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# Knowledge-Based Energy Damage Model for evaluating Occupational Health and Safety (OHS) Construction Risks in Malaysia

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## ABSTRACT

The construction industry is renowned as a high-risk industry which involves complex, time consuming design and construction processes characterized by unforeseen circumstances and which has been plagued with accidents for a long time (Ren, 1994). Eliminating the risk of adverse occurrences is essential in order to provide a safe and healthy working environment on construction sites. This paper presents an initial concept for the comparative evaluation of OHS risks for different construction approaches. The model uses a combination of the 'argument tree' concept and 'energy damage model' theory. The assessment process provides a perspective on how the design decisions can impact on OHS for the workers. The 'delivery' stage of two Malaysia housing projects, procured using both conventional and industrialised methods, are utilized to illustrate the model.

**Keywords:** Industrialised Building Systems (IBS), OHS in construction, knowledge-based energy damage model

## 1. INTRODUCTION

The construction industry is renowned as one of the most hazardous industries with complex processes that contribute to many incidents and fatalities (Saifullah and Ismail, 2012). The major causes of accidents are related to various factors such as the nature of the industry, human behaviour, difficult work-site conditions and poor safety management and culture. This has resulted in unsafe work methods, equipment and procedures and has made occupational health and safety (OHS) management one of the many important elements in the construction industry, which merits attention and study (Abdelhamid and Everett, 2000).

The concept of "designing for safety" is one of the strategies to address this issue. Cooke (1997) and Gambatese *et al.* (2008) suggest that the bad safety performance of construction can be improved through preventing accidents and reducing uncertainty before it happens. Korman (2001) suggests that every construction project should involve architects and design engineers in incorporating safety in the design process. The evidence of the effectiveness of this strategy is confirmed by several authors. According to Furst (2010), among the number of research studies done in both the United States and European Union countries in identifying causes of injuries and fatalities on construction worksites, one particular European study in 1991 found that the cause of about 60% of accidents on worksites could be traced back to decisions made before any construction work started. There is also another study in UK that confirms that there is an absolute link between design decisions and safe construction (Jeffrey and Douglas, 1994). Gibb *et al.* (2004) found that the risk of injury in 47% of 100 accidents examined in the UK construction industry could have been reduced by design change, whereas Behm (2006) reported that the implementation of design-for-safety during the design stage would have avoided, or reduced in severity on one third of 450 examined US construction deaths and disabling injuries. Gambatese *et al.* (2008), using expert panels, formalise the previous research and design for safety investigation model reported by Behm (2005) in which expert panels agree that 71% of the fatality case reviewed were linked to design.

Even though there is some literature available for construction hazards prevention through design (CHPtD), Toole and Gambatese (2008) noted that the technical principles underlying this issue for helping designers better perform CHPtD and facilitating the development of additional CHPtD tools are generally lacking. According to Gangolelles *et al.* (2010), most publications on this subject only offered solutions that can be directly implemented and checklists

for the subsequent monitoring of the design. For example, Health and Safety Executive (HSE) has documented and illustrated on how designers could significantly improved construction safety and reduce costs or programme time using several case studies (HSE, 2003). Other example includes Gambatese and Heinze (1999) who accumulated design suggestions for improving construction worker safety while in the design phase.

In the UK, the CDM Regulations (1994) assigned responsibility to designers to ensure that designs can be constructed and maintained, however, after 12 years of being in place, designers were still looking for ways to comply (Summerhayes, 2007). In Australia, the National OHS Strategy 2002-2012 (NOHSC) triggered the establishment of preventive OHS legislation which specifically addressed the obligations for OHS designers in Western Australia, South Australia, Queensland and Victoria (Bluff, 2003).

