DESIGN PHASE CONSTRUCTABILITY CONCEPTS FOR HIGHWAY CONSTRUCTION

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ABSTRACT: Most highway construction projects are characterized by traffic problems, a substantial number of changes, poor planning, disputes, cost overruns, poor safety practices and time delays. An effective constructability review at the design stage has the potential to incorporate into design best practices and lessons learned from previous projects, thereby improving the project constructability. Several studies have indicated that constructability is not being implemented to its full potential in highway construction projects. This study tries to explore the level of constructability implementation in highway projects in the Malaysian construction industry. The degree of importance and application of constructability concepts were investigated. The results show that a total of eighteen design phase constructability concepts have been regarded as important by participants of the construction industry. Despite its importance the level of application of several constructability concepts are found to be not encouraging. The findings of this study formed a basis for the development of design review guidelines for improving constructability of future highway projects in this country.

Keywords: Constructability, Design Phase, Concepts, Highway

1. INTRODUCTION

The government and private agencies that carried out highway project construction are facing the reality that the public will no longer tolerate construction projects that are insensitive to road users and adjacent communities. According to Russell et al. (1992) highway construction projects are characterized by traffic problems, a substantial number of changes, poor planning, disputes, cost overruns, poor safety practices and time delays. Constructability is seen as one of the best solutions to these problems.

Constructability has been defined in a number of ways. Constructability is described as the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives (CII, 1986). Constructability is also defined as the extend to which the design facilitate ease of construction (CIRIA, 1983). Finally, constructability is often portrayed as integrating construction knowledge, resources, technology and experience into the engineering and design of a project (Anderson et al., 2000).

Highway project constructability can be particularly challenging for a variety of reasons. It is known that highway construction technologies are changing rapidly, and, as with most construction, the work force and site conditions can vary greatly. In the local construction industry most projects are tendered out in open competitive bidding, thereby separating the design and construction phases. As a result, designs prepared by the designers often lack of constructability consideration (Rosli Mohamad Zin, 2004).

According to Hugo et al. (1990) constructability is considered an important element for improving project performance. Constructability has been successfully implemented to reduce project durations. Eldin (1996) in his study highlighted several examples of projects that have successfully applied constructability concepts to reduce project durations without increasing project cost. CII (1992) on the other hand analysed five projects that have implemented constructability and reported 11% to 30% reductions in project duration directly attributed to constructability.

In general the concepts for improving constructability of projects vary between one country to the other. It depends on the nature of the construction industry (Rosli Mohamad Zin, 2004). In view of the uniqueness of the Malaysian construction industry this study is conducted with the aim to identify the constructability concepts that are suitable to be implemented in the local highway construction projects. The identification of design phase constructability concepts for highway construction is one of the important steps toward future research in constructability.

2. DESIGN PHASE CONSTRUCTABILITY CONCEPTS

Concept is a significant, distinct and executable objective for enhancing constructability (Nima, 2001). Concepts are not specific or unique with respect to project type or organization. It presents a desperate need and requirement to improve the construction project constructability (O'Connor and Davis, 1988).

Several basic researches on constructability have been developed over the last two decades. The Construction Industries Research and Information Association (CIRIA) initiated one of the early studies in the development of constructability concepts in the UK. CIRIA identified seven concepts of constructability concepts for implementation during design phase and called them "Buildability Concepts" (CIRIA, 1983). The concepts were further explored by Adam (1989).

In the USA, the Construction Industry Institute (CII), which is based in Texas carried out major researches on constructability. CII identified thirteen concepts of constructability to be implemented throughout the project life cycle (CII, 1986). Out of the thirteen constructability concepts, six concepts are meant for implementation during conceptual stage, seven concepts during engineering and procurement stage and one concept during construction stage. From the study that has been done by Rosli Mohamad Zin (2004), there are eighteen constructability concepts that applicable for the design phase. The same study also found that the constructability concepts for building project were almost similar to the one for highway project. The design phase constructability concepts identified by Rosli Mohamad Zin (2004) is a combination of various constructability concepts identified by previous researchers. Thus, it is more thorough and for that reason the concepts have been adopted for the purpose of this study. The following are detail description of the design phase constructability concepts.

1. *Carry Out Thorough Investigation of the Site*

   Constructability is improved when the information gathered from site investigation is thorough and complete. In this context CIRIA recommended that thorough site surveys (including determination of ground conditions, underground hazards and other potential problems) are essential to avoid risk of delays and design changes during construction.

