Development of a Knowledge-Based Energy Damage Model for Evaluating Industrialised Building Systems (IBS) Occupational Health and Safety (OHS) Risk

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ABSTRACT

Malaysia’s construction industry has been long considered hazardous, owing to its poor health and safety record. It is proposed that one of the ways to improve safety and health in the construction industry is through the implementation of ‘off-site’ systems, commonly termed ‘industrialised building systems (IBS)’ in Malaysia, which require fewer workers on-site. This is deemed safer, based on the risk concept of reduced exposure; however, no method yet exists for determining the relative safety of various construction methods, including IBS.

This thesis presents a comparative evaluation of the occupational health and safety (OHS) risk presented by different construction approaches, namely IBS and traditional methods. The evaluation involved developing a model based on the concept of ‘argumentation theory’, which helps construction designers integrate the management of OHS risk into the design process. In addition, an ‘energy damage model’ was used as an underpinning framework.

Development of the model was achieved through three phases. Phase I involved collection of data on the activities involved in the construction process and their associated OHS risks, derived from five different case studies, field observation and interviews. Knowledge on design aspects that have the potential to impact on OHS was obtained from document analysis. Using the knowledge obtained in Phase I, a model was developed in the form of argument trees (Phase II), which represent a reasoning template with regard to options available to designers when they make judgements about aspects of their designs. Inferences from these aspects eventually determined the magnitude of the damaging energies for every activity involved. Finally, the model was validated by panels of experts (Phase III), and revisions and amendments were made to the model accordingly.

The model provides a means of evaluating OHS risk among construction workers, which could help designers understand the extent to which their design decisions may impact on OHS and thereby assist them to reduce the risk to an acceptable level. The development of the risk assessment model represents structured knowledge that designers can draw on when making judgments about OHS risks, in the form of argument trees. The model was categorized into several damaging energies, which provides a way to evaluate the risk from start to finish.

The research revealed that different approaches/methods of construction projects carried a different level of energy damage, depending on how the activities were carried out. A study of the way in which the risks change from one construction process to another shows that there is a difference in the profile of OHS risk between IBS construction and traditional methods. For example, the potential gravitational damaging energy for certain activities in the in-situ concrete and masonry method can be removed or reduced by the use of IBS/off-site methods such as the wall panel system and the panellised system. This is compatible
with other researchers’ claims that IBS/off-site is safer and carries significantly less risk in traditional construction.

This thesis contributes to knowledge by suggesting options available to product and process designers that allow them to assess the extent to which their design decisions reduce OHS risk in construction, and offering a more rigorous comparison of the OHS risks in IBS and traditional approaches. It is anticipated that the model may provide a way for designers to integrate process knowledge and awareness of safety and OHS risk variables into design to eliminate or reduce hazards in construction.

**Keywords:** IBS, OHS in construction, knowledge-based energy damage model, off-site construction
# TABLE OF CONTENTS

Abstract..................................................................................................................................i  
Acknowledgments...............................................................................................................iii  
Table of contents..................................................................................................................iv  
List of figures.......................................................................................................................xi  
List of tables........................................................................................................................xv  
List of abbreviations.......................................................................................................xviii  

1 INTRODUCTION.................................................................................................................1  
1.1 Introduction.......................................................................................................................1  
1.2 Research context..............................................................................................................1  
1.2.1 Malaysia’s construction industry accident rates .........................................................1  
1.2.2 The relative safety of IBS ..........................................................................................2  
1.2.3 The concept of ‘designing for safety’ and IBS .............................................................3  
1.3 Research purposes .........................................................................................................4  
1.3.1 Research questions and objectives ............................................................................5  
1.3.2 Scope and limitations of the study .............................................................................5  
1.4 Overview of research process ..........................................................................................6  
1.5 Significance of the study ..................................................................................................7  
1.6 Organization of the thesis ...............................................................................................8  
1.7 Summary ..........................................................................................................................10  
1.8 Ethics ...............................................................................................................................11  

2 HEALTH AND SAFETY PERFORMANCE AND ACCIDENT CAUSALITY.............................................................................................................12  
2.1 Introduction.......................................................................................................................12  
2.2 Occupational health and safety (OHS) in construction and the importance of OHS study........................................................................................................................................12  
2.2.1 Disproportionate injury and illness rates ........................................................................12  
2.2.2 High cost of construction accidents .............................................................................15  
2.2.3 Legal requirements ......................................................................................................17  
2.2.4 Types of accidents .......................................................................................................20
2.3 Accident causation .................................................................26
  2.3.1 Definitions of safety and accident .....................................26
  2.3.2 Accident causation models ...............................................27
  2.3.3 Two-factor model ..........................................................28
  2.3.4 Reason’s Accident Trajectory Theory .................................29
  2.3.5 Generic health and safety causation model - ConCA model ...32
  2.3.6 Energy release theory (Haddon, 1973) ...............................34
  2.3.7 Energy damage model (Viner, 1991) .................................33
  2.3.8 Accident causes ............................................................38
2.4 Summary ..............................................................................40
3 INITIATIVES TO IMPROVE OHS PERFORMANCE ..................41
  3.1 Introduction .........................................................................41
  3.2 Safety performance measurement .........................................41
  3.3 Safety management technique and control system ..................44
    3.3.1 Safety culture ...............................................................45
  3.4 Construction as a manufacturing process ..............................47
  3.5 Risk management in occupational health and safety ...............49
    3.5.1 Risk management steps in OHS .....................................51
  3.6 Designing for safety ............................................................54
    3.6.1 Designing for construction safety ....................................54
    3.6.2 Designer’s role to influence safety through design ..........55
    3.6.3 Existing designing for construction safety tools/research ....56
  3.7 Background of ToolSHeD and argument trees .......................59
    3.7.1 Knowledge-based systems and their limitations ...............59
    3.7.2 Argument trees ............................................................60
  3.8 Argumentation theory .........................................................61
    3.8.1 Argumentation and Toulmin’s argument structure (TAS) ....61
    3.8.2 Variations of TAS application ........................................63
    3.8.3 The application of GAAM ..............................................64
  3.9 Summary .............................................................................68
4  INDUSTRIALISED BUILDING SYSTEMS (IBS) IN MALAYSIA ..........69
4.1 Introduction .................................................................................69
4.2 Overview of Malaysian construction industry .........................69
4.3 Definition of IBS and other related terms .................................73
4.4 IBS Classification and Categorisation .........................................76
  4.4.1 Precast concrete framed buildings .......................................78
4.4.2 Formwork systems .................................................................78
4.4.3 Steel framing system ...............................................................79
4.4.4 Prefabricated timber framing system .....................................79
4.4.5 Blockwork system .................................................................79
4.4.6 Innovative ................................................................................80
4.5 IBS Development in Malaysia ...................................................81
  4.5.1 Chronology of IBS Development in Malaysia .......................81
4.5.2 Status of IBS contactors and manufacturers ...........................82
4.5.3 IBS and the Degree of Industrialisation ..................................83
4.6 The phases of IBS construction ................................................86
4.7 Benefits of IBS ...........................................................................88
4.8 IBS Impact upon Safety and Health ..........................................91
  4.8.1 Safety, health and IBS ..............................................................91
4.8.2 Recent research relating IBS to safety and health .....................93
4.8.3 Accident Causation model for IBS .........................................95
4.9 Concluding remark of the literature review– theoretical background for thesis development .............................................................98
4.10 Summary ....................................................................................99
5  RESEARCH METHODOLOGY .................................................100
5.1 Introduction ...............................................................................100
5.2 Research approaches ..................................................................101
5.3 Research design ..........................................................................102
  5.3.1 Case study research overview ..............................................107
5.3.2 Model validation ......................................................................113
5.4 Phase I - Knowledge acquisition ..............................................116
5.4.1 Research context and details of case studies.................................116
5.4.2 Field observation..........................................................................118
5.4.3 Interviews......................................................................................119
5.4.4 Document analysis.........................................................................121
5.5 Phase II - Development of argument trees......................................123
  5.5.1 Knowledge processing.................................................................123
  5.5.2 Argumentation (Argument trees mapping).................................126
5.6 Validation of the model (Phase III)..................................................129
  5.6.1 Expert panel validation survey.....................................................131
  5.6.2 Validate and revise tool.................................................................135
5.7 Application of the model...................................................................136
5.8 Summary............................................................................................139