In Malaysia, initiatives for addressing safety in the design phase are defined in the Construction Industry Management Plan (CIMP) 2006-2015. Some of the positive recommended actions addressing OHS are related to “designing for construction safety” which include education in OHS concepts; and providing guidelines for clients to have safety and health design checks put in place before construction; (CIDB, 2007). However, it is doubtful that Malaysian construction designers adequately understand how to identify, assess and control OHS risks in their designs. Therefore, it is vital for Malaysian construction designers to have a tool which can assist them to better integrate OHS risk management into the design process with specialist OHS knowledge and guidance. To address this issue, this study will develop a model for best practice reasoning that can be used by designers or decision makers when examining the OHS risks posed in the construction of their designs.

This paper serves to outline the assessment of OHS risks for different construction approaches, namely Industrialised Building Systems (IBS) and conventional systems, using the energy damage model (Viner, 1991). IBS is a different term to ‘off-site construction’, in which the construction process is industrialised by which components of a building are conceived, planned, fabricated, transported to and then erected on site (Junid, 1986). The government of Malaysia has been promoting the implementation of IBS in executing construction projects due to the huge demand for construction projects, especially building construction to save on labour, cost and time of construction, and confer quality and durability (Ismail, 2001 and Hamid *et al.*, 2008). IBS is also seen as one of the initiatives to improve the OHS performance of the industry (CIDB, 2004). The importance of IBS is highlighted in the IBS Roadmap 2011-2015 which aims to raise the existing IBS score from 70% to 80% by 2015 for government projects above the value of RM10 million (CIDB, 2010). Furthermore, this Roadmap is predicted to impact the private sector through “public-private-partnership” (PPP), with an average 50% IBS uptake for private projects being achieved by 2015. Therefore, assessing the construction processes of both IBS and traditional approaches is essential because it covers the construction industry in Malaysia. This will effectively address the designers’ role in making decisions in their designs and further understand the level of OHS risk their designs pose.

The paper will provide the development of the model and the theory underpinning it, followed by the methodology involved to execute the study. The paper then discusses the concept of the assessment.

## **2. DEVELOPMENT OF THE KNOWLEDGE-BASED ENERGY DAMAGE MODEL TO ASSESS OHS RISKS IN DESIGN**

This study applies the concept of an ‘argumentation theory model’ (Toulmin, 1958; as cited in Yearwood and Stranieri, 2006) by building on a tool developed by Cooke *et al.* (2008) - ToolSHED, to help construction designers integrate the management of occupational health and safety risk into the design process. It was developed from structured knowledge in the context of uncertainty and discretionary decision making, by involving expert reasoning regarding design impacts upon OHS risk represented by ‘argument trees’. In argument trees, all arguments consist of one conclusion represented by a single ‘root’ node that are proven or supported by ‘child’ and ‘parent’ nodes. The nodes are connected by lines that represent the relevance relations in an argument structure. The values on ‘children’ nodes will conclude the linguistic variable value on the “parent” node using the pre-determined inference procedures, which ultimately give the value of the ‘root’ node. The inference process depicts a template for reasoning in complex situations (Cooke *et al.*, 2006).

The argument trees developed in this study are also underpinned by a knowledge-based energy damage model developed by Viner (1991). The model suggests the identification and control of potentially harmful energy to eliminate or reduce the latent conditions of the unsafe person while operating in an unsafe place. According to Viner (1991), “when an unwanted and harmful energy source is transferred unexpectedly (in type, time, speed or force) to an unwilling or unwitting person, the problem may arise even though the energy itself is not dangerous.” Therefore, identifying such damaging energies is increasingly essential, because a designer is able to provide means of control of these energies, whether to eliminate or reduce the energies. Surrounding the construction process, the types of damaging energies (hazards) include gravitational; noise and vibration; chemical; electrical; mechanical; thermal; pressure; radiation; microbiological; biomechanical/body muscle; and psychosocial (Safetyline Institute, 2005).

