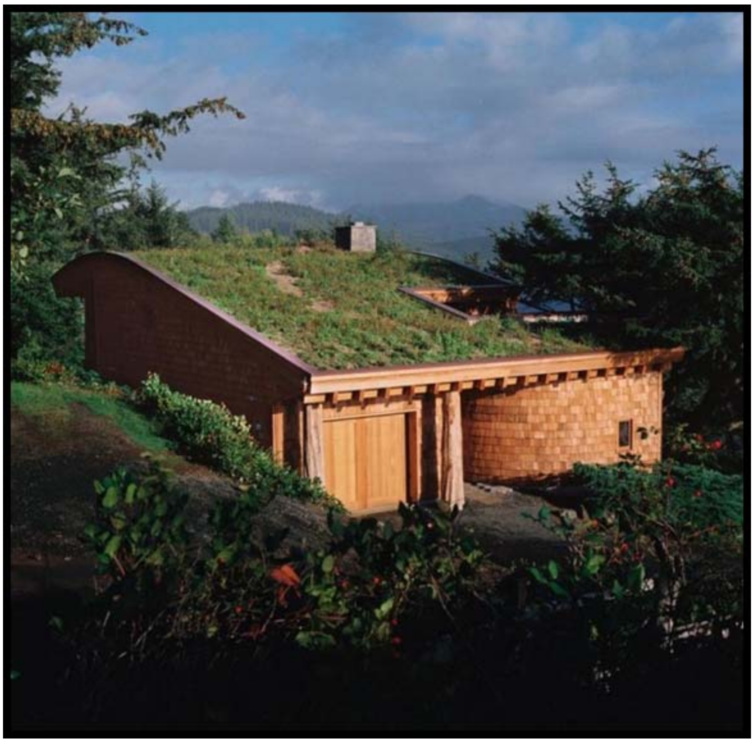

Figure 10: Early contractor involvement in design helps Reducing Life-Cycle Cost Assessment,

During the design process, the project team conducted five half-day eco-charrettes, each composed of the core team, content experts, and guests of the owners, including artists, neighbours, and friends. Involving the contractor early in the design process was paramount, as the contractor contributed expertise to all aspects of the design process. The contractor's contribution to conducting three abbreviated life-cycle cost assessments was critical to the selection of building systems and materials. The contractor also contributed to the design for durability, low maintenance, reducing waste and longevity. Based upon the contractor's opinion that the local knowledge of green building was less than adequate to achieve the aggressive green goals for this project, the design team and owners conducted a six-hour green-building seminar open to subcontractors, building officials, trades people, and the public [46].

6. DATA ANALYSIS

Literature review and case studies showed that reducing construction waste and improving building performance could be accomplished through applying the constructability concept early in the project life cycle. The diverse experience of project participants (i.e. clients, architects, engineers, contractors, suppliers, etc.) represents a great opportunity to achieve the project objectives at the most cost-effective manner and in a way that saves the environment, enhances the society and prospers the economy. Being the entity responsible for constructing the designed facility, contractors have a significant role that could be played towards reducing construction waste and improving building performance during the design phase. As case studies showed, utilising construction knowledge and contractor’s experience during the design phase, helped reducing cost, facilitating construction, reducing waste, resolving conflicts, reducing delays and selecting sustainable materials and better building systems. The main issue is how to make better utilisation and use of the involvement of project participants during the design stage. This necessitated the development of a framework that set the rules and establish the grounds that organise the involvement of construction professionals, contractors in particular, during the design stages as an approach for reducing waste and improving building performance.

7. REDUCING CONSTRUCTION WASTE AND IMPROVING BUILDING PERFORMANCE FRAMEWORK (RCWIBPF)

- ***Definition and Justification of Developing the Framework***

Framework is defined as a structure for describing a set of concepts, methods and technologies required to complete a product process and design [47]. The Reducing Construction Waste and Improving Building Performance Framework (RCWIBPF) (hereinafter referred to as “the Framework” or the “RCWIBPF”) is a proposed framework developed by this research to facilitate the integration of construction knowledge and contactor’s experience in the design process as an approach for reducing construction waste and improving building performance. The justification of developing the framework is a number of folds:

- Using natural resources and energy in an efficient way that reduces construction waste, reduces building and operating costs and enhances the reputation of the building industry.
- Improving building performance in terms of enhancing health, safety, security, function, efficiency, work flow, psychology, society and culture and aesthetic.
- Utilising the construction knowledge and contractor’s experience to support the government initiatives towards achieving their strategies and plans for social and economic development.
- Enhancing the performance of organizations operating in the construction industry by creating partnership between project participants, especially designers and contractors.
- Adding value to the built environment and achieving customer satisfaction.