6 CONSTRUCTION PROCESS SAFETY RISKS: CASE STUDIES.........140
  6.1 Introduction.......................................................................................140
  6.2 Phase I – Data gathering.................................................................140
  6.3 Case study 1.....................................................................................141
    6.3.1 Background of the project..........................................................141
    6.3.2 Reasons for choice of construction method...............................143
    6.3.3 Process and associated risks involved in the ‘delivery’ works.........145
    6.3.4 Process and associated risks involved in the ‘manufacturing’ works. 146
  6.4 Case study 2.....................................................................................148
    6.4.1 Background of the project..........................................................148
    6.4.2 Reasons for choice of construction method...............................150
    6.4.3 Process and associated risks involved in the ‘manufacturing’ works. 153
    6.4.4 Process and associated risks involved in the ‘delivery’ works.........155
    6.4.5 Process and associated risks involved in the ‘component installation’
          works.........................................................................................156
    6.4.6 Process and associated risks involved in the ‘insitu works’ stage.....157
  6.5 Case study 3.....................................................................................158
    6.5.1 Background of the project..........................................................158
    6.5.2 Reasons for choice of construction method...............................160
6.5.3 Process and associated risks involved in the ‘manufacturing’ works……..162
6.5.4 Process and associated risks involved in the ‘delivery’ works…………….162
6.5.5 Process and associated risks involved in the ‘component installation’
works...........................................................................................................162
6.5.6 Process and associated risks involved in the ‘in situ’ works………………164
6.6 Case study 4............................................................................................165
6.6.1 Background of the project.................................................................165
6.6.2 Reasons for choice of construction method.......................................167
6.6.3 Process and associated risks involved in the ‘manufacturing’ works……170
6.6.4 Process and associated risks involved in the ‘delivery’ works………….171
6.6.5 Process and associated risks involved in the ‘component installation’
works.............................................................................................................172
6.6.6 Process and associated risks involved in the ‘in-situ’ works…………….173
6.7 Case study 5............................................................................................174
6.7.1 Background of the project.................................................................174
6.7.2 Process and associated risks involved in the ‘manufacturing’ works……178
6.7.3 Process and associated risks involved in the ‘delivery’ works………….179
6.7.4 Process and associated risks involved in the ‘component installation’
Works.............................................................................................................180
6.8 Discussion...............................................................................................181
6.9 Summary.................................................................................................184
7 KNOWLEDGE-BASED ENERGY DAMAGE MODEL (ARGUMENT
TREES)..................................................................................................................185
7.1 Introduction .............................................................................................185
7.2 Phase II....................................................................................................186
7.2.1 Formulating design aspects for reasoning purposes in the argument trees….187
7.2.2 Translation into argument trees..........................................................189
7.3 Matters related to the development of the argument tree process………..197
7.3.1 The process of translating the knowledge into argument trees – summary ...197
7.3.2 Argument trees (tool) output and features........................................198
7.3.3 Argument trees assessment...............................................................201
7.3.4 Significance of the tool.......................................................................202
8 VALIDATION OF THE MODEL ..........................................................208
8.1 Introduction..................................................................................208
8.2 Phase III......................................................................................208
8.3 Validation survey..........................................................................209
8.3.1 Validation survey procedure.....................................................214
8.4 Results of the validation survey: Revising the tool......................218
8.4.1 Content validity- proximity with tool and expert scores...........218
8.4.2 Inter-rater Reliability- IRA scores............................................226
8.4.3 Amendments on the tree...........................................................229
8.5 Discussion....................................................................................238
8.6 Summary......................................................................................241
9 APPLICATION OF THE TOOL (MODEL)........................................242
9.1 Introduction...................................................................................242
9.2 Comparative analysis of case attributes.......................................243
9.2.1 Risk profiles throughout the construction process – an overview...244
9.2.2 Risk profile of gravitational damaging energy..........................245
9.2.3 Risk profile of kinetic damaging energy......................................250
9.2.4 Risk profile of chemical energy................................................253
9.2.5 Risk profile of vibration energy..................................................255
9.2.6 Risk profile of electrical energy................................................257
9.2.7 Risk profile of noise energy.........................................................259
9.3 Other aspects of the application of the tool.................................261
9.3.1 Form of sensitivity analysis of the argument tree.....................261
9.3.2 ‘Exposure’ measure.................................................................263
9.4 Discussion....................................................................................264
9.4.1 Sophisticated risk assessment tool (3D risk assessment)..........264
9.4.2 Process-focused.........................................................................265
9.4.3 Time-variable risk assessment model.......................................267
9.4.4 Multiple-risk view ................................................................. 268
9.5 Summary ............................................................................. 269

10 CONCLUSION ............................................................................. 270

10.1 Introduction ........................................................................... 270
10.2 Achievement of the objectives ............................................. 270
  10.2.1 Objective 1 ................................................................. 271
  10.2.2 Objective 2 ................................................................. 272
  10.2.3 Objective 3 ................................................................. 273
  10.2.4 Objective 4 ................................................................. 274
10.3 Contribution to knowledge ................................................... 274
  10.3.1 The development of a risk management tool .................. 274
  10.3.2 An understanding of the IBS construction risks ............. 276
  10.3.3 An understanding of the impact of IBS upon construction – implication of the research .................................................................................................................... 276
  10.3.4 Implications for industry ............................................... 278
  10.3.5 Significance of methodology ....................................... 279
10.4 Limitations of the study ....................................................... 280
10.5 Publications from the study ................................................. 282
10.6 Recommendations for future research ............................... 282

References ..................................................................................... 284

