CONSTRUCTABILITY DATABASE KNOWLEDGE MODEL AND GUIDELINES OF INDUSTRIAL PLANT AT CONSTRUCTION STAGE

ERMAN SURYA BAKTI

UNIVERSITI TEKNOLOGI MALAYSIA
CONSTRUCTABILITY DATABASE KNOWLEDGE MODEL AND GUIDELINES OF INDUSTRIAL PLANT AT CONSTRUCTION STAGE

ERMAN SURYA BAKTI

A dissertation submitted in partial fulfilment of the requirements for the award of the degree of Doctor of Engineering (Technology and Construction Management)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

MARCH 2012
This research work is dedicated to:
my beloved mother and wife jefni
who I owe them so much for their inspiration and support and to
my children taufiq, faris, miftah and nadiya
who I had to turn down their entertainment just to find more time for this work
ACKNOWLEDGEMENT

Alhamdulillah for every thing I was able to achieve and for everything I tried but I was not able to achieve.

I express my sincere to my main supervisor Professor Dr. Muhd. Zaimi Abdul Majid, co-supervisor Associate Professor Ir. Dr. Rosli Mohamad Zin of Civil Engineering, Universiti Teknologi Malaysia, and industrial-supervisor Ir. Eko Budi Santoso for their assistance, encouragement and valuable guidance during the years of my study. I would like also to thank Associate Professor Dr. Ismail Mohamad of Universiti Teknologi Malaysia for his honest advise on statistics, Dr. Arham Abdullah of Civil Engineering, Universiti Teknologi Malaysia for his advise on web-design, Mardiyono ST. MSc. of Computer Science and Information System, Universiti Teknologi Malaysia for his support on web-design and Dr Bambang Trigunarsyah for his support on paper preparation.

I would like also to thank to PT Rekayasa Industri and affiliate company that give me chance to get the internal project information, support on the questionnaires and expert panel.

Finally, I most thankful and deepest appreciation to my beloved mother for support and encouragement. My beloved wife, Jefni Anggreini and my children Taufiq, Faris, Miftah and Nadiya for their love, great patient and understanding throughout this study.
ABSTRACT

Constructability is a common issue faced by the construction industry which is defined as the ability to construct effectively. The separation of design from procurement and construction in the traditional contracting system has led to a certain degree of isolation of the construction knowledge from design in construction projects. This contracting system has resulted in poor constructability implementation, thus exceeding time and cost of construction projects. This study aimed to provide a constructability database knowledge model and guideline for implementation of industrial plant at construction stage. The objective includes to identify the constructability problems, innovations, best practices and develop the constructability guidelines and database knowledge model. An extensive study was performed in five distinct phases including literature review, interviews, two stages of questionnaire surveys, and four case studies. The first questionnaire was distributed among headquarter of an organization and the second questionnaire was distributed among key personnel of four construction sites. Then four case studies were performed to provide a basis of constructability innovation, best practices, and method statement. Finally, a constructability guidelines and database knowledge model were developed for construction stage. The constructability model was developed based on the consideration both of United States of America and Australia Construction Industry Institute (CII) model. The guidelines developed for this research has referred to the American College of Cardiology tools and methods. Frequency, average index analysis and Wilcoxon rank test statistical techniques were used in this research to analyse the quantitative data. Two organization were selected to validate the findings. The results indicated that the lack of understanding on the overall constructability concept, the availability of lesson learned, and qualified personnel has prevented them from being more committed in implementing the constructability. Despite the above results, current constructability practices have had some benefits on projects’ performance. Not only design-construction interface and early contractor’s involvement were the main factors in improving project performance, but there are also possibilities for significant improvement at the construction stage. The application of this constructability guidelines and database knowledge model were implemented at the organization. It is recommended to improve constructability by adapting constructability concepts which have been developed in other countries but it is necessary to include the following considerations: appropriate construction methods, available resources and, optimum use of lessons learned and best practices. This research is limited on constructability problems, improvement and contracting using the traditional system of industrial plant at construction stage.
ABSTRAK

# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DECLARATION SHEET</td>
<td>ii</td>
</tr>
<tr>
<td></td>
<td>DEDICATION</td>
<td>iii</td>
</tr>
<tr>
<td></td>
<td>ACKNOWLEDGEMENT</td>
<td>iv</td>
</tr>
<tr>
<td></td>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td></td>
<td>ABSTRAK</td>
<td>vi</td>
</tr>
<tr>
<td></td>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td></td>
<td>LIST OF TABLES</td>
<td>xiii</td>
</tr>
<tr>
<td></td>
<td>LIST OF FIGURES</td>
<td>xv</td>
</tr>
<tr>
<td></td>
<td>LIST OF SYMBOLS</td>
<td>xviii</td>
</tr>
<tr>
<td></td>
<td>LIST OF APPENDICES</td>
<td>xix</td>
</tr>
</tbody>
</table>

