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An Overview of Constructability: A Management Tool for Architects

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Abstract Construction Industry being one of the biggest industry involves many issues. One of such issues is Constructability, which is a management tool to optimize the construction knowledge and experience in various stages of the project, to achieve overall objectives. It is evolving as one of the important considerations for the participants of the project i.e. the client, the Architect/Designer, the Constructor /Contractor and the Consultant. The paper is an overview of issues covered in Constructability concept by various researchers. It also discussed the need for implementation of the concept, its benefits, barriers and the level of awareness among the project participants. Constructability, if involved in the construction projects, at an early stage, can lead to significant reductions in cost and save economy of the country.

Keywords Design Build, Integration, Coordination

1. Introduction

Construction industry is one of the biggest industry in the world and contributes towards the GDP (gross domestic product) of the country. The construction industry creates huge infrastructural facilities for the masses to use and enjoy. It generates employment opportunities for the communities. On the other hand it is the biggest source of creating pollution and exhausting the non-renewable resources of energy. It generates waste and has heavy impact on the environment. The Construction sector is responsible for 50% of material resources which are taken from nature. It is also responsible for 40% of energy consumption and 50% of waste generated (Anink et al. 1996). The management of practices in construction industry is also responsible to great extent for the environmental and sustainability related problems. Over the years, the design, construction and management practices have changed in the industry, thus setting up challenging situations for the participants. There is an emergent need to study and focus on certain areas and concept of management, which can enhance the construction processes by bridging up the gap between key participants: the client, the designer, and the constructor. Constructability has evolved as one such management tool, which can save time, money, reputation and can aid with a lot many tangible and non-tangible benefits, when applied at the right time. Constructability is still not a very popular concept amongst the participants, and has not even reached the developing countries, as it should have been. There is a need to understand the concept, its practices, benefits and barriers, so that proper and timely implementation is possible.

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2. The Energy Consumption in Construction Industry

The construction industry is essentially a service industry whose responsibility is to convert plans and specifications into finished products, it is exceedingly complex and highly individual in character (Peurifoy and Ledbetter, 1985:3). Construction industry consumes large amount of energy, water, materials and land. This contributes to the exhaustion of natural resources and consumption of energy (Poon 2000, Shat et al. 2000).

Energy is consumed throughout the lifecycle of a building. During its construction phase, energy is consumed in the form of embodied energy and also by various equipment functioning on site, for the successful completion of the project. With the increasing desires of the society and the complexity of the projects, this energy is increasing at a fast pace. After the completion of the project, when it is handed over to the client, energy continues to be consumed in its running operations, in the form of various appliances. Janda and Busch (1994) have estimated that 57% of electricity used in the developed countries are consumed directly by buildings. Best (2001) has stated that building sector is responsible for one-third of energy usage in most of the countries.

Shen et al. (2004) have studied various organisations, those which have been working on environment management systems like Building Research Establishment Environmental Assessment Methodology (BREEAM) in UK, the Building Environmental Performance Assessment Criteria (BEPAC) in Canada, the Green Building Challenge (GBC) in US and Hong Kong Building Environment Assessment Method (HK-BEAM) in Hong Kong. The Chartered Institute of Building (CIB, 1989) have identified certain areas for environmental management in construction activities. Some of these areas are efficient use of energy, environment friendly building materials, control of toxic chemicals, pollution control, recycling and waste management (Shen et al. 2004).

3. The Management Scenario in Construction Industry

The increasing complexity and specialization in the projects has changed the scenario of construction industry today. The traditional system of Design Build (DB) type of projects is replaced by a system of multiple contracts in the projects. More the number of participants, more is the management required. Jenitta and Tapadia (2004) have mentioned in their paper that many problems in the construction industry are due to the fragmentation in the industry. Different parties have their isolated goals to achieve such as the designer is concerned about aesthetics and design, the client is interested in the quality, functionality and cost effectiveness. On the other hand, the builder is bothered about buildability and profitability. Most of the problems originate from traditional Design-bid-Build methodology. Different types of Design and Build organizations have been studied and listed as follows:

Pure Design and Build organization: where complete services are provided under one head. These have highly integrated system and teamwork.

Integrated Design and Build organization: where organization contract out packages to specialists as required.

Fragmented Design and build organization: where firms engage in Design and Build contracts. There are sub-contractors into the system and people and problems of communication can occur.

It is important to incorporate the construction knowledge in the design process for the performance improvement (CII 1986; Pocock et al. 2006). Fisher and Tatum (1997) have mentioned in their paper about Gee who says, “The conflict (between design and construction) lies between the need to base the design of many structures on an assumed method and sequence of construction and a desire, contractually, to leave the contractor as much freedom as possible to determine his own methods and sequence, thus making him totally responsible for all aspects of construction”. Motsa et al. (2008) observed that the traditional procurement approaches and the involvement of large number of organizations with conflicting objectives, skills and interests played major role in fragmentation and adversarial relationship between project participants. As a result of this attitude the performance of the final product is affected.

3.1. The Project Phases

O’Connor and Davis (1988) have studied the building projects in three important stages/phases. The conceptual planning phase, the Design and Procurement phase and field operations phase. Bhattarai (2001) has divided the projects into two phases: pre-construction phase and construction phase. Kamari and Pimplikar have also identified two phases under the construction projects. The pre-construction stage comprising of conceptual planning phase. The second stage is construction stage where actual physical construction of project begins on site.