Appendix A ....................................................................................... 305
Appendix B ....................................................................................... 324
Appendix C ....................................................................................... 326
Appendix D ....................................................................................... 336
Appendix E ....................................................................................... 338
Appendix F ....................................................................................... 344
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Flow diagram of the research process</td>
<td>7</td>
</tr>
<tr>
<td>1.2</td>
<td>Structure of the thesis</td>
<td>10</td>
</tr>
<tr>
<td>2.1</td>
<td>Accident statistics (based on types of accidents) in construction industry reported to DOSH for the year 2002-2009 – Fatality</td>
<td>23</td>
</tr>
<tr>
<td>2.2</td>
<td>Accident statistics (based on types of accidents) in construction industry reported to DOSH for the year 2002-2009 - Non-fatality</td>
<td>24</td>
</tr>
<tr>
<td>2.3</td>
<td>The Two-factor model - adapted from Reason (1990)</td>
<td>28</td>
</tr>
<tr>
<td>2.4</td>
<td>Reason’s accident trajectory model- adapted from Reason (1990) to reflect construction</td>
<td>31</td>
</tr>
<tr>
<td>2.5</td>
<td>ConCA model (Haslam et al., 2003)</td>
<td>33</td>
</tr>
<tr>
<td>2.6</td>
<td>Energy Damage Model (Source: Guide to Best Practice for Safer Construction (RMIT, 2009); Adapted from Viner, 1998))</td>
<td>35</td>
</tr>
<tr>
<td>2.7</td>
<td>Opportunities for injury or damage intervention (Source: : Pryor et al., 2009)</td>
<td>36</td>
</tr>
<tr>
<td>3.1</td>
<td>The transitions of safety performance indicators (Source: Jafri et al., 2005)</td>
<td>43</td>
</tr>
<tr>
<td>3.2</td>
<td>Risk management process (adapted from HB205-2004 as in Lingard, Stranieri, &amp; Blismas (2006))</td>
<td>51</td>
</tr>
<tr>
<td>3.4</td>
<td>Time/safety influence curve (Szymberski, 1997)</td>
<td>55</td>
</tr>
<tr>
<td>3.5</td>
<td>Factors affecting implementation of designing for safety (Source: Gambatese et al. (2005))</td>
<td>56</td>
</tr>
<tr>
<td>3.6</td>
<td>Example of Toulmin Argument Structure (TAS), adapted from TAS to represent construction</td>
<td>63</td>
</tr>
<tr>
<td>3.7</td>
<td>GAAM Family Law example (As cited in Muecke &amp; Stranieri (2007))</td>
<td>64</td>
</tr>
<tr>
<td>3.8</td>
<td>The TAS that underlies knowledge representation in Split Up</td>
<td>65</td>
</tr>
<tr>
<td>3.9</td>
<td>Section of Split-Up Argument tree (Stranieri, Yearwood, &amp; Zeleznikow, 2002)</td>
<td>66</td>
</tr>
<tr>
<td>3.10</td>
<td>The inference procedure of ToolSHED (Cooke et al., 2008)</td>
<td>67</td>
</tr>
<tr>
<td>4.1</td>
<td>IBS Thrust in the CIMP 2006-2015</td>
<td>72</td>
</tr>
</tbody>
</table>
Figure 6.11 The activities involved when using a column-wall panel system...........152
Figure 6.12 Production of precast column offsite..............................................159
Figure 6.13 Building construction in progress..................................................159
Figure 6.14 Four-storey hostel construction......................................................159
Figure 6.15 The activities involved in the construction of the precast frame system...161
Figure 6.16 Variety types of blocks (Source: Manufacturer’s website – withheld for anonymity).................................................................166
Figure 6.17 Production facility of the CMU blocks.............................................166
Figure 6.18 Construction of the project using blockwork system.......................167
Figure 6.19 Another view of the blockwork system..........................................167
Figure 6.20 The activities involved in the construction of walls using the dry Blockwork system.................................................................169
Figure 6.21 A view of the manufacturing facility................................................175
Figure 6.22 Slab ready to accept the panels (Source: Manufacturer’s website – withheld for anonymity).................................................................175
Figure 6.23 Panel is being lifted into place by crane (Source: Manufacturer’s website – withheld for anonymity).................................................................176
Figure 6.24 The activities involved in a construction of the lightweight wall panelized system..................................................................................177
Figure 7.1 Steps in developing the argument tree model.................................185
Figure 7.2 Example of the argument tree structure...........................................190
Figure 7.3 Child node and parent node in the argument tree............................190
Figure 7.4 Assigning linguistic and numerical value........................................191
Figure 7.5 Inference procedure.......................................................................192
Figure 7.6 Example of the inference procedure...............................................193
Figure 7.7 Argument tree showing the inference procedure of the potential damaging energy for loading components or material onto a truck........................................195
Figure 7.8 Sample argument tree showing inferences......................................198
Figure 7.9 Example of the confirmation of design inclusion prior to assessing the tree..............................................................................................200
Figure 8.1 Model validation framework (reproduced for convenience)..............209
Figure 8.2 Example of the selection of design options to form scenario features...211
Figure 8.3 Analysis of the participants’ demographic........................................217
Figure 8.4 Example of amended argument trees for lifting element.................231
Figure 8.5  Example of amended argument trees for lifting element

Figure 8.6  Example of amended argument trees for concreting, vibrating and surface finishing

Figure 8.7  Example of amended argument trees for concreting, vibrating and surface finishing

Figure 8.8  Example of amended argument trees for scaffolding works

Figure 8.9  Comparison of participants’ average score and the tool-generated scores for each case study scenario

Figure 9.1  Cross-case evaluation process

Figure 9.2  Risk profile - gravitational energy

Figure 9.3  Risk profile - kinetic energy

Figure 9.4  Risk profile - chemical energy

Figure 9.5  Risk profile - vibration energy

Figure 9.6  Risk profile - electrical energy

Figure 9.7  Risk profile - noise energy

Figure 9.8  Selection of design options to reduce the risk

Figure 9.9  Example of modifying the argument tree to a lower risk level

Figure 9.10 Example of the use of three variables used to form the argument tree

Figure 9.11 Example of the process assessment argument trees for assessing gravitational energy damage at the manufacturing stage

Figure 9.12 Example of multiple-risk view of column-wall panel system
LIST OF TABLES