1 INTRODUCTION 1

1.1 Introduction 1
1.2 Background and Justification of Research 3
1.3 Aim and Objectives of the Study 6
1.4 Research Methodology 7
   1.4.1 Phase 1: Literature Review and Preliminary Data 7
   1.4.2 Phase 2: Questionnaire Survey I 7
   1.4.3 Phase 3: Questionnaire Survey II 10
   1.4.4 Phase 4: Case Studies 10
   1.4.5 Phase 5: Models Development 10
1.5 Scope of the Study 11
1.6 Significant of Research 11
1.7 Structure of Thesis 12
2 CONSTRUCTABILITY PRINCIPLES, PROBLEMS AND KNOWLEDGE DATABASE

2.1 Introduction
2.2 Constructability Definition
2.3 Constructability Principles
2.4 Constructability Development
  2.4.1 Buildability Research in the UK
  2.4.2 Constructability Research in the US
  2.4.3 Constructability Research in Australia
  2.4.4 Constructability Research in Singapore and Hongkong
2.5 Constructability Implementation
  2.5.1 Constructability Benefit
  2.5.2 Constructability Programs
2.6 Constructability Problems
  2.6.1 Traditional Contracting System
  2.6.2 Barriers
2.7 Constructability Guidelines
2.8 Constructability Innovation
2.9 Constructability Best Practices from Lesson Learned Process
2.10 Constructability Database Knowledge Model and Web Application
  2.10.1 Database Knowledge Model
  2.10.2 Web Application at Construction
  2.10.3 PHP and MySQL
2.11 Summary

3 CONSTRUCTABILITY AT CONSTRUCTION STAGE

3.1 Introduction
3.2 Constructability Improvement Research at Construction Stage
  3.2.1 Research by O’Connor and Davis (1998)
  3.2.2 Research by O’Connor and Tucker (1986b)
  3.2.3 Research by O’Connor et al. (1991)
  3.2.4 Research by Turner (1992)
  3.2.5 Research by O’Connor (1987)
  3.2.6 Research by Kartam (1998)
3.2.7 Research by CII (1987); Tatum (1987a); and O’Connor (1986)
3.3 Review of Constructability Improvement Method at Construction Stage
3.4 Summary

4 RESEARCH METHODOLOGY

4.1 Introduction
4.2 Selection of Research Methods
4.3 The Construction Organization and Project Background
4.4 Phase 1: Literature Review and Preliminary Data
4.5 Phase 2: Questionnaire Survey I
  4.5.1 Design of Questionnaire
  4.5.2 Sampling of Respondents
4.6 Phase 3: Questionnaire Survey II
  4.6.1 Design of Questionnaire
  4.6.2 Sampling of Respondents
4.7 Phase 4: Case Studies
4.8 Phase 5: Model and Guidelines Development
4.9 Analytical Methodologies
  4.9.1 Scale of Measurement
  4.9.2 Frequency Analysis and Average Index
  4.9.3 Statistical Test
  4.9.4 Development of the Guidelines
4.10 Summary

5 DATA ANALYSIS AND DISCUSSION

5.1 Introduction
5.2 Phase 2: Questionnaire Survey I - Current Constructability Implementation Practices in the Company
  5.2.1 Organisation Information
  5.2.2 Data Collecting
  5.2.3 Demographics
  5.2.4 Descriptive Analysis of Data
5.2.4.1 Project Goal an Personnel Involvement 127
5.2.4.2 Lesson Learned 129

5.2.5 Constructability Guidelines 130
5.2.5.1 Early involve of Construction Personnel (Construction Knowledge) in the Design 131
5.2.5.2 Overall Construction Schedule are Construction Sensitive 134
5.2.5.3 Modularisation, Preassembly and Standardisation 135
5.2.5.4 Simplified Design Configuration 136
5.2.5.5 Construction Method and Innovation 138
5.2.5.6 Project Performance 138

5.2.6 Barriers and Perception in Constructability Implementation 142
5.2.6.1 Barriers 142
5.2.6.2 Perception and Recommendation on Constructability 144

5.3 Phase 3: Questionnaire Survey II- Project Separate Design, Procurement and Construction at Construction Stage 146
5.3.1 Demographic 147
5.3.2 Constructability Guidelines 150
5.3.2.1 Upfront Involvement of Construction Personnel 151
5.3.2.2 Construction Sensitive Schedule 152
5.3.2.3 Standardisation and Modularization 153
5.3.2.4 Design Facilitate Construction Efficiency 154
5.3.2.5 Innovative Construction Method 155
5.3.2.6 Advance Construction Technology 157
5.3.2.7 Project Performance 158
5.3.2.8 Cause of Delay 159

5.4 Analysis on Implementation of Constructability 160
5.4.1 Constructability Problems 161
5.4.1.1 Project Performance 161
5.4.1.2 Constructability Barriers 164
5.4.2 Input to Database Knowledge Improvement Model 165