- ***The Aim and Objectives of the Framework***

The developed framework is a business improvement tool designed to integrate construction knowledge and contractor’s experience in the design process as an approach for reducing construction waste and improving building performance. This aim could be achieved through accomplishing a set of interrelated objectives as follows:

- Identifying the problems that hinder integrating construction knowledge and contractor’s experience in the design process
- Establishing integration objectives
- Developing integration plans
- Executing integration plans
- Monitoring / Optimising Integration

- ***Description of the Framework***

The framework consists of five steps, namely: identifying integration problems, establishing integration objectives, developing integration plans, executing integration plans and monitoring / optimising integration, see fig. (11).

Figure 11: Improving Building Performance Framework

- **Identifying Integration Problem:** The "Identifying Integration Problem" function is an essential activity of this framework because it enables design firms and construction professionals to identify the core causes that obstruct the integration of construction knowledge and contractor’s experience in the design process. It is of important to build an effective team (including a competent team leader) that will carry out the improvement study. Achieving a balance between the need for participants who represent various areas of expertise and possess diverse background is fundamental for accomplishing the study objectives. The study team should contain between six and twelve full time participants to maintain optimum productivity [48]. Performing an early orientation meeting will help in establishing strategic issues like study duration, resources required and assigning responsibilities to team members. Senior management support will facilitate the provision of needed resources and the adoption of study decision. Data collection methods (i.e. literature review, survey questionnaire and interviews) and data analysis techniques (i.e. quantitative and qualitative) have to be defined and utilised. Brainstorming technique, team consensus and evaluation matrix have to be used for identifying the root causes and rank them according to their importance.
- **Establishing Integration Objectives:** Towards enabling design firms and construction professionals reduce construction waste, improve building performance and adopt appropriate decisions, the objectives of integrating construction knowledge and contractor’s experience in the design process have to be adequately defined and agreed by all participants. This could be achieved through using Brainstorming technique and team consensus to generate and select objectives that address the identified problem. Establishing integration objectives gives team members ownership to these objectives and encourages them to accomplish these objectives. Evaluation matrix will be used to rank these objectives according to their significance. In addition, this function will result also in defining the

criteria to be used to measure the reduction of construction waste and improvement of building performance.

- **Developing Integration Plans:** The "Developing Integration Plans" function aims to set the procedures and actions necessary to accomplish the integration objectives. It will include a work breakdown structure and a responsibility matrix, where the first downsizes the work into manageable work packages and the later links the activity to be done and the responsible person. In addition, the plans should include expected risks and corrective actions to be taken in case of the plan did not go as planned. Furthermore, communication plan amongst project participants have to be developed to portray the reporting structure of the constructability review.
- **Executing integration plans:** Within this function, the plans developed in the previous function will be executed. The execution plans may require that employees involved in the integration process be trained and equipped with all tools and technologies required to guarantee the successful execution of plans. In addition, senior management support and offering required facilities will help achieving the integration objectives. The execution stage should use the work authorization system, which provides for verification of predecessor activities and the permission to begin successor activities. This ensures the quality of work performed.
- **Monitoring / Optimising Integration:** The aim of this function is to ensure that the integration of construction knowledge and contractor's experience in the design process goes according to plan. Comments and feedback from the execution team will enable taking corrective actions if plans were not implemented as planned. Furthermore, this will help improving the performance of the construction industry in future improvement project.