Table 2.1  Percentage ratio of number of fatalities in construction industry to the total fatalities reported to DOSH for the year 2007, 2008 and 2009.............................................13
Table 2.2  Costs associated with disabling injuries and fatalities in the US construction industry........................................................................................................16
Table 2.3  Types of accident and its description .............................................................21
Table 2.4  Description of damaging energies (Source: Safetyline Institute, 2005)...................36
Table 3.1  Some perspectives on safety indicators when measuring safety performance........................................................................................................43
Table 4.1  Classification of offsite system for different countries........................................77
Table 4.2  Level of industrialised production and definition (Source: Gibb, 1999)............77
Table 5.1  Research approaches and designs (Adapted from Fellows & Liu (2008)).............................102
Table 5.2  Relevant situation for different research design or strategy (Source: Yin (2009))..........................................................103
Table 5.3  Research objective and research design..........................................................105
Table 5.4  Types of case studies (Source: Jensen & Rodgers (2001)).................................108
Table 5.5  Details of case studies..........................................................................................112
Table 5.6  Sources of Evidence: Strengths and Weaknesses (Source: Yin (2009))............117
Table 5.7  Information gathered during data collection.....................................................118
Table 5.8  Key individuals of interviews..................................................................................121
Table 5.9  Example of the damaging energies for delivery works using an IBS column-wall panel system................................................................................................124
Table 5.10 Some example of the references of secondary sources in delivery stage......................................................................................125
Table 5.11 Panel of experts details.......................................................................................132
Table 5.12 Results of validation survey for Case A................................................................136
Table 6.1  Damaging energies for delivery during the in situ concrete and masonry method.................................................................145
Table 6.2  Damaging energies for in-situ works using a conventional insitu concrete and masonry method.................................................................147
Table 6.3  Damaging energies for manufacturing works using IBS column-wall panel system.................................................................................................................................154
Table 6.4  Damaging energies for delivery works using the IBS column-wall panel system.................................................................................................................................156
Table 6.5  Damaging energies for component installation works using the IBS column-wall panel system...............................................................................................................157
Table 6.6  Damaging energies for in-situ works using the IBS column-wall panel system.................................................................................................................................158
Table 6.7  Damaging energies for installation works using the precast frame system.................................................................................................................................163
Table 6.8  Damaging energies for in-situ works of the precast frame system...........164
Table 6.9  Damaging energies for manufacturing of the dry blockwork system........171
Table 6.10 Damaging energies for delivery of the dry blockwork system.................172
Table 6.11 Damaging energies for installation works using the dry blockwork system...173
Table 6.12 Damaging energies for in-situ works using the dry blockwork system........174
Table 6.13 Damaging energies involved in manufacturing of panelized system.........179
Table 6.14 Damaging energies for delivery of panelized system...............................181
Table 6.15 Damaging energies for on-site installation works using the lightweight panelised system.................................................................................................................180
Table 7.1  Factors considered for developing argument trees for delivery of components to site.................................................................................................................................188
Table 7.2  Number of relevant factors within tree from which the damaging energies are inferred.................................................................................................................................199
Table 8.1  Description of cases in case study scenarios..............................................210
Table 8.2  Different features in Case A scenarios.......................................................213
Table 8.3  Demographic profile of the participants.....................................................215
Table 8.4  Different features in Case B.................................................................219
Table 8.5  Different features in Case C.................................................................221
Table 8.6  Different features in Case D.................................................................222
Table 8.7  Different features in Case E.................................................................224
Table 8.8  Results from the tool-generated score and participants’ mean score on each case study scenario.................................................................225
Table 8.9  Results from the tool-generated score, participants’ mean score and inter-rater agreement (IRA) within participants’ scores for each case study scenario.......................229
Table 9.1  Comparison of the case studies...............................................................243
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOWEC</td>
<td>Building Operation of Work Engineering and Construction</td>
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<td>CIDB</td>
<td>Construction Industry Development Board</td>
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<td>CIMP</td>
<td>Construction Industry Master Plan</td>
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<td>DOSH</td>
<td>Department of Occupational Safety and Health</td>
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<td>FMA</td>
<td>Factory and Machinery Act</td>
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<td>IBS</td>
<td>Industrialised Building Systems</td>
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<td>KBS</td>
<td>Knowledge-Based Systems</td>
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<td>MMC</td>
<td>Modern Method of Construction</td>
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<td>OHS</td>
<td>Occupational Heath and Safety</td>
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<td>OSHA</td>
<td>Occupational Safety and Health Act</td>
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<td>SOCSO</td>
<td>Social Security Organization</td>
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<td>TAS</td>
<td>Toulmin’s Argument Structure</td>
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<tr>
<td>ToolSHeD</td>
<td>Tool for Safety and Health in Design</td>
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</tbody>
</table>
1 INTRODUCTION

1.1 Introduction

Malaysia’s construction industry has been long described as a dangerous industry, in view of its poor health and safety performance. One initiative of the Malaysian government to address occupational health and safety (OHS) in construction is the widespread adoption of Industrialized Building Systems (IBS), commonly termed ‘offsite’ construction. An IBS approach is commonly deemed to be safer than conventional construction because it changes the nature of the construction process, and requires fewer workers onsite. This assumption is based on the risk concept of reduced exposure to hazards; however, no method yet exists for determining the relative safety of various construction methods, including IBS, compared to traditional in-situ methods. This study explores the impact of IBS on construction workers’ safety and health by a thorough investigation of the activities and associated risks in IBS and traditional construction, with the aim of providing a comparative evaluation of the OHS risks involved in different construction approaches.

This introductory chapter presents the context of the research, including the aims and objectives. It outlines the research methodology, and describes the structure of the thesis.

1.2 Research context

1.2.1 Malaysia’s construction industry accident rates

The Malaysian construction industry plays a significant role in the development and growth of the country’s domestic economy, generating further demands for construction activities (Abdullah & Wern, 2011; Hamid, Majid, & Singh, 2008; Seyyed Shahab Hosseinian, 2012). However, the industry has earned the reputation of being a highly hazardous industry due to its high rates of accidents and fatalities (Abdullah & Wern, 2011; Seyyed Shahab Hosseinian, 2012). There is therefore an urgent need to improve health and safety performance of Malaysia’s construction industry.
Accident statistics for the Malaysian construction industry, as reported in the Social Security Organization (SOCSO) Annual Report, are too high (Foo, 2005; SOCSO, 2000, 2009). The most recent figures produced by the Department of Occupational Safety and Health (DOSH) reveal that twenty-two (22) out of sixty-six (66) fatality cases were attributed to the construction industry (DOSH, 2013). These reports, as explained in section 2.1, provide clear evidence that the industry is one of the critical sectors in need of a significant and rapid overhaul to its current site safety practices (Hamid et al., 2008). This thesis suggests that understanding the hazards within different construction processes, such as IBS, will provide critical new information that can help improve construction health and safety.

1.2.2 The relative safety of IBS

Of the many initiatives that could be implemented to improve OHS performance, offsite construction (commonly termed IBS in Malaysia) has been suggested as a replacement to traditional construction methods (CIDB, n.d., 2007). The Malaysian government is actively promoting the adoption of IBS and encouraging a paradigm shift in the construction process, from a traditional to an industrialized approach. This is demonstrated by the promulgation of the Construction Industry Master Plan (CIMP) 2006-2015 (CIDB, 2007), which specifically mentions IBS and its implementation through IBS Roadmaps.

The nature of activities in IBS differs from that of traditional processes. IBS is an industrialized process in which components of a building are conceived, planned, and fabricated, and then transported to and erected on site (Junid, 1986). Claims have been made that IBS, or more specifically offsite construction, can reduce site accidents (Gibb, 1999; Toole & Gambatese, 2008; Gangolells, Casals, Forcada, Roca, & Fuertes, 2010; McKay, 2010). However, the extent of this impact on safety and health in construction is still unclear, as there are no current systems to comparatively assess OHS risks in different construction processes. McKay (2012) has identified the OHS risks of both onsite and the offsite processes, but presents a static assessment that lists hazards of specific processes, rather than comparing the extent of the risks of the various processes. There is therefore a need for a robust dynamic method for comparing different construction processes, such as IBS and traditional approaches, to determine the relative safety and health performance of these
processes. Further, the context of the Malaysian construction industry needs to be superimposed on this methodology as current work is centred on developed industries such as the UK/Europe, US and Australia.