2. *Design for Minimum Time Below Ground*

   Constructability is improved when the design minimize work below ground. The application of this concept is important especially when the ground is hazardous, poor or wet.

3. *Design for Simply Assembly*

   Constructability is improved when designs are simplified and configured to enable efficient construction. Designers should produce the simplest possible details compatible with the overall requirements.

4. *Encourage Standardization/Repetition*

   Constructability is improved when the number of variations of components is kept minimum.

5. *Design for Preassembly and/or Modularisation*

   Constructability is improved when more preassembled and/or modularised components are being used in project.

6. *Analyze Accessibility of the Jobsite*

   Constructability is improved when the accessibility needs is considered during design. The effect of accessibility can sometimes be quite serious such as delay in progress, slowed productivity and increased damaged to completed work.

7. *Employ Any Visualization Tools to Avoid Physical Interference*

   Constructability is improved when visualization tools are employed to visualize any possibility of physical interference during construction. Computer visualization allows investigations to iron out difficulties that may occur before construction commences on site.

8. *Investigate Any Unsuspected Unrealistic or Incompatible Tolerances*
   Constructability is improved when attention should is given to the problems of fit which occur at the interfaces between different products, methods of construction, materials and method of manufacture.

9. *Investigate the Practical Sequence of Construction*
   Constructability is improved when adequate consideration to practical sequence of construction is given. The method of construction of project should encourage the most effective sequence of construction operations. Simple sequences enable each operation to be completed independently and without interruption. The sequence should assist the coordination of trades and minimized delay.

10. *Plan to Avoid Damage to Work by Subsequent Operations*
    Constructability is improved when the damage to work by subsequent operations is considered.

11. *Consider Storage Requirement at the Jobsite*
    Constructability is improved when storage requirement is adequately considered. Consideration should be given during the design stage to be location of material storage and unloading facilities.

12. *Investigate the Impacts of Design on Safety During Construction*
    Constructability is improved when the impact of design on safety during construction is adequately considered. The design produced by the designers should enable the contractor to carry out their works in a safe like manner. The design should be arranged so as to facilitate safe working in works such as foundation and earth works, when materials and components are being handled, and wherever traversing for access is necessary.

13. *Design to Avoid Return Visit by Trade*
    Constructability is improved when the design enable a trade or specialist to complete all its work at a work place with as few return visit as possible.

14. *Design for the Skills and Resources Available*
    Constructability is improved when the technology of the design solution matched with the skills and resources available. With regard to this constructability concept any design is only good as skills available to execute it, either off-site or on-site.

15. *Consider suitability of Designed Materials*

    Constructability is improved when suitable and robust materials are used. Products and materials should be selected with care, particularly, any which have not long been established and accepted within the industry.

16. *Provide detail and clear Design Information*

    Constructability is improved when thorough and clear presentation of design information before the start of construction. Sufficient time and resources must be allowed for this in design budget.

17. *Design for Early Enclosure*

    Constructability is improved when the design enables early enclosure to be achieved. Following operations can then commence early and they can be carried out without hindrance from weather.

18. *Consider Adverse Weather Effect in Selecting Materials or Construction Methods*

    Constructability is improved when the effect of adverse weather is considered. Project constructed in localities where weather conditions are adverse presents a great challenge to both the designer and the constructor. Designers should investigate ways in which the exposure to temperatures extreme and the effects of rain may be minimized.

3. METHODOLOGY

To achieve the objective of the study, the methodologies adopted were through expert interviews and questionnaire surveys. The literature search enables the design phase constructability concepts to be established for highway project. Expert interviews were then conducted with three project managers to confirm the list of design phase constructability concepts identified for highway project. These constructability concepts were used in the questionnaire exercise. The research focuses on highway projects that were tendered out in competitive bidding within the last five years with contract value of more than RM5 million. The questionnaire and interview were targeted to professionals who worked with the clients, contractor or consultant organisations and have direct involvement in highway project construction. For the purpose of analysis of data collected through questionnaire survey the frequency and average index methods have been used.