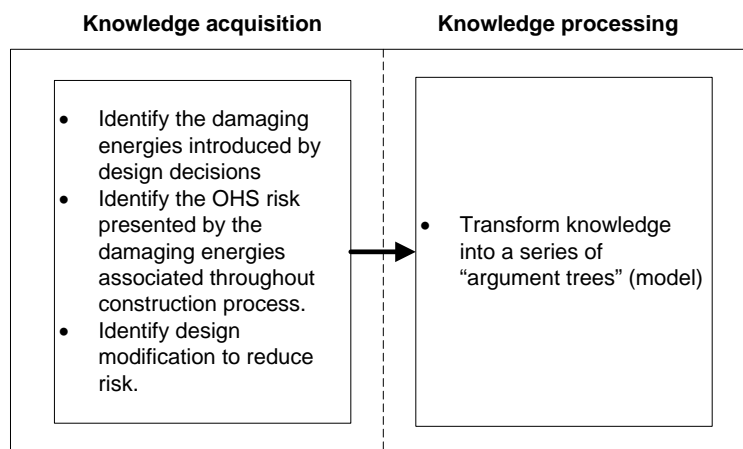
The development of this model contributes by suggesting options for the decisions that can be made by designers, in such a way as to assess the extent to which their design decisions mitigate the OHS risk in the construction process.

### 3. CASE STUDY DETAILS

The scope of the project is focused on occupational health and safety risks (OHS) of IBS and traditional projects for residential building construction. The case study is undertaken for six construction projects that represent both IBS and traditional approaches and cover the ‘structure and envelope of the building’, and also ‘volumetric’ toilet pod units.

#### 3.1 The development process

The development of the model consists of two stages initiated with knowledge acquisition, followed by knowledge processing. Figure 1 represents the development process of the model.



*Figure 1 Model development process*

Knowledge acquisition involves collecting the data that will underpin the model. To assess the construction OHS risks within a design, knowledge about damaging energies (hazards) associated with the construction processes were needed, together with identification of design features which potentially impact upon the risks of the construction process. The knowledge was then transformed into argument trees. The extent of damage depends on the amount the energy deflected by the ‘barriers’. The use of ‘argument trees’ for modeling expert reasoning is better suited to represent the level of ‘how safe is safe enough’ of the designer’s decision on the ‘barriers’ to be used to counter the damaging energies during the construction process. This level of decision will determine the value of a risk rating at the ‘root’ node of an argument tree. The risk rating is determined by the value of risk magnitude at the ‘root’ node expressed by the linguistic variables ‘extreme’, ‘high’, ‘moderate’ and ‘low’.

The scope of the study is focused on the building envelope and volumetric units in order to provide wider coverage of different construction processes. The case studies involved a number of site visits to the IBS manufacturing

factory and construction sites. Five sites were visited, in which three represented IBS and two traditional construction methods. Data collection involved field observation and talking to the managerial staff, operatives and supervisors. Document analysis was undertaken for one case study (prefabricated toilet pod) due to the complexity of getting the feedback from the manufacturer to allow data collection at their site. The details of case studies are as below:

*Table 1 Details of the case studies*

<b>No.</b>	<b>Project</b>	<b>Method</b>
<b>1.</b>	<b>Traditional construction</b> Project: Traditional construction of 3-storey semi-D house using conventional method	Field observation. Interviewing 3 project personnels.
<b>2.</b>	<b>IBS</b> Project: Construction of 4-storey hostel using precast wall system. The precast panel acted as a load bearing wall.	Field observation at the factory and construction site. Interviewing 3 project personnels.
<b>3.</b>	<b>IBS</b> Project: Construction of 4-storey hostel using precast frame system. In this system, the beam and column are precast, whereas the wall is constructed using CMU (bricks).	Field observation at the fabrication yard and construction site. Interviewing 2 project personnels.
<b>4.</b>	<b>IBS</b> Project: Construction of 2-storey academic block using blockwork system. The system uses interlocking CMU to build the structure and envelope of the building where the CMU itself act as a load bearing structure.	Field observation at the factory and construction site. Interviewing 2 project personnels.
<b>5.</b>	<b>Toilet pod</b> Prefabricated toilet pod.	Document analysis - PhD thesis, Author: McKay (2010)
<b>6.</b>	<b>Traditional construction</b> Project: Traditional construction of toilet/washroom in a building.	Field observation. Interviewing 1 project personnel.