Carr et al. (2002) has identified the activities of design firm into three categories. The first one is planning sub phase, which includes planning and conceptual design. The second category is Design sub phase, which talks about preliminary design and detailed design. The third category is construction administration. The planning phase focusses on the attitude towards the openness to alternative solutions. The design phase targets on time and budget. Co-ordination is suggested as the key to achieve targets. The construction phase is critical as the construction administrator may have to deal with unforeseen problems. His role is to access the problem and create alternative solutions. For handling this situation, it is important to have openness for new ideas and possibilities.

3.2. The Project Delays

Delay has been defined as not completing of the entire work within the specified time period designated in the contract that is agreed and signed between the different parties i.e. the Employer and the Contractor (Baral, 2003:36). For the success of construction projects, it is important to understand the reasons that cause delay in construction projects. Unless the reasons for delays are identified and suitable measures taken towards their remedy, it would be difficult to save time and money in the construction projects. Arditi et al. (1985) have discussed that delay does not come in isolation. The delays in construction projects not only affect the construction industry but also influence the state of overall economy of the country. Further, they and many other authors have identified technology related delays as one of the main causes of delay in the construction projects. The technology related delays include inadequate supervision, improper construction methods and shortage of technical personnel. O’Connor et al. (1987) mentioned in their paper that delays in progress, slow productivity and increased damage to completed work are a result of accessibility problems.

Glavinich (1995) discussed that by ignoring constructability in design, the Architects and engineers may be creating the problems for builders like conflicting requirements, inefficient use of resources and out of sequence work which may delay the projects altogether. Arditi et al. (2002) has recognized that failure of design professionals to consider how a contractor will implement the design can cause many problems like scheduling, delays and disputes, thus affecting the project performance.

Bhattarai (2003) has discussed in his paper that the delays in construction projects have direct impact on the cost of the project, in terms of additions of interest on the project cost, loss of revenue generation from project, additional cost of the project due to inflation etc. Besides this the social losses include loss of reputation of the parties involved in the project, conflicts among them and delay in handing over the project on time. Bhattarai (2003) also identified 23 main reasons for project delays. Some of them are worth mentioning like:

- Contractors quoted rates are low and poor motivation to complete the work.
- The estimate is not based on actual evaluation.
- Unforeseen soil conditions.
- Extreme weather conditions such as rain, storm etc.
- Non availability of drawings and detail on time.
- Ambiguity in specification.
- Certain items given in specification but not available in market.
- Lack of contractors experience in handling the project.

Shen et al. (2004) mentioned in their paper that as per Drew (1999), there is a pressure on contractors to finish the projects as early as possible. Generally they are not given much opportunity to take care of environmental considerations. The delays in the delivery of project may cause clients to lose business opportunities and potential benefits. Delays in public projects may cause social and public loss also. Kansara et al. (2007) adds during their study on wastage that delays in the project are also caused if there is improper material management on site. This can happen in case of improper management on account of procurement schedule.

4. The Concept of Constructability

During 1970's, some studies were conducted in United Kingdom and States of America, which aimed at maximizing the efficiency of construction projects, through the concept of constructability. The Construction Industry Research and Information Association (CIRIA) laid emphasis on design process and early involvement of construction expertise. The concept of constructability was very well promoted by Construction Industry Institute (CII), in US. They also formulated guidelines for its implementation (Wong et al. 2006, Trigunarsyah 2004).

CII has defined Constructability as **"the optimum use of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall project objectives"** (CII, 1986). The ability to influence the cost of project decreases with time, hence there is maximum scope in the beginning of the project to consider issues that can affect cost (Figure 1).

Among various other principles the involvement of construction knowledge in conceptual planning stage is the most important and basic principle. CII Australia proposed 12 principles for execution of the constructability programme. These principles are Integration, Construction knowledge, Team skills, Corporate objectives, Available resources, External factors, Programmer, Construction Methodology, Accessibility, Specifications, Construction Innovation and Feedback. In 1990's, some studies were conducted at Singapore under first assessment system for buildability of designs and the results proved that the lack of integration of construction knowledge into the design process resulted in the exceeding budgets and scheduled deadlines of projects (Wong et al. 2006, Trigunarsyah 2004).

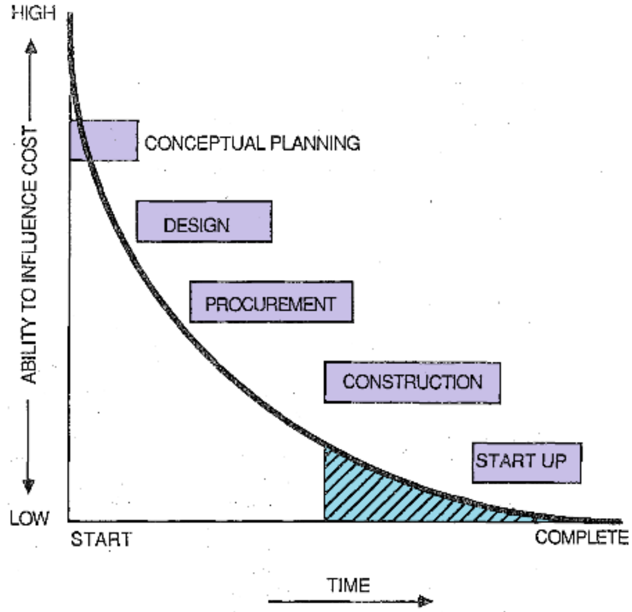

Figure 1. A graph showing various stages of Design process and the cost saving potential

