A Conceptual Method of Constructability Improvement

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***Abstract*—Constructability is the optimum use of construction knowledge and experience in the conceptual planning. This paper aims to illustrate the application of constructability concepts during the design stage by providing a relevant case study which is a three story residential building. The buildability score of this building is accurately calculated and then by comparing to current standard of buildability, it was found that the buildability of the building needs to be improved. Thus, the constructability concepts were implemented and it was found that if the concepts being implemented in design stage, the constructability of the building will be improved. This paper concluded by a guideline which shows relevant suggestions for improving constructability concept.**

***Index Terms*—Buildability score, constructability, construction.**

I. Introduction

Constructability is the optimum use of construction knowledge and experience in the conceptual planning, engineering, procurement, and field operations phases to achieve the overall project objectives [1].

Development of integration planning and control of design is the most important issue in construction industry. To increase the quality of production and achieving the project objectives, the constructability concept was presented in 1970s. This concept integrates knowledge and experience of construction managers and design engineers therefore eliminates the redesign and rework in construction sites. The evidences show that application of constructability in UK, USA and Australia reduces the cost and time of projects [2], [3].

One of the major problems in construction sites is lack of integration between design and construction [4]. Since last decades, the required time and cost for completing a construction project have been increasing due to lack of applying constructability. Therefore, implementation of constructability which involves the size and complexity of projects and also considers the knowledge and experiences of experts is a vital point in construction industry [5].

Although there are various methods for improving constructability on project designs like guidelines, computerized systems, and manual systems but they are not able to optimize design based on several aspects or principles of constructability. Guidelines methods and computerized systems set the industry with common recommendations and designers with an automated evaluation for applying constructability in projects, respectively. In addition, the manual systems make arrangement designers with simple procedure to manually assess the rate of constructability by using scales or formula [4]. The aim of this study is to investigate the concept of constructability in Singapore and discuss the conceptual methods of constructability improvement by providing a relevant case study.

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II. Literature Review

Based on Fischer and Tatum, 1997, constructability is the significant objective in construction projects [6]. Although there are various factors which enhance constructability, e.g. project complexity, design practices and philosophy, and project delivery system [7], designers have a significant role in constructability improvement [6].

There is a classification for knowledge of constructability theory to improve project performance: application heuristics, layout knowledge, dimensioning knowledge, detailing knowledge, and exogenous knowledge [6]. Design team should be well practiced in this area and they need to have ingenuity, knowledge and experience of construction as well [8].

Constructability is not only limited to design stage, but should be considered during whole project lifecycle. By project progressing, the influence of designer reduces while the effect of expenditure increases. Thus, it is recommended to apply constructability at earlier design stages of project so as to achieve the objective of the construction projects (Fig. 1) [9].

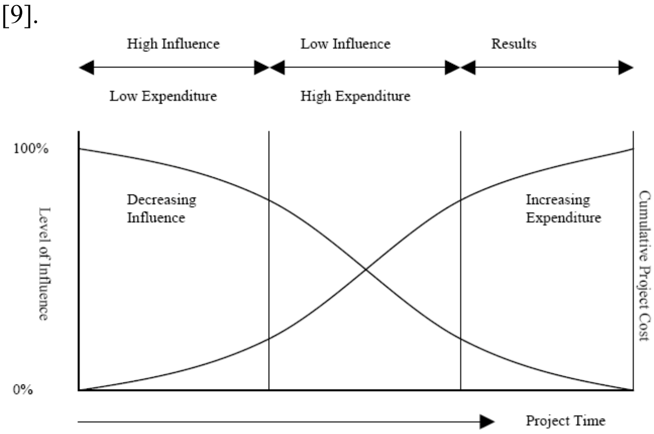

Fig. 1. Project life cycle and designers level of influence.

Implementation Task Force (IFC) and different constructability-implementation programs are currently used in the construction industry. Based on the data obtained from the Construction Industry Institute (CII), the process model of Radtke and Russell is a benchmark for owners to improve constructability in their projects in order to achieve the maximum benefits [10].