5.5 Summary 166
6 DOCUMENTED CONSTRUCTABILITY INNOVATION AND GUIDELINES AT PROJECT LEVEL : CASE STUDIES

6.1 Introduction 168
6.2 Case Study Methodology 169
6.3 Project Constructability Innovation 169
   6.3.1 The Construction Organization Background 170
   6.3.2 Case Study 1: Constructability Implementation for Innovation of Pipe Rack Structure.
      6.3.2.1 Project Description 170
      6.3.2.2 Innovation Process 171
      6.3.2.3 Innovative Construction Method 174
      6.3.2.4 Innovation Result 177
   6.3.3 Case Study 2: Constructability Implementation for Innovation of Sea Water Intake Structure
      6.3.3.1 Project Description 178
      6.3.3.2 Innovation Process 179
      6.3.3.3 Innovative Construction Method 182
      6.3.3.4 Innovation Result 183
   6.3.4 Case Study 3: Constructability Improvement during Construction Stage at Project level
      6.3.4.1 Project Description and Background 185
      6.3.4.2 Constructability Problems 187
      6.3.4.3 Case Study 3 Result: Constructability Problem Identification Model and Guidelines 193
   6.3.5 Case Study 4: Lesson Learned and Best Practices 195
      6.3.5.1 Project Description and Background 196
      6.3.5.2 Existing Lesson Learned and Best Practices 197
      6.3.5.3 Constructability Guidelines 204
6.4 Summary 206

7 CONSTRUCTABILITY GUIDELINES AT CONSTRUCTION STAGE

7.1 Introduction 208
7.2 Constructability Guidelines 208
7.2.1 Guidelines for Constructability Problems Identification Model 209
7.2.2 Guidelines for Constructability Improvement 213
7.2.3 Guidelines for Constructability Best Practices 219
7.3 Summary 223

8 CONSTRUCTABILITY DATABASE KNOWLEDGE AND INNOVATION PROCESS MODEL 225
8.1 Introduction 225
8.2 Constructability Innovation Model 226
8.3 Model Development 228
  8.3.1 Existing Web-based 229
  8.3.2 Constructability Knowledge Database Model (CKDM) 233
  8.3.3 Web-base View 238
8.4 Summary 245

9 CONCLUSIONS AND RECOMMENDATIONS 246
9.1 Introduction 246
9.2 Conclusions 247
9.3 Research Achievements 253
9.4 Limitation of Research 254
9.5 Recommendation to the Organization and Future Research 254

REFERENCES 256
Appendices A-G 265-316
## LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>The Principles of constructability</td>
<td>20</td>
</tr>
<tr>
<td>2.2</td>
<td>Constructability implementation effectiveness parameters (O’Connor, 1994)</td>
<td>35</td>
</tr>
<tr>
<td>2.3</td>
<td>Characteristics of effective barrier breakers (O’Connor et al., 1995)</td>
<td>41</td>
</tr>
<tr>
<td>2.4</td>
<td>Material management responsibility matrix (CII, 2001)</td>
<td>57</td>
</tr>
<tr>
<td>3.1</td>
<td>Constructability improvement classifications</td>
<td>84</td>
</tr>
<tr>
<td>4.1</td>
<td>Grouping of the questionnaire analysis</td>
<td>107</td>
</tr>
<tr>
<td>4.2</td>
<td>Constructability factors coding questionnaire-1</td>
<td>109</td>
</tr>
<tr>
<td>4.3</td>
<td>Constructability factors coding questionnaire-2</td>
<td>111</td>
</tr>
<tr>
<td>5.1</td>
<td>Respondent experience</td>
<td>125</td>
</tr>
<tr>
<td>5.2</td>
<td>Project goal</td>
<td>127</td>
</tr>
<tr>
<td>5.3</td>
<td>Construction management team capability</td>
<td>128</td>
</tr>
<tr>
<td>5.4</td>
<td>Engineering team capability</td>
<td>128</td>
</tr>
<tr>
<td>5.5</td>
<td>Rank of project control team capability</td>
<td>129</td>
</tr>
<tr>
<td>5.6</td>
<td>Rank of implementation of lesson learned</td>
<td>129</td>
</tr>
<tr>
<td>5.7</td>
<td>Identified implementation factor</td>
<td>121</td>
</tr>
<tr>
<td>5.8</td>
<td>Early involvement construction knowledge during design stage from designer view</td>
<td>132</td>
</tr>
<tr>
<td>5.9</td>
<td>Early involvement construction knowledge during design stage from Constructor view</td>
<td>133</td>
</tr>
<tr>
<td>5.10</td>
<td>Rank of construction sensitive in design and schedule</td>
<td>134</td>
</tr>
<tr>
<td>5.11</td>
<td>Rank of using of preassembly and modularisation in design and planning</td>
<td>135</td>
</tr>
<tr>
<td>5.12</td>
<td>Rank of Standardisation</td>
<td>135</td>
</tr>
<tr>
<td>5.13</td>
<td>Rank of Constructability is enhance when design are configure to</td>
<td>136</td>
</tr>
</tbody>
</table>
enable efficient construction