Glavinich (1995) describes constructability of a design as, **"the ease with which the raw materials of the construction process (labour, production, equipment, tools, materials and installed equipment) can be brought together by a builder to complete the project in a timely and economic manner"**. Fisher and Tatum (1997) have quoted in their paper the definitions of Buildability and Constructability according to United Kingdom. Buildability is defined as, **"the extent to which the design of building facilitates ease of construction, subject to overall requirement for the completed building"**. UK definition for Constructability is, **"it is the extent to which the design of building facilitates ease of construction, subject to the requirements of construction methods".** Buildability focusses on design whereas constructability takes into consideration both, the design and management issues. Constructability incorporates project management systems in the construction project and the benefits are perceptible when constructability is introduced at an early stage (Wong et al. 2006).

O'Connor et al. (1987) have presented and analysed seven concepts for improving constructability during engineering and procurement phase of the project. These concepts are: Construction driven schedule, Simplified designs, Standardization, Module engineering, Accessibility, Adverse weather, Specifications.

In another paper, O'Connor et al. (1988) have stated previously determined concepts related to constructability under following heads:

Conceptual Planning stage

- Constructability programmes are made integral part of project execution plans.
- Project planning actively involves construction knowledge and experience.
- The source and qualifications of personnel with construction knowledge and experience varies with different contracting strategies.
- Overall project schedules are construction sensitive.
- Basic design approaches consider major construction methods.

Design and Procurement stage

- Site layout promote efficient construction.
- Design and procurement schedules are construction sensitive.
- Designs are configured to enable efficient construction.
- Design elements are standardized.
- Project constructability is enhanced when construction efficiency is considerered in specification development.
- Module/Preassembly designs are prepared to facilitate fabrication, transportation and installation.
- Designs promote construction accessibility of personnel, material and equipment.
- Designs facilitate construction under adverse weather conditions.

Field Operations stage

- Innovative definitive sequencing of field tasks.
- Innovative uses of temporary construction materials / systems.
- Innovative uses of hand tools.
- Innovative uses of construction equipment.
- Constructor optional preassembly.
- Innovative temporary facilities directly supportive of field methods.
- Post-bid constructor preferences related to the layout, design and selection of permanent materials.

Tatum (1987) investigated 15 projects and identified 3 key issues during conceptual planning stage: developing the project plan, laying out the site and selecting major construction methods. These issues were found beneficial in improving constructability. Radtke (1992) paper outlined research looking at constructability practices to integrate the construction knowledge into design and planning phases of project. These methodologies may be either formal or informal ways. Formal ways are identified as documentation, tracking through past lessons learned, and team building exercises and the participation of construction personnel in project planning. The informal ways be like design reviews and inclusion of construction co-ordinators. Nima et al. (2001) have developed constructability philosophy throughout different phases of construction process (Table 1, 2 and 3).

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 minimize material waste, recycling and cost-effectiveness.
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.

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.

Pocock et al. (1996) presented that one of the "critical factors" identifying successful projects in "constructability information from and available to the project team in a timely manner". Constructability programme implementation have resulted in significant gains in safety performance, schedule and project cost control (Jergeas and Put 2001). Pulaski and Horman (2005) introduced a model CPPMM - Conceptual Product/Process Matrix Model, for organizing constructability information based on timings and levels of detail. They concluded that, "the key to accessing constructability is introducing the right information at the right time and in the right level of detail". In another paper Pulaski et al. (2006) concluded and evaluated four constructability practices that were used to manage sustainability building knowledge at the renovation of Pentagon. These were: (1) an integrated project team, (2) physical and computer models, (3) an onboard review process, (4) a lessons learned workshop.

5. The Major Issues of Constructability

Some of the major issues have been extracted from the research of various authors and organized under various heads for detailed discussion. The issues have been taken which were common to most of the papers and the viewpoints gathered thereof. These 16 issues can be listed as: Integration, Coordination, Bidding Process, Construction driven schedule, Simplification of Design, Standardization of element, Prefabrication, Accessibility to Site, Adverse weather conditions, Specifications, Encouragement to Innovations, Past Lessons Learned Exercise & Reviews, Availability of Resources, Appraise Recycling, Waste Management, Employment of Advance Information Technology.

5.1. Integration

Itani (1987) identified integration as an "invisible asset". O' Connor et al. (1987) writes that the process of schedule development should involve an interdisciplinary team expert and well represented by construction personnel. The experienced construction personnel should be available on a continuing or timely basis so that they can give their inputs to the design team. Construction expertise can also help in identifying potential areas where standardization can be applied in the design. Timely review of project by construction personnel can also minimize accessibility problems on site and hence improve the working.

The Business Round Table Construction Industry Cost effectiveness Project (Business 1982) has laid emphasis on the participation of constructional experts in the conceptual development stage and also the planning stage. The results of this involvement may lead to savings in cost of the project.

Nam and Tatum (1992) highlighted the importance of inter-organizational relations as a means of achieving integration. The construction teams are temporary organizations, which come together for a specific purpose of building a facility. Such an organization, is for short duration but depends on long term relations between the owners, engineers, contractors and suppliers. This relationship is based on trust, reputation and single goal achievement concept. O'Connor and Miller (1994) identified certain barriers that do not allow early involvement of contractor, which can be stated as contracting practice, teamwork and culture. There is a lot of resistance on account of the prevailing culture of adoption contractor at after the design has been finalized.