- ***Limitations of the Framework***

Although the framework is theoretical and needs to be tested, it establishes the steps and set the rules that help integrating construction knowledge and contractor's experience in the design process. In addition, the effective application of the framework depends to a large extent on the willingness and encouragement of the senior management in design firms and construction companies to adopt the framework to reduce construction waste and improve building performance. On the other hand, if the senior management does not have the desire and tended not to use the framework, then its adoption will be limited. Since the adoption and application of the framework is a long-term strategy and due the tight schedule in construction projects, this framework might not be welcomed by some sectors of the industry. Due to the research limited timeframe and resources, it was not possible to apply and evaluate the framework, hence it needs to tested and validated in real construction projects.

- ***Strategies for facilitating the adoption of the framework***

In order to overcome these limitations and increase the opportunities of adopting the framework, the following strategies have to be followed:

- Escalating the awareness of architects with the importance of utilising the construction knowledge and contractor's experience towards delivering better construction projects.
- The benefits of the framework should be presented and explained to senior management of design firms in order to convince them with the role, which the framework could play in reducing construction waste and improving building performance.
- Eliminating the adversarial relationship between the different parties of the construction process through creating partnership between project team members, especially architects and contractors.
- Adopting procurement methods that encourage contractor's involvement during the design process.
- Ample time should be allowed to conduct constructability reviews as it plays a significant role towards reducing construction waste and improving building performance.
- Adopting innovative communication tools and techniques will facilitate conducting constructability reviews and archiving document for future projects.

8. CONCLUSIONS AND RECOMMENDATIONS

Although its role towards social and economic development, the construction industry has a negative impact on the environment and suffers from being a fragmented business. The traditional procurement approach used in construction projects and the different objectives, skills and interests of project participants played a significant role towards separating design from construction. This hindered contractors from conveying their feedback and suggestions to designers and hampered the application of the concept of constructability. Literature review, case studies and examples, clearly showed that the early integration of contractors in the design process, greatly reduces construction waste, improves building performance and enhances the possibility of accruing quantifiable benefits through reducing life cycle cost, compressing delivery schedules, and integrating state-of-the-art construction means and methods. The successful use of construction knowledge and contractor's expertise will optimize the opportunities for project success. Constructability reviews should be conducted at key points in the project life cycle: in the planning phase, early in the design phase, prior to the procurement phase, and again prior to mobilization phase for construction. Constructability integration can result in lower costs, better productivity, earlier completion and start-ups for ultimately better projects. Based on these conclusions, the research recommends that:

- Design firms are advised to integrate construction knowledge and contractor's experience in the design process as an approach to reduce construction waste and improve building performance.
- Construction material database could be developed and used for future use during demolition and urban mining. The location of hazardous and semi-hazardous could be included in this data base.
- Design firms are encouraged to adopt the developed framework and its strategies to facilitate its application in the design process.
- Researchers are directed to study the integration of other project participants such as suppliers in the design stage and other stages of the project life cycle.

REFERENCES

[1] D.M. Roodman and N. Lenssen, N. *A Building Revolution: How Ecology Health Concerns are Transforming Construction.* Paper 124 World Watch Institute, Washington, DC., 1995Albrecht, K. (1986). Stress and the Manager: Making it Work for You. New York: Simon and Schuster.

[2] D. Anink, C. Boodtra, and J. Mark, J. Handbook of Sustainable Development. London: James and James, 1996.

[3] Architectural Review. Comment, Architectural Review, May 1995, p.4.

[4] M.A. Abdellatif and A.A.E. Othman, A.A.E. Improving the sustainability of low-income housing projects: The case of residential buildings in Musaffah commercial city in Abu Dhabi. Emirates Journal for Engineering Research, 11(2), 47-58, 2006.

[5] B. Field and G. Ofori, "Construction and economic development – a case study", Third World Planning Review, vol. 10, no. 1, pp. 41–50, 1988.

[6] A.A.E. Othman, "Sustainable Architecture: an Investigation into the Architect's Social Responsibilities", in the International Conference on Sustainable Human Settlements for Economic and Social Development, Zambezi Sun International Hotel, Livingstone, Zambia, 2007, pp.181-197.

[7] D. Mthalane, A.A.E. Othman, and R.G. Pearl, "The Economic And Social Impacts of Site Accidents on The South African Society", in the 5th Post Graduate Conference on Construction Industry Development, Bloemfontein, South Africa, 2008, pp. 1-10. ISBN 0-86886-758-6.