5.14 Rank of Design are consider for construction efficiency 136
5.15 Rank of Site accessibility 137
5.16 Design consider site condition and weather 138
5.17 Rank of Construction Method and Innovation 138
5.18 Rank of Quantitative Project Performance in execution 139
5.19 Rank of Quantitative Project Performance in cost and schedule 140
5.20 Rank Qualitative Project Performance. 140
5.21 Rank of barrier to implement the constructability 142
5.22 Rank for Saving 144
5.23 Rank of Perception if Constructability be implemented 145
5.24 Rank of Perception to increase the personnel construction knowledge 146
5.25 Cross-tabulation count for Engineering and Construction experiences 148
5.26 Type of the projects 149
5.27 Type of the organization 149
5.28 Upfront involvement of construction personnel gap rank. 151
5.29 Construction Sensitive Schedule gap rank 153
5.30 Standardisation and Modularisation gap rank 154
5.31 Design facilitate construction efficiency gap rank 155
5.32 Innovative Construction Method gap rank 156
5.33 Advance construction technology gap rank 157
6.1 Major volume comparison of Pre-cast Concrete and Steel Structure 177
   Pipe Rack
6.2 Site Conditions and Risks of Conventional Method 181
6.3 Drawing Revision 189
8.1 Constructability Innovation Process 226
8.2 Existing and Recommended Database 233
8.3 Brief of Work Breakdown Structure ID 237
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Research Methodology</td>
<td>8</td>
</tr>
<tr>
<td>2.1</td>
<td>Constructability Improvement during Conceptual Planning</td>
<td>24</td>
</tr>
<tr>
<td>2.2</td>
<td>Framework for determining constructability benefit (adapted from Russell, 1994b)</td>
<td>29</td>
</tr>
<tr>
<td>2.3</td>
<td>Constructability Implementation Roadmap (CII, 1986)</td>
<td>33</td>
</tr>
<tr>
<td>2.4</td>
<td>Traditional approach to construction project development (Goldhaber, 1997, adopted from Trigunarsyah 2001)</td>
<td>39</td>
</tr>
<tr>
<td>2.5</td>
<td>The Constructability System (Griffith and Sidwell, 1995, adopted from Trigunarsyah, 2001)</td>
<td>45</td>
</tr>
<tr>
<td>2.6</td>
<td>The Organisation Constructability Program (CII, 1987)</td>
<td>47</td>
</tr>
<tr>
<td>2.7</td>
<td>Implementation stages for innovation (Slaughter, 2000)</td>
<td>50</td>
</tr>
<tr>
<td>2.8</td>
<td>Innovation in construction firm (Tatum, 1987b)</td>
<td>51</td>
</tr>
<tr>
<td>2.9</td>
<td>Lesson Learned Process (Goodrum et al., 2003)</td>
<td>54</td>
</tr>
<tr>
<td>2.10</td>
<td>Process-centered view model (Fayyad et al., 1996)</td>
<td>65</td>
</tr>
<tr>
<td>2.11</td>
<td>Knowledge discovery in database process model (Li and Ruan, 2007)</td>
<td>66</td>
</tr>
<tr>
<td>2.12</td>
<td>Database Management System (DBMS) System layout (Li Jili, 2006)</td>
<td>66</td>
</tr>
<tr>
<td>2.13</td>
<td>Information Flow of Constructability Review Process Model</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>(Fisher et al., 2000)</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Ability to Influence Final Cost over Project Life (CII US, 1986)</td>
<td>77</td>
</tr>
<tr>
<td>4.1</td>
<td>Process Flow Questionnaire Survey</td>
<td>106</td>
</tr>
<tr>
<td>4.2</td>
<td>Case Study Process Flow</td>
<td>112</td>
</tr>
<tr>
<td>4.3</td>
<td>Case Study Method (adopted from Yin, 1994)</td>
<td>113</td>
</tr>
<tr>
<td>4.4</td>
<td>Convergence of Multiple Sources of Evidence (adopted from Yin, 1994)</td>
<td>113</td>
</tr>
<tr>
<td>4.5</td>
<td>Summary of Case Studies Flow</td>
<td>114</td>
</tr>
</tbody>
</table>
4.6 Statistical Data and Test Flow
5.1 Distribution of respondent experiences
5.2 Respondent Engineering/Design experiences in year
5.3 Respondent Construction experiences in year
5.4 Specialization of the Respondent
5.5 Position of the Respondent
5.6 Rank of Upront involvement of construction personnel
5.7 Rank of Construction sensitive schedule
5.8 Rank of Standardisation and modularisation
5.9 Rank of Design facilitate construction efficiency
5.10 Rank of Innovative construction method
5.11 Rank of Advance construction technology
5.12 Project Performance
5.13 Cause of Delay