Glavinich (1995) discusses that construction manager should be involved as soon as possible in the project, so that he can bring advantage to the project through his expertise during early stage of design. Pocock et al. (1996) found that "it is generally accepted that project performance can be enhanced when interaction occurs on a regular basis, beginning at an early stage in a project, in an open and trusting environment". Kichuk and Wiesner (1997) suggested, that the process of selection of the firm's professional composition should take place before the beginning of the project. This increases the probability of success of the team. Uhlik and Lores (1998) have identified that the contractors play an important role in preparing schedule and budget, selecting major materials, construction methods, suggesting structural systems, if they are involved at conceptual design phase.

Mitropoulous and Tatum (2000) showed concern about fragmentation of goals as one of the major issues that influenced the construction industry in recent days, which was a result of specialization of expertise. As a result, the successful and timely completion of project may suffer. In this situation, the main objective were to develop integration framework. Nine managers were interviewed to derive at managerial techniques employed. The following benefits were identified:

- Improved project cost effectiveness and schedule
- Increased safety
- Prevention of claims
- Improved logistics management and cash flows

It was also observed that integration is important at Design phase for two important reasons: (1) to prevent problems in subsequent processes, (2) to select the alternatives that may optimize the project performance. It is important that contractors and vendors participate as "equal-partners" in design and joint decisions are done. Mitropoulous and Tatum (2000) have mentioned that as per Lawrence and Lorch (1967) the process of integration requires exchange of information and knowledge between the independent subsystems. They also added that integration requires joint decision making. They concluded that owner has to take some important decisions regarding integration process like selection of contractor may not be done at lowest bid but rather focussing on his integration skills. Owner can train personnel's for integration. Besides this, special incentives may be offered to parties actively participating for the project success. The benefits of integration in private sector are, that, in design stage, it leads to the most effective solutions for cost saving and winning the contracts. The performance of such projects has an impact on further relationship of the contractor with the corporate clients. In public sector, contractors previous performance and reputation is important in terms of his aggressiveness and confidence to bid, although lowest bid is important criteria.

Early involvement of contractor in design allows the contribution of construction knowledge and experience to design. Direct involvement of contractor gains better cooperation between contractor and other participants throughout the design and construction process (Jergeas and Put 2001). In another paper, Gil et al. (2004) mentioned the inputs of contractor at early stage into four areas such as: (1) ability to develop creative solutions, (2) knowledge of construction space needs, (3) knowledge of fabrication and construction capabilities, (4) knowledge of supplier lead time and reliability. Othman (2011) has recommended for design firms to integrate construction knowledge and contractors experience in design process as approach to reduce construction waste and improve building performance.

5.2. Coordination

Higgin and Jessop (1965) had studied the building construction industry and identified three main functions of the building process: the design, the construction and the coordination. “Coordination is almost equivalent in meaning to control planning or management but is more descriptive of relating together of separate activities and their concerted direction towards a common purpose”.

Crichton (1966) mentioned in Tavistock studies that the activity of coordination is carried out in an informal manner in the building industry. He further adds that coordination is not generally spoken off on record. It does not appear in the handbooks or formal reports. O’Connor et al. (1987) suggested that inter organizational communication should be encouraged and planned for particularly between designers and contractors. While defining constructability and total quality management Russell et al (1994) analysed that, both of these stress commitment from all personnel from executive level to the level of the construction craftsmen at site. This process requires teamwork as an important tool.

Coordination has also been defined as effective harmonization of planned efforts for accomplishing goals. It is the most important and sensitive issues of management. Coordination acts as a bridge in fills up the voids created in various departments by changing situations in system, procedures and policies (Chitkara 1998).

Saram and Ahmad (2001) performed a research at identifying what activities are performed to achieve coordination, which among those are most important and which among those are most time consuming coordination activities. They identified 64 coordination activities and based on 33 responses received from practitioners in Hong Kong construction industry concluded the results. The six most important coordination activities have been identified as:

- Identifying strategic activities and potential delays
- Ensuring the timeliness of all work carried out
- Maintaining records of all drawings
- Information directives, verbal instructions and documents received from the consultants and client
- Maintaining proper relationship with client, consultant and contractor
- Liaison with the client and the consultant

The activities that consume most of the time are identified as:

- Conducting regular meetings and project reviews
- Gathering information on requirements of all parties and consolidating for use in planning, resolving differences etc.

The study also identified some important facts like; it is important to identify the activities which have greater impact than the other activities.

A paper by Carr et al. (2002) analysed the importance of coordination during design phase of the project and highlighted that the inter personnel interaction is important. This helps in integration of various components of the design. They further added that various professionals must interact with one another in order to bring together the various components of the project in a coordinated fashion. Shen et al. (2004) stated that the multi-tier sub-contracting system makes project communication and coordination difficult.

Jenitta and Tapadia (2004) have quoted that number of communication problems in the construction problems in the construction industry occur because of low coordination low efficiency, poor quality and adverse attitudes. They further explored that Design and Build project lead to better communication in the project team because all the team members work under single entity. All of the parties are working for the same interest hence the communication is better. The working environment is productive and collaborative because the designers and contractors work in simultaneously for single goal to provide the best solution to the client.