### 3.2 Application of the model

From the data, the processes involved in each construction approach were mapped together with their associated risks. The information was then transferred into 'argument trees'. In order to demonstrate the development process of the model, this paper uses the 'delivery' phase of the cases as this provides similarity in the process and damaging energies involved. The activities involved in the delivery phase include loading the element onto a truck, delivery of the element to the construction site, off-loading the element at the construction site and stacking the element. The risks associated with the process include craneage risks, vehicle injury risks, manual handling, inadequate bracing of the element and inappropriate stacking method. The details of the activities and risks involved are shown in Table 2. However, this paper only presents the development of the model (argument trees) for gravitational energy as an example.

Table 2 Activities involved in delivery phase

Activities	Damaging energies	Risks/Hazards	Consequences
Loading elements onto truck	Gravitational	Craneage risks	Fall of element due to crane structural failure.'
	Kinetic	Vehicle injury (mobile plant) risks	Workers hit by moving element; overturning of mobile plant
	Body muscle	Manual handling	MSDs, RSI
Delivery of the elements	Gravitational	Inappropriate method of bracing the element	Fall of element due to inadequate bracing on the truck.
	Kinetic	Vehicle injury risks	Failure of control of vehicle
Offloading the elements	Gravitational	Craneage risks	Fall of element due to crane structural failure.'
	Kinetic	Vehicle injury (mobile plant) risks	Workers hit by moving element; overturning of mobile plant
	Body muscle	Manual handling	MSDs, RSI
Stacking	Gravitational	Inappropriate stacking method	Collapse of element due to inadequate bracing and inappropriate stacking method.

Figure 2 shows an example of a design OHS argument tree for the “gravitational” energy damage for the “loading the element onto truck” activity. A set of linguistic values with numerical values are assigned to each node of the argument tree, regardless of its position. These values are relevant to the design options available to a designer when making judgement upon aspects of design, pertinent to the risk of wall cladding construction.

There are two numerical values at the parent nodes (refer Figure 2, node A, B, C and D). The left ones indicate the summation range of the numerical values of child nodes, whereas the right ones represents the numerical value inferred from the child nodes. For an example of the inference procedure, the construction process is executed using a blockwork system which uses a forklift for loading the elements (blocks) onto the truck; and the scenario is as below (node A):

- i) The weight of the elements to be lifted is “generally estimated on the load weight”. Therefore, the numerical value for this node is ‘5’.
- ii) The distance from the centre of rotation of lifting plant to the truck is ‘not applicable, because this node is applicable to the crane only’. Therefore, the numerical value for this node is ‘1’.
- iii) The parent node is inferred by these two nodes, giving the summation of the values, ‘5 +1’ = ‘6’. Since the value is within the range of 0 to 6, therefore the value of parent node, which is ‘The capacity of lifting plant to support the weight of the element’ is ‘has been assessed and is adequate’, which gives the value ‘1’.

This inference procedure, denoted by A, B, and C, continues until ultimately inferred at the root node (D), the final risk rating. The risk rating at the root node indicates either “extreme”, “high”, “medium” or “low”. It is measured by calculating the values decided by the designer at every child nodes. One may notice that the inference process in structured argument trees apparently mimic the risk assessment process.