[8] N. Motsa, A. Oladapo, and A.A.E. Othman, "The Benefits of Using Constructability During The Design Process", in the 5th Post Graduate Conference on Construction Industry Development, Bloemfontein, South Africa, 2008, pp. 158-167. ISBN 0-86886-758-6.

[9] F.W.H. Wong, D.D.D. Saram, P.T.I. Lam and D.W.M. Chan, "A Compendium of Buildability Issues from the Viewpoints of Construction Practitioners", Architectural Science Review, vol. 49, no. 1, pp.81-90, 2006.

[10] A.A.E. Othman, T.M. Hassan, and C.L. Pasquire, "Drivers for Dynamic Brief Development in Construction", Engineering, Construction and Architectural Management, vol. 11, no. 4, pp. 248-258, 2004.

[11] A.A.E. Othman, N. Harinarain, "Managing Risks Associated with the JBCC (Principal Building Agreement) from the South African contractor's Perspective", Acta Stuctilia, Journal for the Physical and Development Sciences, vol. 16, no. 1, pp. 83-119, 2009.

[12] CII, Constructability concept file, Austin, Construction Industry Institute, 1987.
[13] E.E. Douglas and D.D. Gransberg, "Implementing Project Constructability". AACE International Recommended Practice No. 30R-03. TCM Framework: 11.5 – Value Management and Value Improving Practices (VIPs), 2009. [Online]. Available from: www.aacei.org/technical/rps/30R-03.pdf (Accessed 2 January 2010).
[14] R.C. Aeck and D.I Ruby, "Consider Constructability", Modern Steel Construction, 2006. [Online]. Available from: www.modernsteel.com/Uploads/Issues/.../30752_lansing_web.pdf (Accessed 2 January 2010).
[15] B. Trigunarsyah, "A review of current practice in constructability improvement case studies on 7construction projects in Indonesia", Construction Management & Economics, vol. 22, no. 6, pp. 567-580, 2004.
[16] M.A. Nima, M.R. Abdul-Kadir and M.S. Jaafar, "Evaluation of the role of the contractor's personnel in enhancing project constructability", Structural Survey, vol. 19, no. 4, pp. 193-200, 2001.
[17] D. Arditi, A. Elhassan, and Y.C. Toklu, "Constructability analysis in the design firm", Journal of Construction Engineering & Management, vol. 128, no. 2, pp. 117-126, 2002.
[18] F.T. Uhlik, and G.V. Lores, "Assessment of constructability practices among general contractors", Journal of Architectural Engineering, vol. 4, no. 3, pp. 113–123, 1998.
[19] L.W. Zimmerman and G.D. Hart, *Value engineering—a practical approach for owners, designers, and contractors*, Van Nostrand Reinhold, New York, 1982.
[20] J.L. Burati, J.J. Farrington and W.B. Ledbetter, "Causes of quality deviations in design and construction". Journal of Construction Engineering and Management, vol. 118, no. 1, pp. 34–49, 1992.
[21] G.D. Gustafson, "Why project peer review?". Journal of Management in Engineering, vol. 6, no. 3, pp. 350–354, 1990.
[22] Multimedia constructability tool, INDOT constructability tool, Civil Engineering Dept., Purdue University, West Lafayette, Ind., 1998.
[23] A. Keys, A. Baldwin, and S. Austin, "Designing to encourage waste minimisation in the construction industry", CIBSE National Conference Dublin, Republic of Ireland, 2000.
[24] T.J. O'Connor, and S.J. Miller, "Barriers to constructability implementation", Journal of Performance of Constructed Facilities, vol. 8, no. 2, pp. 110-129, 1994.
[25] R. Mendelsohn, "The constructability review process: A constructor's perspective", Journal of Management in Engineering, vol. 13, no. 3, pp. 17–19, 1997.
[26] V.W.Y. Tam "On prefabrication implementation for different project types and procurement methods in Hong Kong", Journal of Engineering, Design and Technology, vol. 5, no. 1, pp. 68-80, 2007.
[27] L. Roth, *Understanding Architecture: Its Elements, History, And Meaning.* 2nd Ed. London: The Herbert Press Ltd., 1994.
[28] A.C. Hauptfleisch and H.M. Sigle, *Structural of the Built Environment in South Africa.* Hatfield: CONQS-Publishers, 2004.
[29] J. Fales, *Construction Technology: Today And Tomorrow.* 1st Ed. Peoria, Illinois: Macmillan/McGraw Hill, 1991.
[30] Hot Architects, The RIBA Plan of Work. 2009. [Online]. Available from: http://www.hotarchitecture.com/planofwork.html (Accessed 4 January 2010).
[31] Haghi, A.K. *Waste Management: Research Advances to Convert Waste to Wealth (Waste and Waste Management)*. Nova Science Publishers, 2010.
[32] Sustainable Build. Reducing and Managing Waste. [Online]. Available from: http://www.sustainablebuild.co.uk/ReducingManagingWaste.html. (Accessed 25 October 2010).
[33] A. R. Pearce, M. H. and J. A. Vanegas, Decision Support System for Construction Materials Selection using Sustainability as a Criterion. [Online]. Available from: http://www.fec.unicamp.br/arqs/20090520034957-T6- decision%20suport%20system%20.pdf. (Accessed 28 March 2011).
[34] E.R. Skoyles and J. R. Skoyles, Waste Prevention on Site. Mitchell Publishing, London, 1987.
[35] Waste Handling & Disposal Pollution Prevention Procedures. http://www.burlington.org/dpw/Stormwater/procedures/WasteHandlingProcedure.pdf. Available from: http://www.fec.unicamp.br/arqs/20090520034957-T6-decision%20suport%20system%20.pdf. (Accessed 28 March 2011).