5.3. Bidding Process

Tatum (1987, 1990) identified the need for the early involvement of contractor in design. The Chartered Institute of Building (CIOB) (1988) has given the definition of Design and Build method as, “the client deals directly with the contractor for the complete building and it is the contractor who is not only responsible for, but also coordinates the separate design and construction processes, including engagement of the design team who are, therefore, contractually linked with the contractor and the client. The construction process, whilst linked, is still separate from the design process, leaving the consultants free to concentrate on their own roles. The client may, however, directly appoint either in house staff or a separate consultant to check that the contractor is providing value for money and that content and quality are satisfying”.

Glavinich (1995) discussed one of the problems of Design bid Build contracting system. The builder accepts the contract without asking for any kind of corrections in design and bidding time is short and the builder has little time to review. The builder later requests for extra time or extra compensation which appears to be an easy remedy but later on can result in serious impacts like delays of projects or affecting the financial feasibility of the project. Pocock et al. (1996) outlined research looking at project interaction. The author discussed, "Most engineers and architects could benefit from contractor input, but contractors are not usually involved in a project until bidding. They work from completed drawings and specifications without having any input to their contents".

According to Mitropoulous and Tatum (2001), Design and Build contracting is the best and an effective mechanism to facilitate integration of design and construction. 3 main types of mechanism were identified to increase the project integration; (1) contractual, (2) organizational and (3) technological. Design Build contracts have been suggested, as the entire responsibility of engineering, procurement and construction process is under one organization. It is also appreciated because the contractors get an opportunity to participate in the design process right from the beginning of the project. The contractors give importance to corporate relationship and maintain long term relationship with the designers. This helps them understand the needs of the client and win the contract, even if the bid is not lowest. The construction firms which do not have in house design cells, insist on maintaining relationships with the designers. Such relations help them gain projects through joint proposals also, at times.

In the traditional contracting practice, the contractor is selected through competitive bidding when the design has been completed by designer based on the knowledge that he has aesthetics functionality, budget and engineering consideration. In such cases, the contractor have little input to design. The construction knowledge and experience are important inputs for design but their impact is limited in such cases (Arditi et al. 2002). Gil et al. (2004) emphasized that early involvement of the speciality contractors in the design process can be achieved by Design Build contracting system.

Jenitta and Tapadia (2004) have explained the philosophy of Design Build procurement method as "single point source". The Design Build methodology provides best combination of design, construction, buildability and economy. The design Build method has better scope of achieving synergy between the two phases of design and construction as compared to Design Bid Build because in the previous case a single body is responsible for all the major decisions and activities with fewer conflicts. The advantages of Design and Build can be listed as:

- Shorter project execution time
- Single point responsibility
- Very less claims and disputes
- Greater privacy certainty
- Economy of project
- Better communication in the project team
- Collaborative work environment

The authors further added that Design and Build structures could be Designer led Design and build, Contractor led Design and build and Novated Design and Build. In the third category, the client hires the designer and gets the design prepared. The contractors bid on this design and the successful contractor enters into contract with the designer and develops the design details and executes the project.

Kansara et al. (2007) has shown in their research that vendors are selected by companies on the basis of parameters that vary with the projects. Some of these can be listed as lead time, quality, response and expenditure with the vendor.

5.4. Construction Driven Schedule

O' Connor et al. (1987) has discussed that constructability of a project is increased when the design and procurement schedules are construction driven. The construction schedules should be prepared even before the design and procurement schedules are finalized. This leads to reduced project duration, fewer delays in field, effective prioritization of various activities, effective work package and goals of project are well known to the project personnel. Another paper by Glavinich (1995) explains that as the design process progresses the schedule must be updated on a regular basis. A Barr (Gantt) chart schedule should be prepared that identifies important activities. As the design progresses the schedule should evolve from initial bar chart to an informative network type chart schedule that shows activities and durations and their interrelationships. The design process is the time having much potential to correct the scheduling problems.

5.5. Simplification of Design

O'Connor et al. (1987) analysed in their research that constructability is increased when designs have considered efficient construction i.e. designs are configured to enable efficient construction. Some principles that can be adopted for simplifying designs are listed as:

- Use of minimum number of components, elements or parts for assembly.
- Use of readily available materials in common sizes and configurations.
- Use of simple, easy to execute connections with minimum requirement of highly skilled labour and special environment controls.
- Use of design which minimize construction task interdependencies.

It is suggested that the design should be reviewed by qualified construction personnel.

5.6. Standardization of Element

O'Connor et al. (1987) have realized the importance of standardization in their paper. Constructability is enhanced when the design elements are standardized and repetition is followed. This also leads to savings because variations are minimized. Various areas where standardization can be applied are building systems, materials types, construction details, dimensions and elevations. The extent to which standardization may be applied depends on the economic analysis also. The reduction in variety can lead to many benefits like discounts on more of same material, simplified procurement and materials management.

Another paper by Fisher and Tatum (1996) identifies some of the preliminary design variables as important for constructability like dimension of elements, distances between elements, their repetition and modularity of layout. It is also suggested that the constructability can be improved at preliminary design stage in three types of design decisions: the horizontal layouts, vertical layouts and the dimensioning of structural elements.

Kansara et al. (2007) mentioned in their paper that, "when a company sets up its own standards for the codification and own standardization of materials, it helps in the variety reduction as one can constantly monitor the amount of the materials used".