6.1 Innovation process for Pre-cast concrete Pipe-rack
6.2 Typical Column beam fix connection
6.3 First innovation: Pre-cast concrete pipe rack as reference
   (Petrochemical Project, pin connection and combine with steel bracing)
6.4 Second innovation: One layer pre-cast concrete pipe rack
   (Fertilizer Project, fix connection without bracing)
6.5 Pre-cast concrete column-beam: Three dimension planning and installation
6.6 Pre-cast column view: During installed and completed
6.7 Overview: Part of Refinery project
6.8 Conventional SWI construction Method
6.9 New Innovative SWI Construction Method
6.10 Innovative new method: piling, sheet piling, excavation and concreting from onshore
6.11 Chronological project schedule
6.12 Historical of revision drawing and Key personnel change
7.1 Fish bone diagram Brainstorming
7.2 Breakdown Subcontracting problems
7.3 Breakdown Method problems
7.4 Breakdown Manpower problems
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5</td>
<td>Breakdown Logistic and Support problems</td>
<td>212</td>
</tr>
<tr>
<td>7.6</td>
<td>Breakdown Machines/ Construction Equipment Problems</td>
<td>213</td>
</tr>
<tr>
<td>8.1</td>
<td>Constructability Innovation Process Model</td>
<td>227</td>
</tr>
<tr>
<td>8.2</td>
<td>Existing web view Knowledge Center</td>
<td>229</td>
</tr>
<tr>
<td>8.3</td>
<td>Existing web view Lesson Learned Engineering</td>
<td>229</td>
</tr>
<tr>
<td>8.4</td>
<td>Existing web view Lesson Learned Project</td>
<td>230</td>
</tr>
<tr>
<td>8.5</td>
<td>Existing web view Project document online system-overall</td>
<td>230</td>
</tr>
<tr>
<td>8.6</td>
<td>Existing web view Project document online system- Project level 1</td>
<td>231</td>
</tr>
<tr>
<td>8.7</td>
<td>Existing web view Project document online system- Project 1</td>
<td>231</td>
</tr>
<tr>
<td>8.8</td>
<td>Existing web view Project document online system- Project 1-detail</td>
<td>232</td>
</tr>
<tr>
<td>8.9</td>
<td>Existing web view Project document online system- Project 1-document list</td>
<td>232</td>
</tr>
<tr>
<td>8.10</td>
<td>Proposed Constructability Databased Improvement Model (CKDM)</td>
<td>234</td>
</tr>
<tr>
<td>8.11</td>
<td>Use case for Administrator</td>
<td>235</td>
</tr>
<tr>
<td>8.12</td>
<td>Flow System Interface-Administrator 1 of 2</td>
<td>236</td>
</tr>
<tr>
<td>8.13</td>
<td>Flow System Interface- Administrator 2 of 2</td>
<td>236</td>
</tr>
<tr>
<td>8.14</td>
<td>Flow System Interface- Non Administrator Menus</td>
<td>237</td>
</tr>
<tr>
<td>8.15</td>
<td>View proposed Webbased: Home</td>
<td>239</td>
</tr>
<tr>
<td>8.16</td>
<td>View proposed Webbased: The content</td>
<td>239</td>
</tr>
<tr>
<td>8.17</td>
<td>View proposed Webbased: Definition</td>
<td>240</td>
</tr>
<tr>
<td>8.18</td>
<td>View proposed Webbased: Knowledge Focus (limitation)</td>
<td>241</td>
</tr>
<tr>
<td>8.19</td>
<td>View proposed Webbased: Workflow</td>
<td>242</td>
</tr>
<tr>
<td>8.20</td>
<td>View proposed Webbased: Knowledge database</td>
<td>242</td>
</tr>
<tr>
<td>8.21</td>
<td>View proposed Webbased: Construction Specification</td>
<td>243</td>
</tr>
<tr>
<td>8.22</td>
<td>View proposed Webbased: Method Statement</td>
<td>243</td>
</tr>
<tr>
<td>8.23</td>
<td>View proposed Webbased: Edit Menu (Administrator 1 of 3)</td>
<td>244</td>
</tr>
<tr>
<td>8.24</td>
<td>View proposed Webbased: Edit Menu (Administrator 2 of 3)</td>
<td>244</td>
</tr>
<tr>
<td>8.25</td>
<td>View proposed Webbased: Edit Menu (Administrator 3 of 3)</td>
<td>245</td>
</tr>
</tbody>
</table>
# LIST OF SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Ind.</td>
<td>Average Index</td>
</tr>
<tr>
<td>CO2</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>Std. Dev</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>a&lt;sub&gt;i&lt;/sub&gt;</td>
<td>constant expressing the weight given to &lt;i&gt;i&lt;/i&gt;</td>
</tr>
<tr>
<td>x&lt;sub&gt;i&lt;/sub&gt;</td>
<td>variable expressing the frequency of response for &lt;i&gt;i= 1,2,3,4,5&lt;/i&gt;</td>
</tr>
<tr>
<td>3D</td>
<td>Three Dimension</td>
</tr>
</tbody>
</table>
# List of Appendices