[36] R. Pettinger, Mastering Management Skills. Palgrave, New York, 2001.
[37] C.S. Ward, B. Curtis and C.B. Chapman, "Objectives and performance in construction projects". Construction Management and Economics, vol. 9, pp.343–54, 1991.
[38] M. Kagioglou, R. Cooper, and G. Aouad, G. "Performance management in construction: a conceptual framework", Construction Management and Economics, vol. 19, pp. 85–95, 2001.
[39] C.A. Langston and G. K. C. Ding, *Sustainable practices in the built environment*, Langston, Butterworth-Heinemann, Oxford, 2001.
[40] W.F.E. Preiser and J.C. Vischer. C. *Assessing Building Performance.* Elsevier Butterworth-Heinemann, Oxford OX2 8DP, 2005.
[41] P. Barrett, *Facilities Management: Towards Best Practice.* Blackwell Science, 1995.
[42] Vico Software Integrating Construction, Mission Hospital's Virtual Mock-Up. 2009. [Online]. Available from: http://www.vicosoftware.com/st-joseph-mission-hospital-virtual-mock-up/tabid/85920/Default.aspx (Accessed 11 June 2010).
[43] OC&M, Mission Hospital Patient Care Tower, Okerlund Consulting and Management, LLC. 2010. [Online]. Available from: http://www.okerlundcm.com/projects/mission-hospital/ (Accessed 13 June 2010).
[44] Hospital Association of Southern California, Safety & Security Best Practices Library. [Online]. Available from: http://www.hasc.org/safety.cfm (Accessed 29 March 2011).
[45] Home design home, Cannon Beach Residence, 2010. [Online]. Available from: http://www.homedesignhome.com/cannon-beach-residence-by-nathan-good-architect-in-oregon-beach/ (Accessed 15 June 2010).
[46] Cascadia, Cannon Beach Residence, Cascadia Region Green Building Council. 2009. [Online]. Available from: http://casestudies.cascadiagbc.org/process.cfm?ProjectID=428 (Accessed 12 June 2010).
[47] EDMS, Framework. Engineering Data Management Service. 2007. [Online]. Available from: http://cedar.web.cern.ch/CEDAR/glossary.html#Framework> [Accessed 2 January, 2010].
[48] B.R. Norton and W.C. McElligott, Value Management in Construction: A Practical Guide. London: Macmillan, 1995.