1.2.3 The concept of ‘designing for safety’ and IBS

The benefits of IBS can be better understood if viewed as a change from the traditional design of construction products and processes. This is because, moving from traditional construction methods to IBS changes the process, and the changing design decisions may affect the significance of a particular safety risk. Different construction processes possess different hazards and risks. Therefore, by integrating construction process knowledge into design process, hazards and risks during construction can be eliminated or reduced through process change. The decision to use a particular construction method happens at the design stage, when designers put forward the construction method that offers potential OHS risk reduction throughout the construction process. This is in line with the concept of ‘designing for safety’, where all safety aspects are considered during the design process, with the aim of reducing or eliminating hazards during construction (Behm, 2005). The ‘designing for safety’ concept is implicit in product design, therefore many studies relating to ‘designing for safety’ imply product design, rather than process design. This study focuses on process design, which provides options for designers on how to build the product, thus adding value to the current body of knowledge.

In Malaysia, initiatives for addressing safety in the design phase are defined in the Master Plan for Occupational Safety and Health in Construction Industry 2005-2010 (CIDB, n.d.) and Occupational Safety & Health Master Plan for Malaysia 2015 (Ministry of Human Resources, n.d.). Some of the positive recommended actions addressing OHS are related to ‘designing for construction safety’ and include education in OHS concepts, and providing guidelines for clients to have safety and health design checks put in place before construction (CIDB, n.d.; Ministry of Human Resources, n.d.). However, it is doubtful that Malaysian construction designers adequately understand how to identify, assess and control OHS risks in their designs. This assumption is based on the ‘nature of the job/responsibility’, in which designers are usually not involved in or responsible for OHS. Therefore, it is vital to have a
structure that can assist Malaysian construction designers to better integrate OHS risk management into the design process.

In order to evaluate and compare the OHS risks throughout traditional and IBS construction processes, a structured method incorporating specialist OHS knowledge and guidance is required. An ‘argumentation theory model’ (Toulmin, 1958; as cited in Yearwood & Stranieri, 2006) building on the work of Cooke, Lingard, Blismas, & Stranieri (2008) is proposed as a method to integrate the management of occupational health and safety risk into the design process. Cooke et al.’s work was developed from structured knowledge in the context of uncertainty and discretionary decision making, involving expert reasoning regarding design impacts on OHS risk represented by ‘argument trees’ (Cooke et al., 2008). Their model explored the use of argumentation theory in product design, which focused on the implementation of physical aspects of the design. This thesis presents the development of a process-centric model that consists of a series of argument trees for best practice reasoning that can be used by designers or decision makers when examining the OHS risks posed in different construction processes. The argument trees consist of knowledge which were developed by focusing on the process involved to build a product in various construction processes. The model provides consideration of product and process design concurrently, thus contributing to the body of knowledge. In addition to Cooke et al.’s model, an ‘energy damage model’ (Viner, 1991) is used as an underpinning framework for developing the present model. The development of this model suggests options for the decisions that can be made by product and process designers, in such a way as to assess the extent to which their design decisions mitigate the OHS risk in construction, and thereby offering a more rigorous relative comparison of OHS risks between IBS and traditional approaches.

1.3 Research purposes

This section outlines the research question and objectives, with a description of the scope and limitations of the research.
1.3.1 Research question and objectives

There is a crucial need to address the problem of the impact of IBS on health and safety for performance improvement, leading to the research question:

‘How can the relative OHS risks of IBS versus traditional construction processes be determined?’

In order to answer this question, the study aims to develop a paper-based prototype model derived by modelling best practice reasoning used by designers\(^1\) or decision makers. This requires integrating construction process knowledge into design to eliminate hazards and reduce risks during construction in both IBS and traditional approaches.

The proposed solution to this problem is contingent upon completing the following objectives:

1. To map the major activities of the construction process in both IBS and traditional residential construction (in Malaysia and Australia) and identify the OHS risks associated throughout the construction process.
2. To identify process design features that potentially impact on the OHS risks of the specific construction process.
3. To develop an OHS risk assessment model based on argumentation theory and underpinned by the energy damage model to provide a comparative OHS risk rating for different delivery processes.
4. To validate the model using an expert panel.

1.3.2 Scope and limitations of the study

The scope of this study encompasses the occupational health and safety risks (OHS) of IBS and traditional projects for residential building construction. The reason for focusing

\(^1\) Designers are defined as those who, as part of their work, prepare design drawings, specifications, bills of quantities, and the specification of articles and substances, i.e., architects, engineers, and quantity surveyors (CDM Regulations, 2007).
on residential projects is to discount the possible variation due to irregular structural layout plans if other types of projects such as shopping centres, universities, and schools are considered. Moreover, residential projects have typical structural layout plans and are repetitive, even though variation may occur. This makes direct comparison between building systems more representative and unbiased (Abdul Kadir, Lee, Jaafar, Sapuan, & Ali, 2006).

This study covers the major hazards (damaging energies) involved in building construction using both IBS and traditional approaches. The determination of the major hazards was justified from reviews of the safety performance of building construction in Malaysia (section 2.2.4). The types of accident in construction have changed little over the years with construction having a higher proportion of falls and moving/falling objects accidents. The case study approach used in this thesis analyzes five construction projects (four in Malaysia and one in Australia) representing both IBS and traditional processes covering the structure and envelope of the building. This thesis focuses on the Malaysian construction context, and uses an Australian case for comparative and validation purposes.

1.4 Overview of research process

This section provides a brief overview of the research process for this study. A flow diagram of the process (Figure 1.1) includes the main research steps, which are the literature review, collection of data for the case study (phase I), development of the model to evaluate risks (phase II), and verification of the model (phase III). A detailed description of the research approach used for this study is presented in Chapter 4.

A thorough literature review on OHS performance, accident causality, and some initiatives to improve OHS performance in the construction industry indicated a need for performance improvement using IBS construction methods. An appropriate research strategy and associated methods were selected. The research questions were reviewed, and the aim and objectives of the research were confirmed before proceeding to the collection of data.

Five individual case studies were selected for data collection purposes. This involved field observation of live case study projects to explore working practices, interview key
personnel, and analyze documents. The data were processed and reviewed by the case study companies for verification. The main findings from the case study analysis work enabled the development of a model to evaluate the construction risks for different construction processes. A panel of experts was used to validate the model.

**Figure 1.1:** Flow diagram of the research process

### 1.5 Significance of the study

This study contributes to the topic by providing a way for designers to integrate construction process knowledge into design in order to eliminate or reduce hazards during construction. The study also contributes to the knowledge of safe design for construction processes, in contrast with existing research focus on the product design, i.e. ToolSHEd (Cooke et al., 2008). The outcome of this study is a paper-based prototype developed by modeling best practice reasoning used by designers or decision makers when examining the OHS risks posed by their designs, and is capable of assessing the OHS risks in both...
traditional and IBS construction. The fundamental idea is to encourage construction
designers or decision makers to address safety in the design process and encourage them to
examine carefully the probable OHS risk variables involved in the construction process. The
model also fills gaps in existing risk assessment models.

1.6 Organization of the thesis

The thesis consists of nine chapters. A brief overview of the content of each chapter
is presented below. Figure 1.2 graphically illustrates the structure of the thesis.

Chapter 1 – Introduction. This chapter introduces the thesis, and provides a synopsis of
the aims and objectives, as well as justification for the research. It also presents an overview
of the research process and methodology.

Chapter 2 – Health and safety performance and accident causality. A review of health
and safety performance, extracted from the published literature is presented in this chapter.
Construction accident types and a review of health and safety accident causation are
discussed.