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Interview guide</td>
<td>265</td>
</tr>
<tr>
<td>B</td>
<td>Questionnaire Survey Form 1</td>
<td>268</td>
</tr>
<tr>
<td>C</td>
<td>Questionnaire Survey Form 2</td>
<td>282</td>
</tr>
<tr>
<td>D</td>
<td>Sample of Constructability Brainstorming at Construction stage</td>
<td>289</td>
</tr>
<tr>
<td>E</td>
<td>Sample of Method Statement and Job Safety Analysis</td>
<td>296</td>
</tr>
<tr>
<td>F</td>
<td>Work Breakdown Structure</td>
<td>302</td>
</tr>
<tr>
<td>G</td>
<td>Summary/ Samples of Statistical Calculation- SPSS</td>
<td>311</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Introduction

Increased competitiveness in the construction industry requires improvement of a construction organization’s capabilities. Many studies in quality improvement focus on project quality improvement technique and efficiency such as total quality management, value engineering, designability, contractibility, constructability, operability, maintainability and other quality improvement techniques (Trigunarsyah, 2001). Early involvement of construction knowledge and experience reduce the likelihood of creating designs that cannot be efficiently built, thereby reducing design rework, improving project schedule, and establishing construction cost saving (Russell, 1994b).

Many construction projects are awarded on a competitive basis using the traditional contract approach. In this approach, design (or engineering), procurement and contractor are engaged in separate contracts. The Business Roundtable (1982) and Tatum et al. (1987) presented that the contractors are usually not involved until the designs have been completed, this approach ignores opportunities of significant savings in both project cost and completion time that result from the careful interaction of planning, design, and engineering with construction. This division has been suggested to be responsible for poor constructability in construction projects (Griffith, 1984) and has been cited as a reason for projects exceeding budgets and schedule datelines (CIIA, 1992). A careful interaction of planning, design (or
In the US, the CII (1998) has developed 17 Constructability Concepts, which are grouped under the three main phases of Project Life Cycle, viz. conceptual planning, design and procurement, and construction. Those concepts were based on the experience of the owners and contractors represented by the CII Constructability Task Force, and the findings of researchers directed by the CII Constructability task force. The main purpose of the concept is to stimulate thinking about constructability and how to make it work. The second CII Constructability Task Force appended three additional concepts, two for the planning phase and one for the design and procurement phases (Russell et al., 1992).

The concept of constructability in the US (or buildability in the UK) emerged in the late 1970s. It evolved from studies into how improvements could be achieved to increase cost efficiency and quality in the construction industry. It is an approach that links the design and construction process. It became the subject of a number of research works in the 1980s (Sidwell, 1996). Constructability is the capability of a construction project being constructed. A Constructability program is the application of a disciplined, systematic optimization of the construction-related aspects of a project during the planning, design, procurement, construction, test and start-up phase by knowledgeable, experienced construction personnel who are part of a project team, the program’s purpose is to enhance the project’s overall objectives (ASCE CM Committee, 1991). Constructability is also defined as the ability of project condition to enable the optimal utilization of construction resources (O’Connors, 1986b).

The constructability concept was born out of the realisation that designers and contractors see the same project from different perspectives, and optimising the project that requires the knowledge and experience of both parties be applied to project planning and design processes (Gibson, 1996). However, many owners, engineers, and contractors are still not aware of the potential benefits of improved constructability, the opportunities to reduce the schedule, improve the functionality of the final product, and reduce costs are lost when construction is separated from planning and engineering (CII, 1996).
The CII has developed 'Constructability Concepts' to stimulate idea about constructability and how to make it implement, the CII has also shown benefits of implementing constructability, especially in terms of project cost and schedule (Trigunarsyah, 2001). In implementing improvement in constructability, the study by the Australian Construction Industry Institute (Francis and Sidwell, 1996) suggests that it is important to consider the uniqueness of the construction industry in a specific country. The separation of design from procurement and construction in the construction process has led to a certain amount of isolation of the professionals from technical development in the construction industry (Jergeas, 1989; Haider, 2009).

In this study the constructability problems during construction due to the separation of design from procurement and construction, method statement, constructability innovation at project level, project lesson learned, best practices have been identified and investigated. A conceptual guidelines to improve the constructability implementation during construction stage was formulated. The result of this research provides a constructability guideline and constructability improvement model using web-based platform. This research focuses on constructability (or buildability) for implementation at project level during construction stage.

1.2 Background and Justification of Research

The traditional contracting system is a common contracting method used in Malaysia and Indonesia, the traditional approach to construction projects tends to create divisions between design (or engineering) and construction. Russel (1992a) reported in the UK and the US have suggested that this division has led to poor constructability in construction projects, resulting in projects exceeding budgets and schedule. Following these reports, research work in improving constructability was conducted both in the UK and the US which showed that improved constructability can lead to significant savings in both the cost and time required for completing projects and the CICE Task Force of the Business Roundtable has shown benefit-cost
ratios of 10:1 to 20:1 from incorporating construction resources into engineering using a planned constructability program (Trigunarsyah, 2001).

Later case studies by the CII have also indicated a benefit-cost ratio of 10:1 on projects implementing more formal constructability programs, it is believed that this ratio is an underestimation because it was based only on documented and quantified estimates of savings, a significant reduction in total project schedule is also identified as the result of improved project constructability, this case studies showed 5 to 10 per cent reductions in total project duration (Russell, 1992a).

In the UK, research in improvement in constructability stressed the design phase and the designer’s ability to incorporate constructability, but no emphasis was placed on management systems and the involvement of owners and contractors. In the US, the constructability researchers placed emphasis on management systems and the involvement of owners and contractors. They considered constructability to be an integral part of the whole project life cycle. The Construction Industry Institute (CII), which is the leader in this area, has established 17 concepts of constructability and guidelines on programs for implementing constructability (Trigunarsyah, 2001).