3.1 Average Index

The data collected on the degree of importance of the design phase constructability principles were tabulated based on the number of response for each category of degree of importance. Based on the frequency analyses the average index was then calculated to determine the ranking of each constructability principles being considered. The average index is calculated as follow (Abd. Majid, 1997):

$$\text{Average Index} = \frac{\sum a_i x_i}{\sum x_i}$$

Where, a_i = constant expressing the weight given to i

x = variable expressing the frequency of response for i = 1,2,3,4,5

Based on the assumed values stated earlier, x_1 = frequency of the "very important" and corresponding to $a_1 = 5$, x_2 = frequency of the "important" and corresponding to $a_2 = 4$, x_3 = frequency of the "moderately important" and corresponding to $a_3 = 3$, x_4 = frequency of the "less important" and corresponding to $a_4 = 2$, and x_5 = frequency of the "not important" and corresponding to $a_5 = 1$.

In order to determine the degree of importance of the constructability principles considered in this study the classification of the rating scales proposed by Abd. Majid (1997) have been used. The classifications of the rating scales are as follows:

Very Important	$4.50 \leq$ Average Index < 5.00
Important	$3.50 \leq$ Average Index < 4.50
Moderately Important	$2.50 \leq$ Average Index < 3.50
Little Important	$1.50 \leq$ Average Index < 2.50
Not Important	$1.00 <$ Average Index < 1.50

For the level of application, x1 = frequency of the "high application" and corresponding to $a_1 = 4$, x_2 = frequency of the "medium application" and corresponding to $a_2 = 3$, x_3 = frequency of the "little application" and corresponding to $a_3 = 2$, x_4 = frequency of the "not apply at all" and corresponding to $a_4 = 1$. The classifications of the level of application are as follows:

High Application	3.50 ≤ Average Index < 4.00
Medium Application	2.50 ≤ Average Index < 3.50
Little Application	1.50 ≤ Average Index < 2.50
Not Applied At All	1.00 < Average Index < 1.50

4. RESULTS AND DISCUSSION

All together, 70 professionals from various companies or organisations were contacted. 35 responded fully to questionnaire, giving a 50 percent of response rate. The characteristics of the respondents in term of type of companies, level of education, position, design and construction experience are given in Table 1 to 5. It can be seen that 49.0% of respondents was employees of consultants followed by contractors (31.0%) and client (20.0%). Thus the respondents are well distributed among the three types of organisations. A relatively high percentage of the respondents (60.0%) hold B.Sc. degree. Designer and planner are the two most common job positions among the respondents. In term of experience most respondents have 5 years or less experience either in design or construction.

The average index analysis results of the survey are shown in Table 6 and 7 and presented more clearly in Figure 1 to 6. It can be seen that the average indices of all concepts are more than 2.5, which shows that all concepts are at least moderately important from the perspective of the contractor, consultant and client. Likewise, the average indices of the level of application of all concepts are also more than 2.5, which indicate that the concepts are in medium to high application from the perspective of the professionals in the Malaysian construction industry.

Table 1. Type of Organisation

Type of Organisation	Percentage (%)
Client	20.0
Contractor	31.0
Consultant	49.0

Table 2. Level of Education

Level of Education	Percentage (%)
B.Sc.	60.0
M.Sc.	17.0
Others	23.0

Table 3. Position

Position	Percentage (%)
Designer	30.0
Planner	43.0
Quantity Surveyor	14.0
Others	23.0

Table 4. Design Experience

Design Experience	Percentage (%)
0-5 yrs	88.6
6-10 yrs	5.6
11-15 yrs	2.9
More than 15 yrs	2.9

Table 5. Construction Experience

Construction Experience	Percentage (%)
0-5 yrs	91.0
6-10 yrs	3.0
11-15 yrs	3.0
More than 15 yrs	3.0

Table 6. The Response of the Overall Respondents on the Level of Importance for Each Design Phase Constructability Concepts

No.	CONSTRUCTABILITY CONCEPTS	Average Indices (Consultant)	Average Indices (Contractor)	Average Indices (Client)
P1	Carry out thorough investigation of the site	4.76	4.64	4.86
P2	Design for minimum time below ground	3.94	3.64	3.86
P3	Design for simple assembly	3.71	3.73	3.43
P4	Encourage standardisation/repetition	3.76	3.82	3.71
P5	Design for pre-fabrication, pre-assembly or modularization	3.53	4.27	3.14
P6	Analyse accessibility of the job site	4.65	4.36	4.43
P7	Employ any visualisation tools such as 3D CAD to avoid physical interferences	3.82	3.91	3.29
P8	Investigate any unsuspected unrealistic or incompatible tolerances	4.18	4.27	3.29
P9	Investigate the practical sequence of construction	4.06	4.64	4.14
P10	Plan to avoid damage to work by subsequent Operations	3.88	4.09	4.29
P11	Consider storage requirement at the job site	4.06	4.73	4.00
P12	Investigate the impact of design on safety during construction	4.35	4.45	4.14
P13	Design to avoid return visit by trades	3.53	3.82	3.43