Chapter 3 – Initiatives to improve OHS performance. This chapter presents a review of
some initiatives to improve OHS performance, emphasizing the concept of “designing for
construction safety”.

Chapter 4 – Industrialized Building Systems (IBS) and their implementation in
Malaysia. A review of IBS in Malaysia is presented including its terminology and role in
health and safety, and government promotion in regard to OHS improvement in the
Malaysian construction industry.

Chapter 5 – Research methodology. The strategies and methods adopted for this study are
discussed in this chapter.

Chapter 6 – Construction process safety risks: case studies. This chapter presents the
collection of case study data, using field observation, interviews, and document analysis.
The construction activities and risks for different construction processes are identified and evaluated. The results have informed development of the model.

**Chapter 7 – Knowledge-based energy damage model (argument trees).** This chapter presents the model, which is intended to assist construction designers in considering the OHS risks posed in the construction process. The model is presented in the form of argument trees.

**Chapter 8 – Validation of the model.** This chapter presents the discussion on the model validation process.

**Chapter 9 – Application of the tool (model).** This chapter demonstrates the application of the model in real case studies.

**Chapter 10 – Conclusion.** This chapter concludes the thesis, presenting conclusions drawn from the findings and recommendations for further study.
1.7 Summary

This chapter has presented the research context and the aims and objectives of the thesis. It has provided an overview of the study’s contribution to knowledge, and outlined the structure and organization of the chapters, setting out the means by which final conclusions will be made.
1.8 Ethics

The Human Research Ethics Committee at RMIT University approved the ethics application for the collection of data in July 2011. The approval letter from the committee is reproduced in Appendix A. The documents relating to data collection, such as the plain language statement (letter for recruitment of participants), consent form, and interview protocol are also given in Appendix A. The author also obtained statements of willingness to participate in the research from the organizations involved.
2 HEALTH AND SAFETY PERFORMANCE AND ACCIDENT CAUSALITY

2.1 Introduction

The first chapter introduced the research and outlined the aims, objectives and the justification of the research. This chapter provides a background to the safety literature pertaining to the research topic. It commences with an overview of occupational health and safety (OHS) in construction before suggesting a theoretical approach for the research related to several key theories of accident causality. The following chapter (Chapter 3) resumes the theoretical approach with regard to the initiatives to improve OHS performance in the construction industry.

2.2 Occupational health and safety (OHS) in construction and the importance of OHS study

The construction industry is renowned as a high-risk industry which involves complex, time consuming design and construction processes characterized by unforeseen circumstances and has been plagued with accidents for a long time (Ren, 1994). The major causes of accidents include the nature of the industry, human behaviour, difficult work-site conditions and poor safety management and cultures, which result in unsafe work methods, equipment and procedures (Abdelhamid & Everett, 2000). This section elaborates on the importance of OHS research.

2.2.1 Disproportionate injury and illness rates

The high occupational injury rate in the construction industry is not limited to one region, but is evident across the globe. For some countries, the fatality and disability rates may be declining, but it is undeniable that there is a highly disproportionate injury and fatality rate in the construction industry.
In Malaysia, safety and health performance in the construction industry has lagged behind most other industries as evidenced by its disproportionally high rate of accidents compared to other industries (Social Security Organization (SOCSO) Annual Report, 2000). Statistics reveal between 4,500 and 5,000 cases of construction site accidents every year, with an average of 80 to 90 fatalities per year (Foo, 2005). According to the SOCSO report in 2000, the fatality rate in the construction industry in Malaysia was more than 3 times that of all other workplaces, 3.3% in the construction sector compared to all other workplaces of 1.1% (SOCSO, 2000 as cited in Foo, 2005). The statistics in 2009 indicate that among the 4108 accidents reported in the Malaysian construction industry, 116 cases resulted in a fatality and 977 in permanent disabilities (SOCSO, 2009).

The data collected by the Department of Occupational Safety and Health (DOSH) as shown in Table 2.1 further indicates that the construction industry had recorded the highest number of fatalities reported for the year 2007. The trend decreases for 2008 and increases gradually for 2009 and 2010. The lowest number of fatalities were recorded in 2011, before increases sharply in 2011. The latest statistics show that the trend increases gradually from 2012 to 2014 (DOSH, 2014). However, it is to be noted that the figures only cover the cases reported to the Department. The construction industry contributes more than one-third of fatalities out of all industries and further proves that safety performance in the construction industry lags behind most other industries.

Table 2.1: Percentage ratio of number of fatalities in construction industry to the total fatalities reported to DOSH for the years 2007 until 2014(Source from(DOSH, 2014).

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of fatalities in the construction industry</th>
<th>Total number of fatalities reported to DOSH for the respective year</th>
<th>Percentage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>95</td>
<td>219</td>
<td>43.4</td>
</tr>
<tr>
<td>2008</td>
<td>72</td>
<td>230</td>
<td>31.3</td>
</tr>
<tr>
<td>2009</td>
<td>62</td>
<td>185</td>
<td>33.5</td>
</tr>
<tr>
<td>2010</td>
<td>63</td>
<td>175</td>
<td>36</td>
</tr>
<tr>
<td>2011</td>
<td>51</td>
<td>176</td>
<td>29</td>
</tr>
<tr>
<td>2012</td>
<td>67</td>
<td>191</td>
<td>35.1</td>
</tr>
<tr>
<td>2013</td>
<td>69</td>
<td>185</td>
<td>37.3</td>
</tr>
<tr>
<td>2014 (until Nov)</td>
<td>70</td>
<td>184</td>
<td>38</td>
</tr>
</tbody>
</table>
Looking outside Malaysia, the construction industry seems to account for the largest number of fatalities in other developing countries too. For example in Thailand, the number of deaths and injuries from 2002 to 2005 in the construction industry increased, and the accident rate in the industry was reportedly the highest when compared to other industries in 2005 (Kulchartchai & Hadikusumo, 2010). In Singapore, Malaysia’s closest neighbouring country, the fatality rates in the construction industry appear to be decreasing. For 2005, 2006 and 2007 respectively, there were 11.9, 9.4 and 8.1 fatalities per 100,000 workers (Ministry of Manpower (MOM), 2007 as cited in Lai, Liu, & Ling, 2011). However, the fatality rate in the construction industry was the highest among the other industries in 2007, which suggests that the industry is still plagued with safety problems (Ministry of Manpower (MOM), 2007 as cited in Lai et al., 2011). A similar trend was also recorded in the Hong Kong construction industry from 2000 to 2004 (Wong et al., 2009).

A similar scenario appears in developed countries too. In the United States of America (USA), Hallowell (2008) found that the data gathered by the National Safety Council (NSC, 2003), showed construction accounts for approximately twelve per cent of occupational fatalities and consistently has the third highest fatality ratio of all US industries. In the United Kingdom (UK), Carter and Smith (2006) found that the fatality rate among construction workers is five times higher and serious injury twice as likely than the all industry average. In 1998, the fatality rate in the UK was 5.6 fatalities per 100,000 workers and, during the same year, the average fatality rate in construction for the European Union (EU) as a whole was over 13 fatalities per 100,000 workers (Carter & Smith, 2006).