Further research work on the implementation of constructability improvements has shown significant benefits in terms of project costs and schedules. However, it is important to consider the type of construction when implementing the CII’s constructability concepts. Russell (1992b) suggested that there are differences in how and when specific constructability concepts can be applied, based on the facility delivery process or, in other words, on the type of the construction, i.e. residential, buildings, heavy engineering or industrial. The study by the Australian CII (Francis and Sidwell, 1996) went even further. Their starting point was that in implementing constructability improvements, it is important to consider the uniqueness of the construction industry in a specific country. The CIIA used the CII’s constructability concepts as references and examined them against Australian conditions. Their research findings resulted in twelve principles that embody the overriding concepts of constructability. They represent what are considered as current good practices in constructability in Australia, and are designed to stimulate thought about constructability and its application within the Australian construction industry.
In Indonesia, most public work projects, including construction projects under government authority or under state-owned companies (BUMN), are awarded on a competitive basis using a lump-sum contract. Professional designers and constructors are engaged in separate contracts. The contractors are usually not involved until the designs have been completed. This division has been suggested to be responsible for the poor constructability of construction projects in Indonesia, leading to projects exceeding budgets and schedule deadlines. Furthermore, most project planning and design is prepared in the national capital, Jakarta. Infrastructure projects throughout the country, for example, are planned and designed in Jakarta. Similarly, many companies such as banks plan and design their branch offices in their head office in Jakarta, and contractors are not involved until after the contract has been awarded. Problems arise during construction where buildings or facilities cannot be built as planned and designed, or cannot be constructed efficiently. It is not uncommon that construction projects exceed budgets and schedules. With improved constructability both the cost and time required to complete projects are expected to be reduced (Trigunarsyah, 2001).

In the Malaysian Construction Industry, there is no distinction between practiced and unpracticed and between the known and the unknown requirement for enhancing constructability. This is due to mainly to the lack of reliable documentation of cases in which those requirements are applied or ignored (Nima, 2000). The construction industry in Malaysia is renowned for its lack of integration between design and construction (Mohd.Zin, 2004).

As suggested by the research findings in the US, Australia, Indonesia and Malaysia, implementation of constructability improvement has to consider the uniqueness of the construction industry in a specific country. Therefore, construction projects shall be studied to improve the constructability in Indonesian and Malaysia.

From the above discussion, it is clear that there is a need to improve the constructability. This research is a continuity of the constructability research from Trigunarsyah (2001), and Bakti (2002) in Indonesia and this organization for Industrial Plant project. This research is the incremental implementation of constructability. It start from awareness of the personnel involvement, and construction
method at construction stage. This approach will mobilize the organization to implement constructability formally for all stages of design, procurement and construction.

Due to the separation above design and construction in the traditional contracting system the designs that are being produced have minimum construction input. This has resulted in a lot of problems which are related to execution at the construction stage. On the other side, the lack of construction experiences and procedures especially in construction method has resulted in poor constructability implementation that lead to project exceeding budget and schedule. To minimize the gap, this research started to implement the constructability from the construction methods as “a trigger”, followed by its adoption by the organization for implementing the constructability concepts at all stages of the projects.

1.3 Aim and Objectives of the Study

This study aimed to develop constructability database knowledge model and guidelines for the constructability implementation of industrial plant at construction stage. The study focussed on the projects that were tendered using the traditional contracting system. The innovation and improvement method if implemented would minimize or overcome the construction related problems.

To achieve the above aim the following objectives have been identified:

1. To identify the constructability problems at construction stage due to separation of design from procurement and construction;
2. To identify and establish the constructability innovation process at project development;
3. To identify and establish the project best practices from the lesson learned process related to constructability;
4. To establish the constructability guidelines at construction stage; and
5. To develop the constructability database knowledge model using web-base platform for construction stage.
1.4 Research Methodology

Research methodology guides the researcher in the process of collecting, analyzing, interpreting and observing. It is a logical model of proof that allows researchers to draw inferences concerning relations among the variable under investigation. To respond to the aim and objectives of this research, Figure 1.1 outlines the methodology of this study.

There are five distinct phases of the study: phase 1 involves literature review and preliminary data; phase 2 and 3 deals with data collection and analysis using interview, two stage of questionnaire survey 1 and 2; phase 4 involves the case studies and, phase 5 comprises developing the constructability guidelines and database knowledge model. Detailed discussion of the research methodology is given in Chapter-4.

1.4.1 Phase 1: Literature review and Preliminary Data

Phase 1 is aimed at reviewing information on construction implementation, problems, constructability/ buildability principles, constructability improvement method, and previous research that has already been conducted at the organization, to establish the problem area. Interviews were performed for the study on the organization.

1.4.2 Phase 2: Questionnaire Survey I

In order to determine the constructability problems, potential and actual benefit of constructability, the following survey and data collection were performed:

1. A self administered questionnaire survey was used to acquire the perception of the key personnel of the project (owner and contractor) on the implementation of constructability at construction stage.
Figure: 1.1: Research Methodology
2. The case studies were used to support the constructability guidelines, documented innovation process and database knowledge model.