5.7. Prefabrication

While discussing constructability, O'Connor et al. (1987) identified that ease of construction enhances if preassembly work is thought of in advance and preassembly/module designs are incorporated in advance to facilitate the process of fabrication, transport and installation. It should be take care off at the conceptual planning stage. The items which can be prepared off site should be analysed at early stage of design. This can lead to many benefits like improved task productivity, parallel sequencing of activity, increased safety, improved quality control and reduced need for scaffolding. O' Connor et al. (1988) also studied that preassembly can increase constructability in case of elevated works because the need for scaffolding is reduced/eliminated. This issue also helpful in situations where site is congested and quality sensitive work is to be produced. Adverse weather conditions also promote the need for modular construction practices.

5.8. Accessibility to Site

O' Connor et al. (1987) addressed that the constructability enhancement can be achieved when the design promotes accessibility of manpower, material and equipment. As study of accessibility becomes very important and crucial in cases where the sites are tight or roads capacity is limited, in case of renovation projects, working on high elevations, sites with steep grade changes, sites with extreme weather conditions or environmental conditions (like vegetation) or sites where multiple contractors are working. It is important to plan accessibility to site in terms of project elements, well defined and specified access lanes, clear spaces for placement of equipment. Proper communication is required with designers regarding transport, erection and sizes of equipment in terms of clearances etc.

5.9. Adverse Weather Conditions

According to O' Connor et al. (1987), constructability can be increased when design facilitates construction under adverse weather conditions, in case they exist. This is crucial in countries where climate is a challenge for construction activities smooth functioning. Both the designer and constructor have to be sensitive towards planning in such regions. Proper investigation is required to be done by the designer in advance to find out ways in which exposure to temperature extremes and effects of rain can be minimized. One of the major concern in such cases is the quality control. Some of the important measures that can be incorporated are allowance for large enclosed spaces which can be used as fabricating shops and equipment storage, early paving of site to eliminate muddy operations, specifications such as admixtures for overcoming the effects of extreme weather and maximizing off site work.

5.10. Specifications

O' Connor et al. (1987) mentions that inputs should be invited from the construction personnel in finalizing of preferred specifications and methods but that should not be constraining design configuration. In case the views of construction personnel vary, specifications should allow for cost effective alternatives. Glavinich (1995) mentioned that the specification of special or custom equipment or material should be avoided. Also the specification of obsolete materials, equipment and construction techniques should be avoided.

5.11. Encouragement to Innovations

Cox (1985) defined innovation as an attempt by, "right people" to the demands of their job. It is defined as, "Innovation is a by-product" of people who are acting on their unique strengths and who are refining their gifts". Foster (1986) explains that people who work for innovation are driven by higher project objectives and have a balanced perspective on change. Such people have an aggressive "attacker" approach and they are working on improving the inadequacies of current technology.

O' Connor et al. (1987) identified that good management practices should include practices like challenging of past practices and rewarding innovative ideas. They also mentioned in their paper that good ideas should be developed and success should be documented. Further O'Connor et al. (1988) added that there are certain common innovation practices that can enhance the constructability of construction projects. These have been listed under various heads like: sequencing of field tasks, materials, equipment etc. Some of the ideas are:

- Sequencing of equipment like crane, scaffolding, hoisting equipment, especially if they are to be used by multiple sub-contractors. This will help reduce confusion and congestion on site.
- Lighting systems may be installed at an early stage to reduce the need for temporary lighting.
- Stairs and platforms may be erected at an early stage. That may also help speeding up of work.

- Methods like steam curing, ground freezing are some advances in temporary construction systems.
- Innovations in formwork, like flying formwork, ship form system are easily erectable.
- Advances in labour hand tools can increase mobility, accessibility, safety and reliability like cordless power hand tools, automatic nailing gun etc.
- Constructability is also tending to make processes more of machine driven than worker driven. The processes can be speeded up with fully automated concrete batch plants, remote controlled welding systems, automated concrete floor finishers, spray robot for structural steel fire proofing etc.
- Temporary innovative facilities like enclosures of work space in adverse weather with easier erectable tent, site pavement with easily available local material like shells etc.

5.12. Past Lessons Learned Exercise & Reviews

O' Connor et al. (1987) writes that if the specifications are reviewed in detail by the designer, the owner and construction personnel, the constructability of project enhances and field operations become simplified. Later O'Connor (1988) added that future chances for increasing the constructability can be thought off by documenting the preferences and innovative ideas of the constructors. This will help and benefit the future projects. Poor documentation work cannot be retrieved on time, when required and can hinder the constructability. Proper information management systems should be taken care off by the designers as well as the constructors.

Russell et al. (1994) writes that maintaining a lessons learned database allows communication of positive and negative activities and experiences from one project to the future project. Glavinich (1995) made a mention of the term Design Phase Constructability Review and discussed that the design reviews should be conducted by senior design and field personnel prior to the start of the work which helps in promotion of better relationship between office and field personnel. The benefits of such reviews are increased client goodwill, greater design constructability and continuous scrutiny of the firm's design policies and standards.

Another paper by Fisher and Tatum (1996) concluded that often the corporate lessons learned are overlooked. Generally there are no formal systems of keeping the feedbacks. It is important and a formal system is required to acquire construction knowledge and to channel this knowledge to designers so that it can prove to be beneficial for the designers and contractors. The knowledge is collected during and after the construction phase of the project and the information is used as ready reference for other projects in future, so that those hindrances and problems are avoided.

5.13. Availability of Resources

O' Connor et al. (1987) writes that it is always advisable to avoid materials which are difficult to obtain. A paper by Glavinich (1995) discusses that the architects and engineers should consider the available local material, conditions as well as construction practices. The availability of labour, material and equipment should also be considered in design i.e. the type of labour skills and construction practices which are not locally available should be avoided, so that the project cost can be controlled and delays avoided.