P14	Design for the skills available	4.06	4.27	3.29
P15	Consider suitability of designed materials	4.24	4.55	4.00
P16	Provide detail and clear design information	4.53	4.73	4.43
P17	Design for early enclosure	3.82	4.00	3.57
P18	Consider adverse effects of weather in selecting materials or construction methods	4.00	3.73	4.14

Note: degree of importance 5=very important; 4=important; 3=moderately important; 2=little important; 1=not important

Table 7. The Response of the Overall Respondents on the Level of Application for Each Design Phase Constructability Concepts

No.	CONSTRUCTABILITY CONCEPTS	Average Indices (Consultant)	Average Indices (Contractor)	Average Indices (Client)
P1	Carry out thorough investigation of the site	3.76	3.64	3.43
P2	Design for minimum time below ground	2.88	2.82	3.14
P3	Design for simple assembly	3.18	3.27	3.00
P4	Encourage standardisation/repetition	3.12	3.00	3.57
P5	Design for pre-fabrication, pre-assembly or modularisation	2.88	2.91	2.71
P6	Analyse accessibility of the job site	3.47	3.18	2.86
P7	Employ any visualisation tools such as 3D CAD to avoid physical interferences	3.65	3.09	2.86
P8	Investigate any unsuspected unrealistic or incompatible tolerances	2.94	3.09	2.86
P9	Investigate the practical sequence of construction	2.82	3.55	3.00
P10	Plan to avoid damage to work by subsequent Operations	3.12	3.27	3.29
P11	Consider storage requirement at the job site	3.35	3.09	3.29
P12	Investigate the impact of design on safety during construction	3.24	3.36	3.14
P13	Design to avoid return visit by trades	2.82	3.18	3.14
P14	Design for the skills available	3.24	3.45	3.29
P15	Consider suitability of designed materials	2.59	3.55	3.29
P16	Provide detail and clear design information	3.41	3.09	3.43
P17	Design for early enclosure	3.06	3.09	2.71
P18	Consider adverse effects of weather in selecting materials or construction methods	3.18	2.91	3.14

Note: degree of application 4=high application; 3=medium application; 2=little application; 1=not applied at all

In the questionnaire survey the design phase constructability concepts identified through literature were used to test the level of importance and application of those concepts in highway projects. Survey results indicate that the levels of importance of the identified design phase constructability concepts are within the moderate to very important range. The results obtained from the survey are in line with the findings of Rosli Mohamad Zin (2004). Therefore, the survey exercise confirmed that eighteen design phase constructability concepts are regarded suitable to be implemented in highway projects. The survey also confirmed that the current levels of applications of those concepts during design phase are at the medium or high application. The followings are the eighteen design phase constructability concepts.

- Principle P1: Carry out thorough investigation of the site;
- Principle P2: Design for minimum time below ground;
- Principle P3: Design for simple assembly;
- Principle P4: Encourage standardisation/repetition;
- Principle P5: Design for pre-assembly and/or modularization;
- Principle P6: Analyse accessibility of the jobsite;
- Principle P7: Employ any visualisation tools such as 3D CAD to avoid physical interference;
- Principle P8: Investigate any unsuspected unrealistic or incompatible tolerances;
- Principle P9: Investigate the practical sequence of construction;
- Principle P10: Plan to avoid damage to work by subsequent operations;
- Principle P11: Consider storage requirement at the jobsite;
- Principle P12: Investigate the impacts of design on safety during construction;
- Principle P13: Design to avoid return visit by trade;
- Principle P14: Design for the skills available;
- Principle P15: Consider suitability of designed materials;
- Principle P16: Provide detail and clear design information;
- Principle P17: Design for early enclosure; and
- Principle P18: Consider adverse weather effect in selecting materials or construction methods.

5. CONCLUSION

This study tries to identify the design phase constructability concepts that are suitable to be implemented in highway construction projects in Malaysia. Through an industry-wide survey eighteen concepts of constructability that the designers need to consider during the design process in order to improve design contructability have been identified. The finding of this study can be considered as an initial step toward improving constructability of future highway construction in this country.

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