A. Constructability Concept

There are 15 preconstruction concepts which are represented as following [11], [12].

Project constructability enhancement during conceptual planning phase comprises of Concepts C1–C7:

- Concept C1: The project constructability program 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 throughout all its phases.
- Concept C3: Individuals with current construction knowledge and experience should partake in the early stage of project planning so that any misunderstanding between design and construction phases will 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 analyzed in-depth as early as possible to direct the design according to these methods.
- Concept C7: Site layout should be studied carefully to ensure that the construction, operation, and maintenance proceed efficiently, and to avoid any interference between the operations performed during these phases.

Project constructability enhancement during design and procurement phases comprises Concepts C8–C15:

- Concept C8: Design and procurement schedules should not 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 field of construction industry. The usage of those technologies could overcome the problem of fragmentation into specialized roles in this field to enhance constructability.
- Concept C10: Designs, with design simplification by designers and design review by qualified construction personnel, must be configured to enable efficient construction.
- 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 the 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 construction personnel, materials, and equipment accessibility to the required position inside the site.
- Concept C15: Design should facilitate construction during adverse weather conditions. Great emphasis should be made to planning for the construction of the project under suitable weather conditions; but otherwise, the designer must plan and take into consideration the project elements that could be prefabricated in workshops.

B. Stage of Constructability

The processes of constructability are based on followings [13]:

- Organizing the design team,
- Collecting data,
- Identify the constraints,
- Developing program,
- Framing options evaluation,
- Developing preliminary design,
- Checking of options,
- Final design process,
- Developing bid package,
- Procedure of bidding,
- Procedure of fabrications,
- Installation process.

C. Purpose of Constructability

The objective of constructability is to determine the following items [14]:

- Fault of design either dimension or select materials indistinct features
- The specifications of Project will be difficult or high cost to construct based on design
- Exceeding the project features in capability of industry to properly build
- Project properties that are difficult to understand and also are hard to correctly bid.

III. Buildability Scores (BS) in Singapore

In the Asian arena, Singapore has pioneered with quantifying buildability based on a scheme known as the Buildable Design Appraisal System (BDAS). It has culminated in statutorily requiring building designs to fulfill a Minimum buildability Score since 2001. Under the Building Control Act, the requirement is a prerequisite for approval of submitted building plans. The three key design principles based on which a design is judged for buildability include standardization, simplicity and single integrated elements. The buildability Scores are given according to the relative extent of labor saving that can be achieved by the use of different construction systems. Designs with higher scores are generally more buildable and fewer site workers are needed by the same contractor.

The buildability score is calculated by adding four elements together, namely Structural System (maximum 50 points), Wall System (maximum 40 points), Other Buildable Design Features (maximum 10 points) and Bonus Points to promote single integrated components. The calculation of the buildability Score is based on the formula as shown in Fig.2, [15]. The BDAS was regarded as successful with empirical evidence of correlations between productivity and buildability Score for residential buildings.

IV. Case Study

The project that was selected for this case study is the three story building which is located in Singapore. The properties of this building are illustrated in Table I.

TABLE I: Properties of Building

Location	Singapore
Type of Building	Residential (non-landed)
No. of Story including roof (Typical Story)	3
Area of each Story	126 m^2
Total Floor Area of Apartment	2*126= 378 m^2
Roof Area (assume same as typical floor)	126 m^2
Total Floor Area of Building including Roof Area	378 m^2
Type of Structure	Cast-in-situ
Type of external Wall Design	RC/Brick wall with plaster/paint finishing
Type of internal Wall Design	Traditional brick wall or RC wall

V. Calculation of BS for the Case Study

Buildability score of this building is calculated based on its components such as structure, wall system, size of doors and windows and etc. The result of this calculation was 57.29 over 100.