5.14. Appraise Recycling

Hemlatha et al. (2008) discussed construction and demolition waste and highlighted the importance of recycling. The construction and demolition waste is 10-20% of municipal waste. The construction and demolition is said to be produced whenever any construction or demolition activity takes place. Such wastes are heavy, bulky and need huge amount of space for storage. The authors have made a mention in their paper that according to Technology Information Forecasting and Assessment Council (TIFAC), New Delhi, 70% of the construction industry is not aware of the recycling techniques. The construction and demolition waste management has been categorised in 4 stages: (1) storage and segregation, (2) collection and transportation, (3) recycling and reuse, (4) disposal.

5.15. Waste Management

Haghi (2010) defined waste management as "the collection, transport, processing, recycling or disposal, and monitoring of waste material". The term is generally employed when referring to materials produced by human activity. Waste management needs to be done to recover resources from it and to reduce its impact on the health and the environment or aesthetics.

Earlier Kansara et al. (2007) have stated that waste is something that is unwanted and may be produced on the construction site or may be on the closure of the project. According to the authors, in order to increase the profits, it is very important to reduce the wastage, which is the indirect expenditure. Management software can help in keeping a check on the amount of material used in the project but generally the companies are not employing these methods and checking the waste manually on site, which leads to time wastage. Waste management has not gained importance in Indian construction industry. Waste needs to be cut down in order to save economy. Government should set norms and standards for allowable waste percent. Based on severity, certain causes of waste have been identified.

The highly severe causes are:

- Improper planning
- Poor management
- Improper quality control
- Lack of individual responsibility
- Overall negligence

The moderately severe causes are:

- Improper designs
- Improper specifications

- Improper labour and supervision to faulty systems

The low severity causes are:

- Lack of technological know-how
- Unavailability of resources
- Unhygienic working environment
- Lack of standardization

5.16. Employment of Advance Information Technology

O'Connor et al. observed that Computer aided design (CAD) overlay techniques have proven useful for studying the accessibility problems during the project execution, in advance. In some complex cases, computerized simulation models have been prepared to plan work flow and logistics. A paper by Fisher and Tatum (1996) concludes that Computer aided design (CAD) and expert system technology can also help in corporate knowledge like lessons learned from the projects, so that it can be applied at the design stage automatically and in this process the constructability of the project will be increased by higher quality of product. Such data system with past lessons learned information incorporated in their programme, will help the designers save time and energy and make the project cost effective. Kansara et al. (2007) found that companies in India are using most commonly "MS Project" to plan out the quantities of material to be used. "PRIMAVERA" is also used by some to cross check the planning done by first.

6. The Awareness about Constructability

Unlik and Lores (1998) indicated that 90% of general contractors, whom they surveyed did not have formal constructability programmes. They did not either take action towards its implementation.

Cox and Thomson (1998) surveyed 332 construction projects in UK, and found that Design Build contracting is 12% faster than the traditional designing and procurement methods. They are 13% cheaper and 50% more likely to finish on time.

Arditi et al. (2002) in the United States found that most design firms perceive the concept of constructability to 95.7%. Almost 50.7% of respondents have formal corporate philosophy about constructability in their organization. The author also indicated that 87% of surveyed design firms used constructability reviews during developed design stage. They stated that 95% of the respondents believed that construction engineers should be involved in the design phase, in addition to other professionals, who are already participating at this stage. Of these 57% respondents believed that they should be involved, regardless of project conditions, whereas 38% indicated that the involvement should depend on size, complexity and type. Pocock et al. (2006) have shown that constructability has gained importance and it is increasingly being adopted and applied in early project stages.

Othman (2011) has mentioned of a survey study, in his paper, which was conducted in South Africa, and it was found that 84% design firms were aware of constructability concept. 76% of the firms indicated that they require contractors experience in their design because they had better knowledge about material availability and application technology that affects design and cost. All the respondents agreed, that structural engineers were most commonly involved professionals. 44.7% respondents stated that specialist sub-contractors were least involved.

Kamari and Pimplikar conducted a survey of four construction companies in India and identified that most of the time the problem occurred with drawings because a thorough review was missing. The best type of contract was Build Operate Transfer (BOT) and Design Build (DB) as they had less number of constructability issues. It was found that 25% of the respondents performed constructability analysis throughout the entire design process (from conceptual to the finishing of design). It was also observed that 51% firms start performing reviews as early as conceptual planning stage. The most significant factor (87%) that affects constructability was project complexity. The second highest factor (75%) was design practices and philosophy i.e. designers approach to problem which includes his attention to construction details, site experience etc. The three important factors that were found to cause constructability problems were faulty ambiguous or defective working drawings and adversarial relationships. The respondents listed the most magnificent benefit of constructability reviews to design firms as: Better relationship with contractor and client (83%) and Reduction in lawsuits and number of claims (72%). They also performed a survey related to architectural designs and constructability issues directly. There were many architectural aspects which were to be rated as constructability issues. The most significant factor was architectural drawing (95%), compatibility between interior and exterior designs (75%), architectural new styles and shortage of enough knowledge (75%), shape of structure (65%), procedure of developing architectural designs (65%), architectural design and acoustic solutions (65%), materials chosen by Architects (60%).