In Australia, the Cole Report (2003) concluded that the OHS performance of the building and construction industry is unacceptable. At 28.6 per thousand employees, the number of injuries in the construction industry for 2000/2001 was almost double that of the Australian average of 15.2 per thousand employees (Cole Report, 2003). However, the fatality rate for the construction industry has decreased over the past decade. In 2007/2008, the number of fatalities in construction was 40, with a fatality rate of 4.2 (per 100,000 workers) (SafeWork Australia, 2011). The construction industry was ranked fourth for the highest fatality rate behind agriculture, forestry and fishing; transport and storage; and the mining industry. The number declined to 28 deaths, with a 2.8 fatality rate for the year 2009/2010 (SafeWork Australia, 2011). It is deemed that one of the factors for the reduction in the number of injuries and fatalities in the workplace is adequate training in OHS, in-line
with the Australian Government’s National OHS Strategy 2002-2012 to raise awareness of the importance of OHS programs, and encourage excellence in OHS practices (Wingate, 2012). However, there is still room for improvement in the efforts to reduce the statistics for the construction industry, especially when compared to other industries, such as manufacturing.

The components that form these statistics vary from country to country with respect to the legal requirements in reporting, the economic sectors covered and the definition of the workforce (Poon, Tang, & Wong, 2008), hence it may not be possible to compare directly the accident rates in different countries or regions. In Malaysia, the issues of under-reporting and non-standardized accident statistics mean that there is more effort needed to make the statistics comparable to other countries. This could be done by standardizing the occupational accidents based on for instance, fatality rate per thousand workers, as has been implemented in many developed countries. Apart from the very high human cost, accidents and injuries also have a high economic cost, as will be described below.

2.2.2 High cost of construction accidents

Accidents leading to injuries have a detrimental effect on construction business. A report by SOCSO in 2000 indicated that the compensation costs paid by the organization for industrial accidents and diseases in Malaysia accounted for almost RM 650 million (approximately AUD 217 million at 2012 exchange rates). Further, SOCSO paid about RM 754 million as compensation for industrial accidents in 2003 (Hamid, Majid, & Singh, 2008) and it was estimated that in 2004, the amount would reach over RM 800 million (Fong, 2004). Even though the figure covers all industries and did not specifically account for the construction industry, it is believed that the amount consumed by the industry is significant based on the high number of fatalities compared to other industries.

Hallowell (2008) analysed US data of the costs related to workers’ injuries and fatalities provided by NSC (2006) and found that the high rate of workers’ injuries could affect the cost of construction accidents. The increasing rate of workers’ compensation insurance premiums as observed by Hinze, Devenport and Giang (2006) is an indicator of the importance of construction safety. This is proven by data collected from NSC (2006 as
cited in Rajendran, 2006) showing that there were 460,000 disabling injuries in 2004 in the USA, and the cost of these disabling injuries was approximately $15.64 billion. The number of fatalities estimated was 1,994 and the average cost of these fatalities was approximately $1,150,000. Therefore, for 10.3 million employees in the construction industry, the average total cost for disabling injuries and deaths per construction employee can be calculated to be $1,656. These figures are outlined in Table 2.2.

Table 2.2: Costs associated with disabling injuries and fatalities in the US construction industry (NSC, 2006; as cited in Rajendran, 2006).

<table>
<thead>
<tr>
<th></th>
<th>Number in 2004</th>
<th>Cost per fatality/injury</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatalities</td>
<td>1,194</td>
<td>$1,150,000</td>
<td>$1,373,100,000</td>
</tr>
<tr>
<td>Disabling injuries</td>
<td>460,000</td>
<td>$34,000</td>
<td>$15,640,000,000</td>
</tr>
<tr>
<td>Construction workers</td>
<td>10,272,000</td>
<td></td>
<td>$17,013,100,000</td>
</tr>
</tbody>
</table>

In an attempt to calculate the true costs of accidents in the UK, the Health and Safety Executive (HSE) has found that the cost of accidents on one particular construction site is equivalent to 9.5% of the tender price of the project being undertaken (as cited in The Institution of Engineering and Technology, 2012). This results in an increase in construction cost. HSE also reported an estimated 74,000 total cases and 31,000 new cases of work-related ill-health in the UK construction industry for the year 2011/2012 (LFS, 2012). This has resulted 818,000 working days lost due to ill health in 2011/2012 out of the total 1.4 million working days lost in the construction industry (LFS, 2012).

The accident statistics and high compensation rates show that OHS in the construction industry is still unsatisfactory. One of the main reasons is that safety is always considered a secondary factor in construction, below time, cost and quality (Hamid et al., 2008). However, according to Saifullah and Ismail (2012), OHS issues are most important to the project process as they influence the quality of work and completion time. Therefore, OHS in construction needs a significant and expedient overhaul of its current site safety practices, as it is a legal requirement mandated by Malaysia’s government to ensure safety and health within the industry. The next section explains the legal requirements for OHS in Malaysia.
2.2.3 Legal requirements

According to Poon et al. (2008), the poor safety performance in the construction industry can be monitored through the use of legislation. Proprietors and parties concerned who have not discharged their safety responsibilities diligently and effectively may run the risk of being prosecuted. As such, legal requirements are seen as a driver to improve OHS in the construction industry. In Malaysia, the Department of Occupational Safety and Health (DOSH) is the main government department in charge of construction safety, placing emphasis on the safety of workers. The legislation covering health and safety in the workplace is the Occupational Safety and Health Act (OSHA) 1994 and Factory and Machinery Act (FMA) 1967. The introduction of this comprehensive legislation was in response to the need to cover a more diverse employee base and newer hazards introduced in the workplace.

The following sections describe the legislation in detail. The intention of these legislations is to avoid accidents and ensure that the workplace is a safe and healthy environment.

(i) Factories and Machinery Act (FMA) 1967

The Factory and Machinery Act (FMA) was enacted in 1967. Enforcement of the Act’s provisions for managing safety and health problems associated with manufacturing industries was the responsibility of the Factories and Machinery Department. (The Factories and Machinery Department was formerly known as Machinery Department. It is now known as the Department of Occupational Safety and Health, or DOSH, to reflect changes in its responsibilities under the Ministry of Human Resources.) The objective of the Act is to regulate the control of factories with respect to matters relating to the safety, health and welfare of its employees, an improvement over earlier legislation. In 1970, a number of regulations were introduced to further strengthen this Act. This includes the Building Operations and Works of Engineering Construction (BOWEC), a piece of legislation addressing specific safety and health issues in the construction industry. BOWEC was introduced in 1986. The limitations of FMA include: i) it only encompasses ‘factories’, ii) it was prescriptive in nature, the ways to overcome the identified
hazards were stipulated and in a command form, and iii) the risk control approaches relied heavily on the effectiveness of enforcement. Nevertheless, the FMA 1967 (and its regulations) was the cornerstone for OHS improvement before the introduction of the Occupational Safety and Health Act 1994.

(ii) Factories and Machinery (Building Operation of Work Engineering and Construction (BOWEC)) 1986

BOWEC was gazetted by the Malaysian Parliament on 1 October 1986 and is implemented under section 56, sub-section 1 of the Factories and Machinery Act 1967. This safety legislation has been enacted in order to provide a more comprehensive legal framework for the prevention of accidents, particularly on building and construction sites. This legislation is divided into 17 parts and was gazetted for the purpose of providing a guideline to execute operations of building or engineering works safely. This legislation includes a very comprehensive list of safety measures for building operations and engineering work in the construction industry.