A. Minimum Buildability Scores in Singapore

The minimum build-ability which will be applied to all building/development is shown in Table II, [16].

Minimum BS for this case is 67. Therefore, the BS of this residential building (57.29) is less than the minimum BS in Singapore (67).

TABLE II: Minimum Buildability Score in Singapore

Category of Building/ Development	2, 000 m^2 ≤ GFA< 5,000m^2	5,000m^2 ≤GFA< 25,000m^2	GFA≥ 25,000 m^2
Residential (landed)	60	65	68
Residential (non-landed)	67	72	75
Commercial	69	74	77
Industrial	69	74	77
School	64	69	72
Institutional and others	60	66	69

VI. Improving Buildability Score

As it mentioned earlier, 15 preconstruction concepts are represented to enhance constructability. Relevant cases are discussed to improve it as followings.

Concept C3 demands for the individuals who have the experience and knowledge for organizing the preliminary stage of project, namely design stage. As a consequence of this concept, the compatibility between design and construction stage would be kept.

Concept C6 emphasizes the analysis of the main construction methods in the conceptual planning phase. As a result, it looks impractical to progress the design stage without regarding to the methods of construction. It means that constructability concepts should be considered in the initial phases of the project.

Concept C11 considers standardization. The standardization should be considered for all elements of this project such as column, slab, beam, and parapets.

Concept C12 organizes the appropriate specifications for the project to improve constructability.

Concept C13 advocates using modules and preassemblies in design.

Finally, Concept C14 asks for accessibility of providing construction personnel, materials and equipments.

The significant point in construction in Singapore is using less number of workers, so that to improve buildability score, this study suggests following systems:

- Precast concrete [PC] construction, (c) PC Slab and Cast-in-situ column/wall/beam
- Precision block wall with plaster/paint finishing,
- Dry Partitions.

TABLE III: Implemented Constructability Concepts

Concept	Application status	Reason of application
Concept C3	Applied	The compatibility between design and construction stage would be kept.
Concept C6	Applied	The designers would be aware to consider constructability concepts in the initial phases of the project.
Concept C11	Applied	Designer would be aware to save cost by standardization.
Concept C12	Applied	Tailoring specifications for each project to promote construction efficiency
Concept C13	Applied	Easing construction tasks
Concept C14	Applied	Minimum usage of workers.

Although there is no tool to measure the exact effect of these concepts in construction projects, they definitely enhance the constructability of the building. For instance, by implementation of the Concept C14 which focuses on use of minimum workers and changing the structure of the building, buildability score will reach to 75.24 which is higher than minimum BS in Singapore.

VII. Recommendations

There are some barriers for implementation of buildability concept which has been investigated by MacDowall as followings [17]:

- Lack of construction experience in the design stage
- Lack of respect between constructors and designers
- Construction input that is requested too late to be of value
- Unwillingness to invest cost in the early stages of a project.

The authors believe that the most important barrier is lack of knowledge and awareness of constructability concept. When designer be aware of benefits of this concept, they persuade the client to invest in design stage or if client be aware of this concept, (s)he will engage the experienced designer and will invest willingly to apply constructability in design stage and avoid design related problems in construction stage.

Awareness and knowledge of constructability should be trained and practiced in academic organization because BDAS and such standards cannot improve the culture and awareness of constructability.

VIII. Conclusion

This paper has discussed the constructability score for a residential building in Singapore. The results obtained from this study confirmed the barriers for implementation of this application during planning and design stages.

The major problems in this phase are; lack of knowledge about constructability concepts, unwillingness to devote extra money for this in initial stages of projects, and shorten of team building and partnering.

In this study, the result of constructability score was less than the standard. In Singapore, it is preferred to benefit from fewer workers during progress of projects. Thus, it is recommended to use precast system instead of Cast-in-Situ RC construction, and also dry partitions for internal wall instead of traditional brick-wall or RC wall. Therefore, by considering the concepts of constructability during design stage, the BS is achieved to standard.

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