The first questionnaire survey was focussed on the understanding of the various disciplines on implementation and improvement in constructability and its impact/ problems on project performance. The questionnaires were distributed among three key personnel of construction projects namely engineering team, procurement
team and construction team. The questionnaire survey was conducted mostly in the organization main office. Data obtained from the survey was tested in a series of statistical tests which include validity, reliability, normality data test, frequency analysis, average severity index, and non parametric test using SPSS software package.

1.4.3 Phase 3: Questionnaire Survey II

Similar to the above survey, the second questionnaire survey more focused on constructability implementation at construction stage and also the gap between potential and actual benefit of constructability implementation. This second questionnaire survey was distributed to the four (4) main industrial plant projects of organization in Malaysia and Brunei that used traditional contracting system.

1.4.4 Phase 4: Case Studies

Case studies were used to investigate the implementation of constructability improvement in the organization. This case study aimed to support the questionnaire survey result and to answer the fourth and fifth of the research objectives. There are selected four case studies in this research.

1.4.5 Phase 5: Models Development

The analyse results obtained from Phase 1, 2, 3 and 4 formed the basis for development of constructability guidelines, innovation process and database knowledge model using web-base platform.
1.5 Scope of the Study

This research focused on constructability (or buildability) for implementation at project level during construction stage. The specific research was carried out on project execution at the organization related to constructability implementation, improvement and innovation at construction stage. The first questionnaire was developed to obtain the implementation of the constructability practices for all stages of process from the design, procurement and construction. The second questionnaire on the other hand focussed on the current implementation of the project at the construction stage to identify the gap of the potential and actual benefit of the constructability implementation. This research limited on: first, the type of the projects carried out based on the traditional contracting system i.e. the design was seperated from procurement and construction; second, narrowing at the construction stage only and; third, the project type was Industrial Plant. On the other hand, the case studies were performed to get an insight on the real implementation and to explore the project document to be proposed as guidelines and knowledge database to the organization. As such constructability improvement for other phases throughout the project life cycle are not covered.

1.6 Significance of Research

The separation of design (or engineering), procurement and construction leads to poor of project performance. The over design, drawing inaccuracy and delay are part of the poor project performance related to separation of design, procurement and construction. The findings of this research show a significant impact can be achieved from constructability improvement at construction stage.

The constructability innovation had the documented cost saving and reduced the time. The qualitative benefits of constructability innovation include: reduction of time schedule; increased focus on common goal; increased understanding of purpose/ effect of individual involvement; increased commitment from team member;
improved quality and site accessibility; safety enhancement; and better control of risks.

The main contribution of this study to the body of knowledge falls under the following aspects: first, the study give emphasis on identifying the constructability problems due to traditional contract and support of the constructability theory and practice; second, to provide and establish constructability innovation process, guidelines and database knowledge model using web-base platform to the organization and construction industry. This research would implement constructability from the construction methods as “a trigger”, followed by its adoption by the organization to implement constructability at all stages of the projects.

1.7 **Structure of the Thesis**

This thesis consists of nine chapters. A review of the relevant literature is given in Chapters 2, 3, and 4. To achieve the aim of this research, the thesis starts with an overview of the constructability principles and improvement in Chapter 2. This chapter begins with a discussion of the definition of constructability. This is followed by a description of constructability principles, constructability development, constructability implementation program, improvement and innovation. The principles of constructability suitable for implementation were referred particularly from publication of the Construction Industry Institute (CII) of US, Australia, Singapore and Construction Industry Research Information Association (CIRIA) of UK. Other important sources of reference included journals and conferences papers.

Chapter 3 then discusses constructability improvements in construction stage and also discusses the common problem of separation of design from construction resulting from the current construction process, particularly from the selection of project delivery approaches. This division has led to poor constructability of projects, which has been suggested as a reason for projects exceeding budgets and schedule.
Chapter 4 describes the research methodology adopted in the study. This Chapter sets the concept of the research that leads to the establishment of the methodology to answer the objectives of the research. Methods for answering these questions were then selected and discussed. The first method assessed current constructability practices using a questionnaire survey distributed to the organization, i.e. the engineering, procurement and construction division of the organisation. The second questionnaire focussed on the project using traditional contracting system at construction stage. The respondents were selected from the key construction personnel at project site. This chapter also reviews the analytical methodologies and statistical analysis used in this research.

Chapter 5 gives details of the questionnaire survey, and the results obtained. The second method used case studies to provide the basis for achieving the fourth and fifth research objectives. The selection of the case study projects, the work done on them and the results obtained are described in Chapter 6.

Chapter 7 discusses the constructability guidelines. This will lead to the conclusions of this research, the constructability knowledge model using web-base platform which are presented in Chapter 8.

Finally Chapter 9 concludes the research and brings forward recommendations for future studies.
REFERENCES


Li, Tian Rui. and Da Ruan (2007). An extended process model of Knowledge Discovery in Database. *Journal of Enterprise Information Management* Vol. 20 No. 2, 169-177