(iii) Occupational Safety and Health Act 1994

The Occupational Safety and Health Act (OSHA) 1994 is enforced by the Department of Occupational Safety and Health (DOSH) (previously known as Factory and Machinery Department). The principle of the Act is:

To make further provision for securing the safety, health and welfare of persons at work, for protecting others against risks to safety or health in connection with the activities of persons at work, to establish the National Council for Occupational Safety and Health and for matters connected therewith.

This Act was created from the philosophy of the Roben’s Commission and Health and the UK Safety at Work Act 1974. Prior to 1994, the legislation (such as FMA 1967) was prescriptive, thus the Roben’s style ‘general duties’ approach legislation in 1994 was introduced in response to the need to cover newer hazards in the workplace due to a wider employee base.
Besides that, the promulgation of OSHA 1994 has overcome the lack of human aspects (in terms of preserving and protecting human resources in the workplace) in FMA 1967, by providing adequate provisions to ensure the safety and health of employees at the workplace in Malaysia (Bakri, Zin, Misnan, & Hakim, 2006). The human aspects are addressed within the legislation by emphasizing self-regulation and the duties of employer, employee, designer or manufacturer.

The duties of the employer include the provision of: a safe system of work; training; maintenance of the work environment; and arrangement of works for minimising risks to a level as low as is reasonably practicable. Meanwhile, the duties of the designer or manufacturer are to ensure the plant and substance they design, manufacture, import or supply are safe and without risk to health, maintaining risk levels that are as low as is practicable. However, the duties of the designer prescribed in this Act are general and do not specifically address the designers of buildings/structures. The duties of employees include ensuring the safety and health of themselves and other persons who may be affected by their acts or faults at work. Therefore, it can be said that the Act empowers the participation of all person in OHS, where the responsibility of OHS is made to rest on those who create the risks (employers and designers or manufacturers) and those who work with the risk (employees).

The emphasis on the prevention of accidents, ill health and injury has made OSHA 1994 the main Act that can help to reduce occupational accidents in the Malaysian construction industry. Moreover, the contents of the Act, which enforce prosecution for any failure to comply with the Act, could result in legal sanctions and other adverse consequences (for example, bad corporate image, or excessive legal fees, or the meting out of substantial fines).

Apart from enforcing the legislation, DOSH also provides a comprehensive list of orders, codes of practice and guidelines, which cover safety and health in the construction industry. The OHS performance of Malaysia’s construction industry may be unsatisfactory, but has been acknowledged by the government for decades, demonstrated by this legislation. This also demonstrates the importance of OHS in the construction industry and the need of more research in the area. Further, more concerted efforts are required to improve the safety
performance of the construction industry in Malaysia. One of the ways to do this is to identify the root causes of accidents. The high number of incidents, injuries and fatalities among construction workers has generally been due to the nature of the works, weather condition and variety of hazards involved. Fall from heights, movement of plant and machinery, electrical shocks and excessive noise are several hazards that construction workers are often exposed to. The next section will discuss the types of accidents that often occur within the construction industry.

2.2.4 Types of accidents

In Malaysia, the source of accidents and diseases are provided by two organizations, which are the Social Security Organization (SOCSO) and DOSH. There are many work hazards involved during the construction phase.

Cham (2011) in his study found that the top five causes of construction accidents between 2005 and 2009, in accordance with the statistics produced by SOCSO are i) stepping on/striking against or struck by objects; ii) falls; iii) other types of accidents; iv) caught in between objects; and v) over-exertion or strenuous movements. Cham’s (2011) description of ‘causes’ are accurate if addressed as ‘types’ of accidents. However, this problematic interpretation of the data is common, with the terms ‘cause’ and ‘type’ often used interchangeably by scholars. The classification of causes of accident by Cham (2011) are described in Table 2.3 below:
Table 2.3: Types of accident and its description.

<table>
<thead>
<tr>
<th>Types of accidents</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stepping on/striking against or struck by objects</td>
<td>Happens when moving construction equipment strikes a worker, or when a worker steps on an object.</td>
</tr>
<tr>
<td>Falls</td>
<td>Categorized under 11 groups: falls from stairs or steps; falls through existing floor openings; falls from ladders; falls through roof surfaces; falls from roof edges; falls from scaffold/staging; falls from building girders or other structural steel; falls while jumping to a lower level; falls from floors, docks or ground level; and other non-classified falls to lower level (The US Department of Labor, 2003).</td>
</tr>
<tr>
<td>Other types of accidents</td>
<td>For example, structure collapse, electrocution, fire, drowning, explosion and toxification.</td>
</tr>
<tr>
<td>Caught in between objects</td>
<td>Usually relating to something/somebody buried inside a hole or trench.</td>
</tr>
<tr>
<td>Over-exertion or strenuous movements</td>
<td>Ergonomic related injury due to great effort and energy for movements, especially occurs during compact work program and delay in project schedule.</td>
</tr>
</tbody>
</table>

The issue of Cham’s (2011) description of types of accident is that the category of ‘stepping on/striking against or struck by objects’ would be more accurate if it were described as ‘happens when workers are struck by a moving object; or strike or step on an object’. From the description, it is clear that the event scenarios for ‘stepping on/striking against or struck by objects’ are likely to have very different causes, hence grouping them together is problematic especially for analysis purposes. However, it is important to emphasize that this study only intends to use the information of major accident types for developing the model, and does not seek to analyse the accident data in greater depth.

However, there is a slight difference between the reports from SOCSO and DOSH. Statistics from DOSH reveal that the top four most common accident causes are falls of person; caught in or between objects; struck by falling objects; and stepping on, striking against or struck by objects. These types of accident have consequences ranging from injuries to fatalities.

Figure 2.1 depicts the fatality rate in the construction industry reported to DOSH from 2002 to 2009 and 2012 to 2014. It is to be noted that the data for 2010 and 2011 is missing due to insufficient information provided. ‘Falls of persons’ is undoubtedly the type of accident which causes the highest fatality rate compared to other types such as ‘caught in
or between object’, ‘stepping on, striking against or struck by objects’, ‘struck by falling objects’ and others. Even though in 2009 the highest contribution to fatality is from ‘other types of accidents’ category, the source is varied and from a combination of multiple types of accidents, therefore it cannot be considered as the most common type of accident that causes fatality. For non-fatality rates as shown in Figure 2.2, the trend seems similar to the fatality rate where most injuries are due to ‘fall of persons’ followed by other types of accidents. However, similar to ‘stepping on/striking against or struck by objects’, the ‘fall of persons’ category is also problematic because the number of accidents are due to several causes i.e ‘fall from height’, ‘falls at same level’ etc., thus it is difficult: i) to obtain the exact number of accidents, for example the number of ‘falls at same level’ solely; and ii) to identify which category has more accidents compared to others.
Figure 2.1: Accident statistics (based on types of accidents) in construction industry reported to DOSH for the year 2002-2009 and 2012-2014 – Fatality (Source: DOSH, 2010)
Figure 2.2: Accident statistics (based on types of accidents) in construction industry reported to DOSH for the year 2002-2009 and 2012-2014 - Non-fatality (Source: DOSH, 2010)
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