7. The Benefits of Constructability

Long-time back, the construction projects were single handed by the master builder, who used to take care of the design as well as the construction activities for a project. There was huge amount of integration in this process as the design and construction considerations were very well taken care off. The early decisions regarding construction materials and methods could improve design and increase the buildability of the project. With the increase in the specialization in the construction industry, the design and construction activities got separated considerably. With lesser concern and knowledge about each other's areas of specialization, the buildability got affected and the need to reassure and integrate the two processes of design and construction, brought into picture the concept of constructability. Constructability is a value management tool developed as an attempt to bring closer the design and construction activities to the level of integration, once achieved by master builder (Russell et al. 1994).

Russell et al. (1994) have also discussed in their paper the qualitative and quantitative benefits of constructability. The quantitative benefits may be stated as reduced engineering cost, reduced schedule duration and reduced construction cost in terms of labour, material, and equipment. The qualitative benefits may be listed as improved site accessibility, improved safety, reduced rework, increased communication, reduced maintenance cost, increased focus on common goal, increased construction flexibility etc. There are many significant benefits of incorporating constructability programme, for the contractors are paid off with more and steady construction (Gil 2001) and for the designers in terms of better relationships with owners and contractors, lesser lawsuits and good reputation (Arditi et al. 2002).

Arditi et al. (2002) identified and ranked the benefits of constructability in design firms as: Better relationships with clients and contractors, Being involved in fewer lawsuits, Building good reputation, Professional satisfaction, Efficient design. In another paper, Motsa et al. (2008) enquired and stated that implementation of constructability leads to enormous benefits (Figure 2). The major benefits are in the areas achievement of better design, improved site management and enhanced quality of the project.

8. The Barriers to Constructability

CII (1987) has classified barriers to constructability into various categories as general barrier, owner barrier, designer barrier, contractor barrier etc. They can be listed as follows:

General barrier

- 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 Barrier

- 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 Barrier

- 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

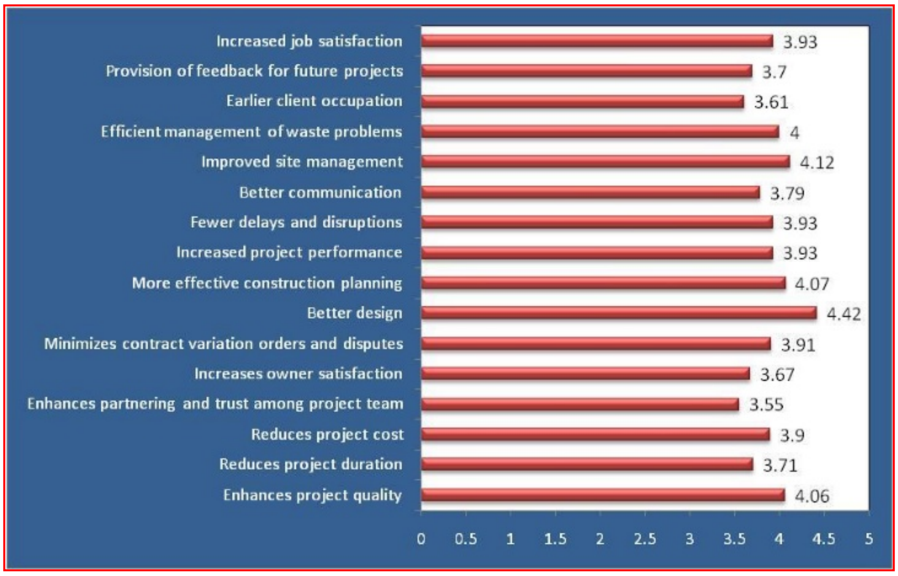

Figure 2. Benefits of Constructability

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

O'Connor (1994) added some more barriers to constructability like:

Organized Barriers

- Preassembly limitations
- Other work restrictions

Vendor Barriers

- Fragmentation and difficult communication interfaces
- Restrictions on proprietary designs

Code Authority Barriers

- Rigid, outdated codes and design standards
- Non rigorous approach to establishment of tolerances

Research Barriers

- Difficulty in proving the economics of constructability

Barrier to constructability is that impediment that stops effective implementation of constructability programme. O' Connor and Miller (1994) assessed the barriers through in depth interviews of representatives from 62 companies which claimed to have been using constructability programmes. They identified the most problematic barriers to effective constructability improvement. These are: (1) Complacency with status quo, (2) reluctance to invest additional money and effort in early project stages, (3) limitations of lump-sum competitive contracting, (4) lack of construction experience in design organizations, (5) designer's perception that "we do it," (6) lack of mutual respect between designers and constructors, (7) construction input is requested too late to be of value, (8) belief that there are no proven benefits of constructability.

9. Conclusions

An overview of the concept of Constructability has been presented in this paper. Its importance with respect to savings in overall economy of the country have been highlighted. Sixteen major issues of Constructability have been identified as: Integration, Coordination, Bidding Process, Construction driven schedule, Simplification of Design, Standardization of element, Prefabrication, Accessibility to Site, Adverse weather conditions, Specifications, Encouragement to Innovations, Past Lessons Learned Exercise & Reviews, Availability of Resources, Appraise Recycling, Waste Management, Employment of Advance Information Technology. The barriers need to be taken care of and hurdles passed for successful implementation of the concept. Early implementation of the constructability principles as management tool is recommended to make projects successful and achieve better results in terms of better design, improved site management tools and enhanced project quality. The tool is also expected to save money and resources as the Construction Industry is responsible for 40% energy consumption and 50% waste generation.

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