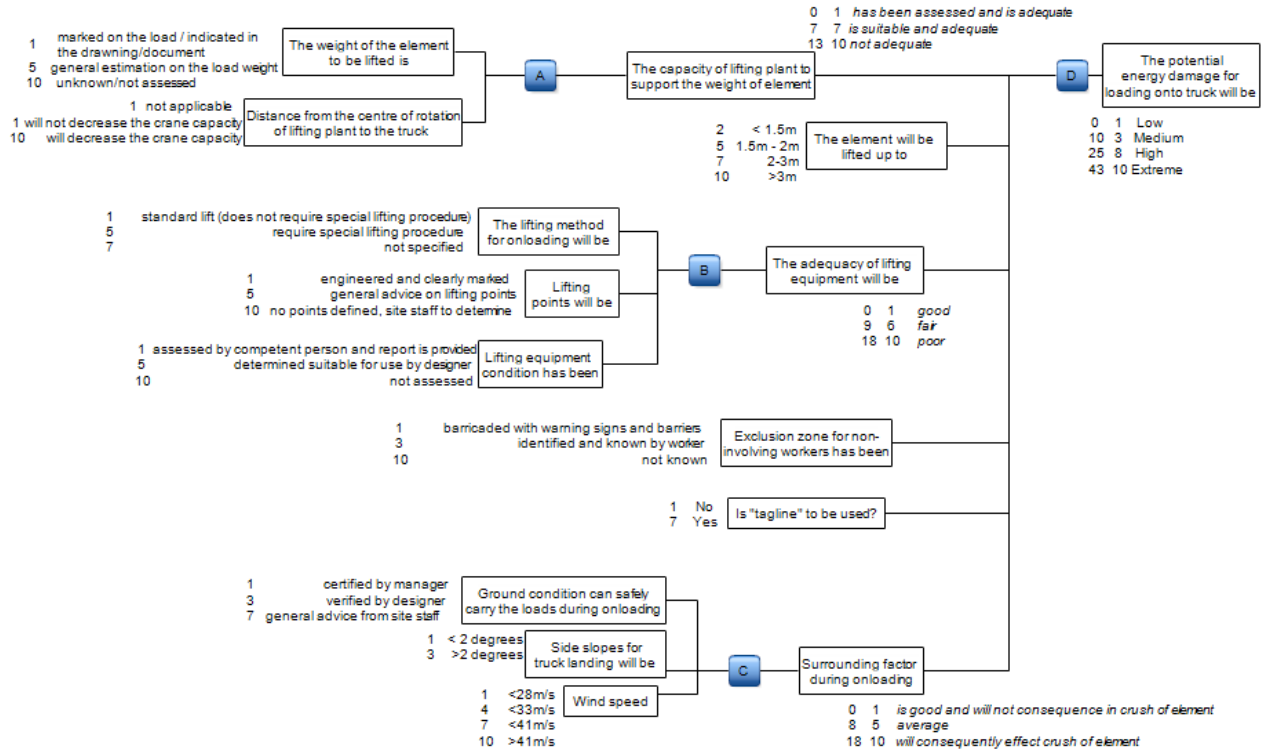


Figure 2 Example of argument tree showing the inference procedure

## 5. CONCLUSION

This paper presents the development of a knowledge-based energy damage model to assess OHS risks designed in construction processes. The model is developed by using a combination of “argumentation theory” and the “energy damage model”, building on a risk assessment tool named ToolSHED. The model will effectively address the designers’ role in making decisions in their designs and further understand the level of OHS risk their designs pose. It is anticipated that the model could contribute in providing a way for designers, to integrate construction process knowledge into design to eliminate or reduce hazards during construction.

Since the construction industry in Malaysia is actively implementing IBS as an alternative to the traditional construction method, addressing the issue of health and safety in IBS construction is vital because it will affect the industry as a whole. For this reason, the use of this model can provide a mechanism for the relative comparison of hazards of different construction approaches. The tool enables a risk profile to be generated across different phases of a process, thereby providing powerful assistance to designers and contractors. Currently, OHS is considered post-design, and therefore options for hazard elimination are largely removed. This tool offers scenario testing in earlier design phases, so that OHS can inform design rather than the current approach in which OHS bears little influence over design. Therefore, whether the option is an IBS or traditional approach, the fundamental idea of the model will initiate construction designers or decision-makers to address safety in the design process and encourage them to examine carefully the probable OHS risk variables surrounding an action; thus preventing accidents in construction.

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